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THESIS

LOGISTICALLY SUSTAINING AFLOAT-STAGED SPECIAL OPERATIONS FORCES THROUGH AN LPD-17 CLASS SINGLE-SHIP SEABASE

by

Christopher A. Waldron

March 2007

Thesis Advisor:	Arnold H. Buss
Second Reader:	Susan M. Sanchez

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Today's global terrorist threat has the ability to operate in denied and sensitive regions of the world, performing missions to undermine government control through acts of violence delivered via unconventional methods. Operations against this type of enemy require a quick and decisive military capability. The flexibility, scalability, and unconstrained maneuverability inherent in a Seabase, coupled with the decisive, powerful, and precise combat potential of Special Operations Forces (SOF), brings together a force capable of reacting quickly to changes in an operational theater requiring military diplomacy. A Discrete Event Simulation is used to explore and analyze various configurations to a seabase's structure and force compliment for the purpose of sustaining multiple SOF units engaged in a variety of land-based operations. Analysis of the data generated by the model shows the LPD-17 class is capable of sustaining multiple SOF units operating ashore. The allocated area for SOF equipment storage designed on the LPD-17 class does not constrain the ability to sustain multiple units. Embarking the maximum number of helicopters a LPD-17 class is designed for minimizes the occurrence of and time spent in a delayed state by a unit between mission assignments, and allows accomplishment of concurrent missions beyond logistic sustainment of SOF units.

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LOGISTICALLY SUSTAINING AFLOAT-STAGED SPECIAL OPERATIONS FORCES THROUGH AN LPD-17 CLASS SINGLE-SHIP SEABASE

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MASTER'S OF SCIENCE IN OPERATIONS RESEARCH

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ABSTRACT

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LIST OF ABBREVIATIONS, ACRONYMS, SYMBOLS

AFSOC	Air Force Special Operations Command
AIMD	Aircraft Intermediate Maintenance Department
ALSS	Advanced Logistics Support Site
AOR	Area of Responsibility
APOD	Air Point of Debarkation
ASOT	Advanced Special Operations Technique
C2	Command and Control
CAO	Civil Affairs Operation
COCOM	Combatant Commander
CONREP	Connected Replenishment
CONUS	Continental United States
COTS	Commercial Off-The-Shelf
CPWMD	Counterproliferation of Weapons of Mass Destruction
CT	Counterterrorism
DA	Direct Action
DES	Discrete Event Simulation
ESG	Expeditionary Strike Group
FADL	Flyaway Dive Locker
FARC	Flyaway Recompression Chamber
FEL	Future Event List
FID	Foreign Internal Defense
FLS	Forward Logistics Site

FOB	Forward Operating Base
GWOT	Global War on Terrorism
IO	Information Operations
JFC	Joint Forces Commander
JFMCC	Joint Forces Maritime Component Commander
JOA	Joint Operations Area
JTF	Joint Task Force
LCAC	Landing Craft Air Cushion
LEGO	Listener Event Graph Object
LOGCOP	Common Logistics Operating Picture
LOGSU	Logistics Support Unit
MARSOC	United States Marines Special Operations Command
MOE	Measure of Effectiveness
NOLH	Nearly Orthogonal Latin Hypercube
NAVSPECWARCOM	Naval Special Warfare Command
NSW	Naval Special Warfare
NSWG	Naval Special Warfare Group
NSWTG	Naval Special Warfare Task Group
ODA	Operational Detachment Alpha
OTH	Over the Horizon
POL	Petroleum, Oil, Lubricants
PSYOP	Psychological Operations
ROMO	Range of Military Operations
SBT	Special Boat Team

SDV	SEAL Delivery Vehicle
SEAL	Sea, Air and Land
SOC	Special Operations Craft
SOPMOD	Special Operations Peculiar Modification
SPOD	Sea Port of Debarkation
SR	Special Reconnaissance
UDA	Urgent Deployment Acquisition
USASFC(A)	United States Army Special Forces Command (Airborne)
USASOC	United States Army Special Operations Command
USSOCOM	United States Special Operations Command
UW	Unconventional Warfare
VERTREP	Vertical Replenishment
VTOL	Vertical Take-Off and Land

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First and foremost, my deepest appreciation goes to my loving wife, Marleen. Your support and patience throughout this process has been the energy I need to accomplish such a milestone. I will be forever grateful and committed to you, my soul-mate.

To my family: Words are not enough to express the sincere appreciation I have for all you have done for me. Your love and support was instrumental in allowing me to follow my dreams and desires to serve our country. The person I am today is a direct reflection of the patience, dedication, and guidance you have given me throughout my life.

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To the personnel of United States Special Operations Command (USSOCOM) Acquisition and Logistics – J4, I extend my gratitude for taking the time in helping me to understand the scope and missions Special Operations are defined by. A special thank you goes to Commander (Sel) Bobby Pitts and LCDR Liz Farrell for showing me around the maze of USSOCOM and introducing me to the right people.

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Finally, Professor Arnold Buss, my deepest gratitude for the guidance and late night debugging of code necessary for the simulation to function properly. The journey from writing “Hello World” code to the completed simulation could not have been achieved without your guidance. This thesis was a significant milestone in my professional career, and its successful completion is owed to your unwavering assistance.

EXECUTIVE SUMMARY

The global terrorist threat our nation faces today requires a force capability unlike the United States has ever seen. The ability to proactively seek out the enemy using a precise, agile and quick reactionary force can only be achieved through a joint military strategy. The current joint vision of the future introduces a concept known as Seabasing to employ, sustain, and reconstitute forces from a maritime environment.

The employment of forces today typically originates from land-based forward operating stations. These bases require a large footprint ashore and a substantial level of force protection measures prior to, during, and post military operations. In addition, political and cultural effects could be felt through the physical occupation of U.S. forces within the host countries national borders. Seabasing leverages the internationally recognized maritime space to maneuver and scale its capabilities in support of operations ashore. Seabasing minimizes the U.S. footprint ashore, reducing the risk of political and social animosity towards military occupation. The limited access a maritime environment provides, along with the maneuverability of a seabase, increases the force protection of forces embarked on the seabase. A seabase's size is scaled to the capabilities required and the level of forces being embarked. One ship or multiple ships forming a strike group can perform seabasing functions necessary to accomplish operational objectives. This thesis uses the LPD-17 San Antonio class as a single-ship seabase in support of Special Operations Forces (SOF).

Special Operations Forces typically engage the enemy in denied and clandestine environments through unconventional means of warfare. Their precise, powerful, and covert delivery of combat power makes them the force of choice in fighting the global terrorist threat. United States Special Operations Command (USSOCOM) is the lead combatant commander in executing all operational plans associated with the Global War on Terrorism (GWOT). USSOCOM is responsible for training, equipping, and employing SOF to other regional combatant commanders in support of GWOT operations. The Army Special Forces (SF) and Navy Sea, Air, and Land (SEAL) teams are used in the model to perform land-based missions while being supported from a LPD-17 single-ship seabase.

The thesis utilizes Discrete Event Simulation to model the necessary structure of a single-ship seabase in support of multiple SOF units operating ashore. The simulation is written in the Java computer language, and utilizes a simulation package known as Simkit written by Professor Arnold H. Buss, Naval Postgraduate School. The seabase and each SOF unit are designed with a capacity to hold five distinct supply commodities. The five supply commodities are: Ammunition, Equipment, Medical, Subsistence, and Water. SOF units, comprised of two to twelve personnel, move randomly within the operating environment and consume supplies upon completion of an assigned mission. The units will communicate the amount of each supply commodity, via a supply requisition, to the seabase. The seabase will check for available helicopters embarked on the seabase to deliver the requested material. If there are no helicopters available, the units will enter a ‘balk’ state, and remain idle at their current location until one is available to deliver the requested supplies. Upon availability of a helicopter, supplies will be loaded and delivered to a designated waypoint. SOF units will move to the designated drop waypoint, receive the material issued, and move to their next assigned mission. Upon reaching a given reorder level, the seabase will request an underway replenishment via a resupply ship operating within the theater.

The input parameter levels to the simulation are varied using the concepts of experimental design. A unit’s frequency and time spent within a balk state, the embarked helicopters’ utilization, and the seabase’s supply inventory net effectiveness are the Measures of Effectiveness (MOE) used in this thesis. Data generated by the simulation are analyzed using regression, statistical and marginal benefit techniques to show how the MOEs are affected by varying levels of the input parameters.

The seabase’s supply inventory net effectiveness is 100 percent for all design points input to the simulation. This indicates the capacity of a LPD-17 single-ship seabase is adequate, given the availability of a resupply ship and regardless of the seabase’s reorder level, to support up to ten SOF units operating ashore. The average number of idle helicopters appears to remain constant and is not affected by the addition of helicopters to the seabase. Helicopter utilization increases linearly, for each level of helicopters embarked, as the number of SOF units being supported by the seabase increases. A large marginal benefit is realized in reducing a unit's frequency and time spent in a balk state by increasing the number of helicopters embarked on the seabase as logistic support assets. Increasing the model's number of helicopters embarked on the seabase to minimize a unit's frequency and time spent in a balk state appears to have not reached the point of diminishing returns. The LPD-17 class ship is therefore adequate in filling the role of a single-ship seabase to sustain SOF operations.

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I. INTRODUCTION

A. ROLE OF THE UNITED STATES IN THE 21ST CENTURY

The United States faces a much different world in the 21st century than any other previous century. The U.S., along with its allies and partners, utilize political and military strategies to protect the sovereignty of nation states throughout the world. The purpose is to establish countries that govern themselves in a free political and economic environment that conforms to international laws and policies. The prosperity, freedoms, and peace that result from these strategies are threatened by a faceless, borderless enemy. This enemy, known as terrorists, comes from either ungoverned countries, or countries that are politically and economically weak. The legacy structure of a 'Cold War military' will not sufficiently contain and defeat the activities of terrorists across all dimensions of warfare. What is required is an agile and decisive force capable of responding proactively to both certain and uncertain threats posed by terrorist groups (National Defense Strategy, p. 5, 6).

Constructing a force with the necessary agility and decisiveness requires the leveraging and integration of cutting-edge technologies to military strategies, along with overcoming entrenched paradigms that hinder the forward progression of the force shaping. The National Military Strategy defines agility as "the ability to rapidly deploy, employ, sustain, and redeploy capabilities in geographically separated and environmentally diverse regions" and decisiveness as "overwhelming adversaries, control situations and achieve definitive outcomes…through tailored packages of joint capabilities." The catalyst in achieving this force structure is the military's ability to act as a joint force. A joint force capitalizes on the efficiencies and expertise each service brings to the table with regard to specific areas of responsibility. This capitalization greatly enhances the agility, decisiveness, and preparedness of our forces to deter any level of aggression and counter coercive terrorist acts (National Military Strategy, p. 15, 16).

Transformation within the Department of Defense is outlined in the National Defense Strategy through eight operational capabilities: Strengthening Intelligence;

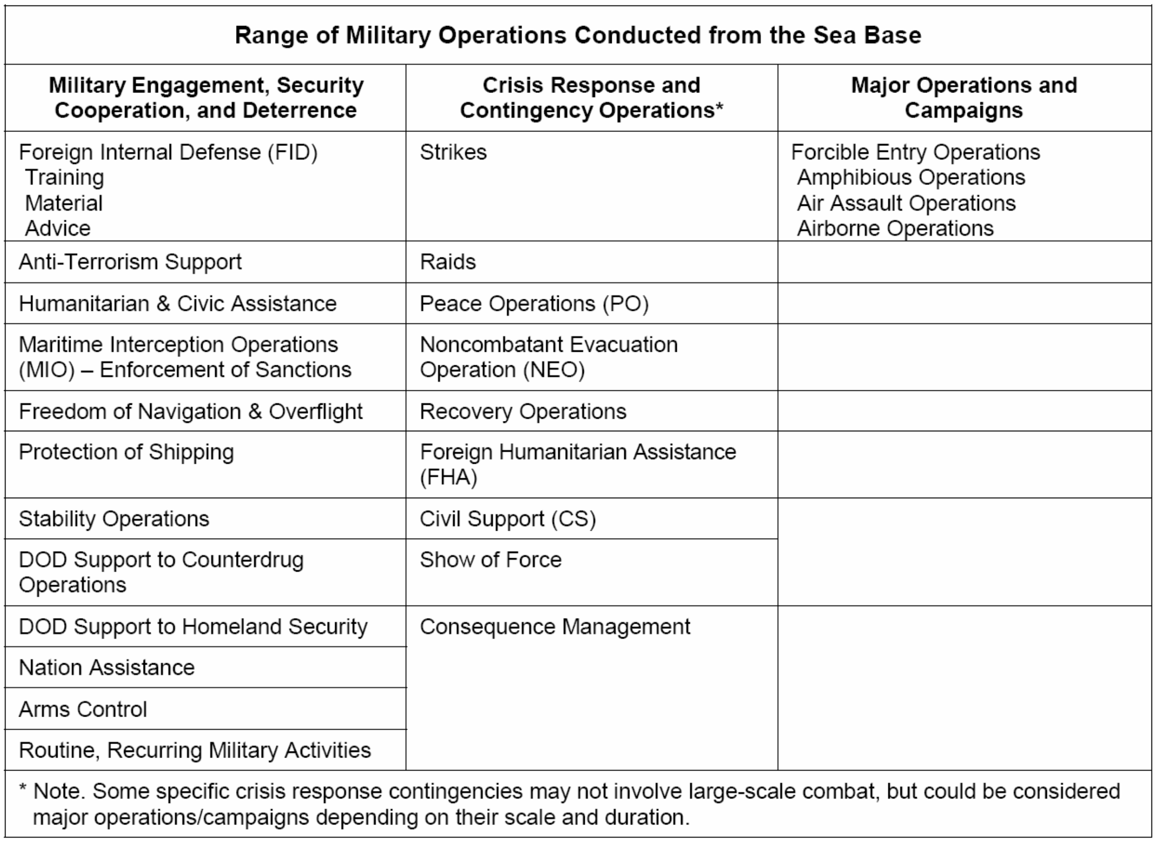
Protecting Critical Bases of Operation; Operating from the Global Commons; Projecting and Sustaining Forces in Distant Anti-Access Environments; Denying Enemies Sanctuary; Conducting Network-Centric Operations; Improving Proficiency against Irregular Challenges; Increasing Capabilities of Partners – Domestic and International. The foundation of these eight operational capabilities focuses on the integration of an agile joint force able to project a decisive degree of military power from any platform in any environment. Many challenges present today attempt to prevent the forward progression of this force transformation. One of these challenges is the potential denial of U.S. military access to countries we believe terrorist groups are operating. This denial can be accomplished through political or military means (e.g., ground movement restrictions through a country's territory, mining of harbors, stationing of anti-air/surface missiles, etc.). The use of international operating environments, such as international airspace or waters, to project power and sustain our forces will overcome this challenge and allow military operations to be successful (National Defense Strategy, pp. 12-17). A concept within the Navy known as Seabasing captures the elements within the eight operational capabilities and gives the flexibility to Combatant Commanders (COCOM) to employ forces at a moments notice from any international operating environment.

B. SEABASING CONCEPTS AND IMPORTANCE

1. Concept

Seabasing is a concept described in many of the Navy and Marine Corps 21st century visions and strategies. The seabase takes advantage of the open sea to maneuver, operate and engage in command and control (C2), tactical strike, power projection via air and surface, and logistics missions dictated by the Joint Forces Commander (JFC). It is defined as "the rapid deployment, assembly, command, projection, reconstitution, and re-employment of joint combat power from the sea, while providing continuous support, sustainment, and force protection to select expeditionary joint forces without reliance on land bases within the Joint Operations Area (JOA)…" (Seabasing JIC, p. 5). The seabase is able to achieve this through its scalability in size and components. Based on the mission given, a seabase can be as small as a single ship to as large as an Expeditionary Strike Group (ESG), and composed of service-specific, joint, or multinational forces.

This gives the JFC extreme amounts of flexibility in designing plans to support the wide Range of Military Operations (ROMO) a seabase can perform (NWP 3-62M, pp. 1-3). Table 1 below shows the diverse operations across a seabase's ROMO.



Range of Military Operations Conducted from the Sea Base

Military Engagement, Security Cooperation, and Deterrence	Crisis Response and Contingency Operations*	Major Operations and Campaigns
Foreign Internal Defense (FID) Training Material Advice	Strikes	Forcible Entry Operations Amphibious Operations Air Assault Operations Airborne Operations
Anti-Terrorism Support	Raids	
Humanitarian & Civic Assistance	Peace Operations (PO)	
Maritime Interception Operations (MIO) – Enforcement of Sanctions	Noncombatant Evacuation Operation (NEO)	
Freedom of Navigation & Overflight	Recovery Operations	
Protection of Shipping	Foreign Humanitarian Assistance (FHA)	
Stability Operations	Civil Support (CS)	
DOD Support to Counterdrug Operations	Show of Force	
DOD Support to Homeland Security	Consequence Management	
Nation Assistance		
Arms Control		
Routine, Recurring Military Activities		

* Note. Some specific crisis response contingencies may not involve large-scale combat, but could be considered major operations/campaigns depending on their scale and duration.

Table 1. Seabase Range of Military Operations (From: NWP 3-62M, p. 5-2)

The seven foundation principles of Seabasing focus on the exploitation of the maritime operating area that either minimizes or negates the footprint required ashore for joint forces. Seabasing utilizes its mobility and scalability to target weaknesses within the enemy's defense, while monopolizing on the large logistic lift capacity of maritime support forces for sustainment. Adherence to these principles allows the JFC to rapidly deploy forces while providing a high degree of force protection across all operating dimensions (NWP 3-62M, pp. 1-2). The seven principles listed below are taken directly from the NWP 3-62M pages 1-4 thru 1-5.

- *Use the sea as maneuver space*. Seabasing exploits the freedom of the high seas to conduct operational maneuver in the maritime environment (to include the littorals) relatively unconstrained by political restrictions. Sea-based operations provide the JFC with the operational flexibility to support the immediate deployment/employment/sustainment of expeditionary forces across the extended depth and breadth of the battlespace.

- *Leverage forward presence and joint interdependence*. Joint forces operating from the sea base in conjunction with other globally based joint forces provide the JFC with credible offensive and defensive capabilities during the early stages of a crisis. Forward-deployed joint forces can help to deter or preclude a crisis while enabling the subsequent introduction of additional forces, equipment, and sustainment.
- *Protect joint force operations*. Seabasing provides a layered defense for its forces derived from its freedom of operational maneuver in a maritime environment. The combined capabilities of maritime platforms across all dimensions of the maritime environment (surface, subsurface, air, and land) provide the joint forces a defensive shield at sea and ashore. The integration of these capabilities and freedom of maneuver degrade the enemy’s ability to successfully target and engage friendly forces while at the same time facilitating joint force deployment, employment, and sustainment.
- *Provide scalable, responsive joint power projection*. A force rapidly closing the sea base gives the JFC the ability to rapidly scale and tailor forces/capabilities to the mission. A seabase can consist of one ship or dozens of ships, depending on mission requirements. Seabasing provides the JFC the option to mass, disperse, or project joint combat power throughout the operations area at the desired time to influence, deter, contain, or defeat an adversary.
- *Sustain joint force operations from the sea*. Sea-based logistics entails sustaining forces through an anticipatory and responsive logistics system to support naval forces afloat and selected joint/coalition forces operating ashore. The seabase is sustained through the interface with support bases and strategic and operational logistics pipelines, enabling naval and selected joint forces to remain on station, where needed, for extended periods of time.

- *Expand access options and reduce dependence on land bases***.** Seabasing supports global and sea-based power projection capabilities to provide the JFC with multiple access options, to include unimproved ports and airfields. This will complement forward basing in the JOA, reducing, but not eliminating, reliance on forward basing.
- *Create uncertainty for adversaries*. The dispersed and distributed operations of seabasing provide multiple points and means of entry. As a result an adversary must either disperse his forces to cover all possibilities or concentrate forces on what he deems to be the most likely or dangerous options, creating opportunities to exploit seams and gaps in defenses.

2. Importance of Seabasing

The ending of the Cold War brought about a renewed life in small, moderately developed states to take accountability for themselves. As the years progress, they evolve to politically and economically independent states that have a voice in the international community. Political pressures from neighboring states may cause these newly developed independent states to show no affiliation to the U.S., thus remaining neutral in themselves. This can cause countries to withhold support of U.S. troops and equipment within their borders in the event of deterring or preventing escalating conflict from within or surrounding countries adjacent to the host nation. Seabasing allows the U.S. military to exploit the international sea space as a maneuvering environment to project sustained joint combat power without support from host nations. Joint forces can act quickly and decisively to theater missions through the mobility and support a seabase brings to their combat organization. This brings the forces closer to the fight, decreasing the logistics support chain required to consistently sustain them.

The increased acts of terrorism, proliferation of weapons of mass destruction (WMD), and influence of non-state actors within the international community directly threatens national security and military forces stationed abroad. Maintaining a large footprint ashore increases the visibility of forces within the geographic area, subjecting them to an increased risk of attack via conventional or unconventional means. Increased amounts of resources are then allocated to ensure a secure level of force protection is maintained at these Forward Operating Bases (FOBs). Seabasing, on the other hand, utilizes the inherent Sea Shield capabilities to give an increased force protection to joint forces assigned to, or in support of, the seabase. This decreases force protection redundancies between the seabase and FOBs ashore, and also frees resources, that would otherwise be providing security at the FOB, to fulfill other missions within the theater. Combining the seabase's mobility and flexibility in exploiting enemy weak points for force entry with the level of force protection given to assigned joint forces, seabasing will be a viable alternative to establishing FOBs ashore and "a critical capability for joint forces…that increases options while decreasing liabilities both politically and militarily" (Seabasing JIC, p. 17).

C. SPECIAL OPERATIONS FORCES (SOF)

1. Background

Special Operations Forces are a collection of specially trained highly skilled warriors. They are trained and equipped to operate in denied or sensitive areas, adept at accomplishing covert and discrete types of missions conventional forces are otherwise incapable of performing. SOF is a very powerful weapon, able to project a decisive strike quickly and efficiently without leaving behind a large footprint.

The use of Special Forces is prominent throughout military history. One example is Napoleon's Sapper Units which engaged in demolition, sabotage, reconnaissance, and deception warfare against enemy forces and fortifications (577th Engineer Battalion website). Present-day forces are better equipped, trained, and knowledgeable in leveraging technology to their advantage in swiftly striking an enemy's capability.

United States Special Operations Command (USSOCOM) manages, equips, trains, and employs SOF units for each military service. Currently, USSOCOM has over 52, 000 active and reserve military and civilian workforce, and is expected to grow further as the Global War on Terrorism (GWOT) environment expands. USSOCOM was established in 1986 as a product of the Goldwater-Nichols Act. The Goldwater-Nichols Act established the strategy and mentality of organizing the military into a joint force. Among other changes, it removed functional control of combat forces from the service chiefs to the Combatant Commander (COCOM). Each COCOM is given charge over forces within their assigned geographical region provided by each military service. Unlike other COCOM, USSOCOM has its own funding source from Title 10 U.S. code, resulting from the Nunn-Cohen amendment to the Goldwater-Nichols Act (Tribute to SO, p. 32). This gives the power to adjust, reorganize, and directly equip forces assigned to the command. The flexibility given in managing its own forces is instrumental in SOF's role as a global war asset (SOF Posture Statement, p. 4).

After the September 11, 2001 attack on the World Trade Center, USSOCOM initiated operations against the Taliban and Al-Qaeda terrorist networks. Their effective interagency planning and execution of operations against the terrorist organizations led the President of the United States in 2004 to enlarge USSOCOM's role in the GWOT. Their role, as stated in the 2004 Unified Command Plan, is "the lead combatant commander for planning, synchronizing, and as directed, executing global operations against terrorist networks in coordination with other combatant commanders" (SOF Posture Statement, p. 3). A Joint Special Operations Task Force is set up to coordinate all military functions required to accomplish the specified mission within a geographic COCOM's JOA.

USSOCOM achieves its desired objectives as a joint forces command through the special operations subordinate commands within each service. The Army Special Operations Command (USASOC), Naval Special Warfare Command (NAVSPECWARCOM), Air Force Special Operations Command (AFSOC), and Marine Corps Forces Special Operations Command (MARSOC) directly provide the training, equipping, and support of their respective service SOF personnel as directed by USSOCOM. These subordinate service commands tailor their force training, structure, and support to fulfill their specialized tasks as the operational environment dictates.

2. SOF / Seabasing Integration

SOF operates in denied access and clandestine environments that require high degrees of stealth, decisiveness, and combat capability. They rely on the element of surprise and covertness throughout the insertion, support, and extraction evolutions to gain combat advantages over the enemy while maximizing the safety of personnel within the units. The units are trained and structured to deploy in a very small amount of time, sometimes less than 24 hours. The speed at which they assemble, deploy, and accomplish their missions requires pinpoint operational placement of the units to maximize battlespace and operational effects. Placement of these units can be done via single or multiple modes of transportation, e.g., foot, land vehicle, airborne drop, to their intended target. SOF units which originate from FOBs can have a degraded level of surprise and stealth due to the enemy and local populace's knowledge of the base's approximate or known location. Restricting the 'visibility,' or footprint, of the FOB constrains operating functions, e.g., force protection levels, C2, or logistic support traffic. This in turn can adversely affect the security and readiness of forces employed.

An alternative to land-based SOF is placing them on a seabase. The seabase's mobility and unrestricted access to internationally-neutral or denied land-based operating environments lends itself perfectly to a platform that reacts quickly to a theater's changing combat environment. This results in the seabase swiftly being on station to employ SOF and supporting forces as required. The location and freedom to maneuver inherent within a seabase minimize the constraints placed on operating functions as required per mission parameters. Logistics, C2, and other operational functions SOF units need will utilize existing technologies and support networks already managed by the seabase. A JFC can capitalize on the scalability of a seabase to rapidly deploy quick reactionary forces in operations before, during, or post-campaign (NWP 3-62M, p. 5-1).

The unrelenting pace at which SOF units are employed around the world lends itself as an excellent candidate for sea-based operations. The agile maneuvering and speed of a maritime platform to deliver force capability is directly in-line with SOF capabilities as a rapid, precise, and lethal weapon. Once inside the JOA, sustainment of a joint SOF will be the most challenging and crucial step in maintaining force dominance across the Seabase's ROMO.

D. RESEARCH OBJECTIVE AND PURPOSE

The purpose of this thesis is to identify what levels of support and capability are required to logistically sustain a varied amount of SOF units from a single-ship Seabase. The model, and subsequent analysis, will help in determining the structure and support asset capabilities required of a single-ship Seabase in supporting SOF units engaged in a variety of missions ashore.

Traditionally, SOF units operating in a combat theater populated by conventional forces, regardless of military-specific service, rely on a mature and established logistics network innate to the theater. Combat Support Units supporting the SOF coordinate with the COCOM J-4 to provide requisitioned material and services. (NWP 3-05, p. 2-15) On the other hand, SOF units employed in denied and clandestine environments face many logistic support challenges. This may be due to the sensitivity or level of covertness required of the missions normally generated for these types of environments, for example. Seabasing provides SOF forces with a central platform to perform all the supporting operational functions, regardless of the operational environment's deniability to military force access.

E. MODEL SCOPE AND ASSUMPTIONS

SOF units tailor the supplies outfitted to personnel based on the requirements defined by a mission's objective. For example, body armor is given to those units engaging in Direct Action missions, but would not be given in most cases to units engaged in Special Reconnaissance missions. The commodities of supplies carried by the units within the model represent categories of common-use items used in most, if not all, of the missions SOF is capable of performing. The categories include: Ammunition, Equipment, Medical, Subsistence, and Water. SOF Peculiar items are not modeled as an item supplied or requiring support.

SOF units will perform one of four mission types: Direct Action; Special Reconnaissance; Search and Rescue; and Unconventional Warfare. These missions will cause the units to consume on-hand supplies, and initiate a request for additional supplies, if necessary, prior to continuing. Missions are assumed to be 100% successful.

Supplies are carried by the helicopters internally. The added weight restricts a helicopter's speed, but does not render it operationally handicapped if required to enter a combat zone in support of ground-based SOF units. SOF units operate within the range of sea-based helicopter assets; therefore the risk of a 'bingo' (i.e., near empty) fuel state is nearly zero. The helicopter acts solely as a logistic delivery vehicle, and is assumed to enter a non-combat environment when delivering supplies to the SOF units.

Additional assumptions:

1. SOF units and the helicopter assets do not vary speeds.
2. Equipment specifically designed for a mission type, e.g., body armor for Direct Action missions, is assumed to be delivered or returned as necessary to perform the upcoming assigned mission dictates.
3. The capacity of the resupply ship, along with its source of material being delivered to the seabase, is considered infinite.
4. Loading and offloading times for the helicopters, and the resupply time for SOF units upon receipt of material, are exponentially distributed.
5. Mission times and intensities are randomly assigned using the triangle distribution.

F. METHODOLOGY

The model is based on a temperate region of the world which requires the deployment of individual or multiple SOF units from a single-ship Seabase to perform various missions. A Discrete Event Simulation written in Java computer language, utilizing a package known as Simkit, represents the fore-mentioned scenario. The simulation is run repetitively based on input parameters defined in the model. Data are produced for each simulation repetition and subsequently analyzed for changes to the Measures of Effectiveness (MOE). Multiple simulation runs, with multiple repetitions for each run, will be performed using varied levels or degrees of input parameters. This procedure, known as Design of Experiments (DOE), can show indications of how MOEs are affected by the various levels of input parameters to the simulation. Further analysis was performed on the output from the DOE process.

The remainder of this thesis is organized as follows:

1. Chapter II builds a solid foundation on Seabasing and the military components modeled within the simulation.
2. Chapter III describes the model in detail by explaining the purpose of each Java class and associated interactions.
3. Chapter IV introduces the type and methods of analysis used, along with data and graphic displays of the results.
4. Chapter V discusses the conclusions of the study and gives further research recommendations.

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II. MODEL COMPONENTS

A. SEABASING

1. Assumptions Underlying a Seabase

The operating assumptions underlying Seabasing contain concepts derived from the other three Naval Capability Pillars: Sea Strike, Sea Shield, and Force Net. The seabase must possess the capability to protect itself and forces embarked from a multitude of air, surface, subsurface, and space weaponry. This may be difficult for a single ship seabase to fulfill, and would require a maritime escort to supplement with applicable defensive technologies absent in the seabase. The flexibility and adaptability to differing missions requires the seabase to possess at their disposal the offensive striking power necessary to support joint forces ashore. This can include naval fire support, air strike, or precision-guided munitions launched from platforms within or around the seabase. These elements cannot all be achieved without proper coordination through a robust joint / multinational Command and Control (C2) network. The ability to share a common operating picture across all elements of the seabase is essential to conducting sustained full spectrum combat operations. A challenge inherent within this assumption is the technology possessed by multinational forces as compared to U.S. joint forces. Inferior technologies may have limited or nonexistent integration capabilities to fully realize the critical advantages a secure and reliable C2 network can bring to the fight. These assumptions rely on a stable environment around the seabase. High sea states can wreak havoc on simple operations within the seabase. The receiving of personnel and equipment essential to the mission may not occur given weather conditions outside operating envelopes for air or sea delivery. This adversely affects the underlying seabasing principle of maintaining a base afloat capable of rapidly receiving and deploying forces ashore (NWP 3-62M, p. 1-4, 6-1).

2. Attributes of a Seabase

Capability of a seabase is based on size, composition, and mission requirement constraints. It is measured in six attributes. The first attribute, Capacity, is a measure of how much capability a seabase can manage. This capacity covers things such as the number of personnel berthing available to embarking units, the storage area available for material and equipment, and the number and types of vehicles assigned to the seabase for force delivery ashore.

The second attribute is the rate at which measures of performance are accomplished over a period of time under normal conditions. These measures of performance are components of the Seabasing Lines of Operation:

- Close – the coordination and delivery of forces to an area of conflict;
- Assemble – the transitioning of seabasing assets and arriving forces to fulfill all required capabilities dictated by the mission;
- Employ – the employment of forces from the seabase to achieve mission requirements;
- Sustain – the sustainment of all forces by and from the seabase across all military operations; and
- Reconstitute – the ability to rapidly recover, re-supply, and re-deploy forces from the seabase to support subsequent operations.

The rate will be an important measure to gauge whether a single ship or a collection of ships will effectively support the force components required for the assigned mission.

The third attribute is associated with the infrastructure inherent to the seabase. This infrastructure covers all systems available to the JFC in accomplishing the mission. Over The Horizon (OTH) strike capability, logistics and support services, and vehicle specific well deck or aviation capability are some examples of infrastructure systems a single or multiple-platform brings to the operational theater. An evaluation of the seabase infrastructure must be included in the operational planning process to complement the forces being embarked.

Interoperability between seabase systems and embarked force composition is the fourth capability attribute. Interoperability of the systems is measured over the full range of the seabase lines of operation previously mentioned. The sharing of technologies and innovations across services is vital to joint forces' ability to seamlessly integrate into a seabase. If, for example, communications technologies used by Army Special Operations Forces (SOF) are not compatible with the seabase's communications suite, the Joint Forces Commander (JFC) may resort to using inferior communications or require the addition of other maritime assets with the communication capability to the seabase. This can require additional time and funding to establish proper interoperability, thus slowing down the planning process and subsequent mission commencement.

The fifth attribute describes how survivable the seabase is, and how it can protect the forces assigned to it. It extends to forces within the seabase and those forces ashore supported by the seabase. The level of security given to forces ashore is constrained by the assets available to the seabase, and is dependent on the operating environment and covertness of the mission. This is currently one of the most challenging attributes to maintain at an appropriate level of security given the dynamic and asymmetric threats the U.S. faces from its enemies.

The final capability attribute is accessibility. Accessibility refers to both the seabase's and the embarked force's ability to operate within an environment susceptible to harsh weather conditions, multi-dimensional threats, geographic challenges ashore, or depth of operations dictated by the mission. Equipment and materials available to the seabase may be incompatible to fulfill the mission objectives, thus requiring the establishment or use of a logistics network to requisition needed materials, or scaling of the seabase to acquire capabilities necessary to fulfill those objectives (Seabasing JIC, pp. 7 – 9; NWP 3-62M, p. 6-2).

3. Seabasing Logistics

Seabasing logistics is a dynamic process that spans the entire Range of Military Operations (ROMO) and has its foundation in supporting joint forces both afloat and ashore. Across the Joint Operating Area (JOA), logistic capabilities are controlled by the Joint Force Maritime Component Commander (JFMCC). These capabilities, along with C2, must be integrated and synchronized with the objectives and operational plans being pursued by the sea-based forces. Scalability and flexibility of the capabilities are crucial to allow proper adaptation of logistic plans and networks to the sea base's operating environment (NWP 3-62M, p. 2-1).

Each individual service component commander maintains control of all logistic capabilities for their own services' forces. The coordination of all service component commanders' logistics is the responsibility of the JFC. It is the JFC who has directive authority to shift and/or align logistic resources among the service component commanders to or through the seabase in aligning operational plans to the corresponding support required. During the initial stages of an operation, forward-deployed and pre-positioned forces will utilize existing pre-positioned material and logistic networks until the seabase arrives and is fully functioning. Advanced Logistic Support Site (ALSS) and a Forward Logistic Site (FLS) are both established to act as transshipment points between Continental United States (CONUS)-based support activities and the sea base itself. Through these logistic sites, all material and personnel are routed to support sea-based operations within the JOA. The rapid establishment of these sites is critical in the initial stages of the operation to provide a stable and responsive logistic network to "receive, reconfigure, store, load, transport, and distribute supplies and material throughout the seabase and supporting sites" (NWP 3-62M p. 6-1). Figure 1 below is a basic representation of a seabase's logistic structure for a given JOA.

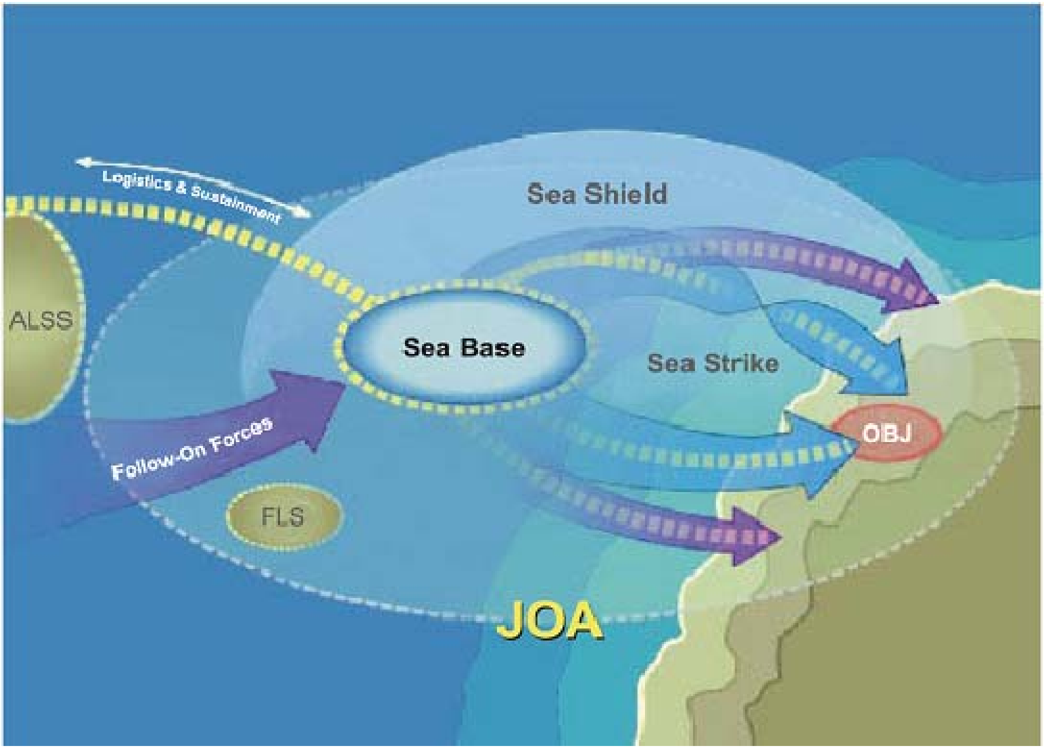

Figure 1. Overview of Seabasing (From: NWP 3-62M, p. 1-2)

Peacetime logistic pipelines are expanded early in the operational planning process to support the increased volume of resources flowing into and out of the seabase. Logisticians face an extreme challenge in balancing the increased flow of material into theater with the effective sustainment of joint sea-based forces over the entire ROMO, while facing numerous constraints (mentioned previously in the Seabasing – Attributes of a Seabase section) on the logistical capability of the seabase. These constraints are considered within the planning process to provide the groundwork for a logistic network to be established through the seabase. They must be managed carefully to avoid overstating or understating the required logistic support of sea-based forces. Once the logistics network is erected, a Common Logistics Operating Picture (LOGCOP) is generated which provides decision makers enhanced response and flow information of material through this network. In other words, it provides real-time visibility and status of material and equipment entering and exiting the JOA. In addition, LOGCOP provides micro-level information on critical requisitioned parts and its effects on force capability (NWP 3-62M, pp. 6-2 thru 6-5).

Once operational, the seabase performs all logistic functions for the sea-based forces employed. The degree and scalability of the planning considerations will determine the degree and scalability of logistic functions the seabase will perform. This is an important factor when considering whether a single or multiple-ship seabase is appropriate for the mission. The logistic functions are listed below as they pertain to the seabase structure and design.

- *Supply and Sustainment* – The seabase is responsible for the supply and sustained delivery of material to forces within the theater. This material includes ordnance, provisions, consumables, repair parts, construction material, petroleum oil and lubricants (POL), and major end items. The number of consumers, commodity consumption rate, and composition of the force will determine the level of supply and sustainment required.

- *Contracting* – Contracting with local host nation entities enhances each of the logistic functions of the seabase. It utilizes local supplies and services to perform the functions otherwise performed by entities external to the JOA. Local contracting speeds up the process of delivering critical material and services to forces relative to waiting for the scheduling of internal delivery assets and transit time to provide supporting requirements.

- *Transportation and Distribution* – Critical to the pace of the operations is the process of delivering material to the fighting forces. The pace is constrained by several physical variables. First is the amount of logistic delivery assets available to the seabase. This includes both inter-theater and intra-theater transportation. Once the amount and type of assets available are known, the second variable, accessible infrastructure, constrains the type of logistic delivery assets available. For example, a region within the JOA may not contain runways long enough to handle the C-5 Galaxy take-off and landing length requirements. This will prevent heavy airlift from delivering material, and may require additional land assets to be used as a suitable substitute. The third variable is the distance and geographical boundaries between the ALSS, FLS, and the seabase. This variable may restrict the types of air, land, and maritime logistic delivery vehicles used to support operating forces. Additional scheduling of refueling assets to extend delivery vehicle range or pre-positioning additional material may alleviate deficiencies within this variable. Prioritization of supplies and C2 coordination of delivery assets is the final variable, and critical to optimizing the use of assets while serving the critical requirements needed by forward operating forces.
- *Maintenance* – Maintenance is segregated by the level of repair required on a serviceable part or major end item. The three levels are Organizational, Intermediate, and Depot. The capability of a seabase only extends to the organizational and intermediate levels of maintenance. Organizational repair will be done at the unit level repair organizations located at the seabase or within the forward operating forces. Intermediate repair can be done within the seabase infrastructure, such as the Aircraft Intermediate Maintenance Department (AIMD) on aircraft carriers, or ashore within maintenance activities located at forward operating bases. Maintenance is dependent on the Transportation and Distribution function to move parts and equipment to and from the maintenance

activities. This can constrain the scheduling and turn-around of equipment to operating condition based on the logistic delivery assets available to the seabase.

- *Engineering* – Employment of engineering battalions early in the phases of an operation can aid in the smooth transition of logistic function responsibility from the pre-positioned force support structure to the seabase. Engineers can construct, modify, or repair Air Point of Debarkation (APOD), Sea Port of Debarkation (SPOD), and ALSS, FLS, and intra-theater transportation infrastructure necessary to establish the required logistics network dictated by the operational planning objective.
- *Health Service Support* – This function provides the full spectrum of medical care and preventive measures to maintain proper health and sanitation within the JOA. The seabase is responsible for the full spectrum of medical support to the operating forces, to include evacuation of casualties to the seabase, providing adequate medical infrastructure on the seabase, and the evacuation of casualties from the seabase to advanced medical care facilities outside the JOA.
- *Other Services / Facilities Support* – Seabasing operations may require additional services not previously mentioned, to include “salvage and harbor clearance, mortuary affairs, postal, disbursing, billeting, exchange services, food services, etc” (NWP 3-62M, p. 6-9). These services can either be inherent within the seabase’s infrastructure, or gained from external sources such as the ALSS, FLS, or host-nation contracting. The seabase has a limit on the size of force and duration of the operation it can support with other services / facilities. Arranging additional logistic sorties or establishing contracts within the JOA early in the planning process will enable the seabase to support forces in the chance that operations exceed the required timeline of completion.

As the operational picture changes during a campaign, so should the logistics network which supports the operational forces. Planners will constantly evaluate the planning considerations and functions of the seabase to gauge whether or not effective logistic practices are in place. A delicate balance of what resources are available and the application of those resources can be the decisive point in achieving the operational dominance across the ROMO (NWP 3-62M, pp. 6-5 thru 6-10).

B. LPD – 17 SAN ANTONIO CLASS AMPHIBIOUS DOCKING SHIP

1. Background

The LPD – 17 class amphibious assault ships is the first of many weapons systems coming online to support the current and future U.S. defense strategies. Planning for the ship class started in fiscal year 1991, and was subsequently contracted to Northrop Grumman for building in late 1996. The ship was christened in July 2003, and commissioned in 2005 when it set sail for its homeport of Norfolk, Virginia. The San Antonio class is scheduled to have twelve ships in total by 2008, to include those in planning, construction, and full operational capability. It will replace four classes of amphibious ships: LPD – 4 Austin class transport docking ships; LST-1179 Newport class tank landing ships; LSD-36 Anchorage class dock landing ships; and LKA-113 Charleston class amphibious cargo ships (LPD-17 ORD, p. 1).

2. Operational Capability

The ship was built to handle the risks associated with operating in the littorals. Ship stealth technologies are implemented within the class. The hull and superstructure are shaped and designed to decrease the radar cross-section of the vessel. This in turn makes the ship appear as a smaller object on an enemy's radar. Numerous pieces of equipment normally placed on the exterior of the ship are brought either inside or placed within pockets to further decrease its radar visibility. Hot spots on the hull were cooled to aid in the ship's defense from heat sensing weapons and visual sensing technologies. As seen in Appendix A, its anti-air and surface defense capabilities, along with its radar and electronic warfare suites, allow senior decision makers to employ the vessel either with an ESG or as a stand-alone detachment. This flexibility allows multiple missions across multiple dimensions to be accomplished simultaneously (Defense Industry Daily).

The ship's primary missions are centered on amphibious operations and command and control of those operations. A secondary mission that the LPD-17 can support across all dimensions is Special Operations. A minimum of four hundred square feet of equipment and cargo space is set aside for SOF detachments. In addition to this storage capacity, the ship can embark a containerized Flyaway Dive Locker (FADL) and a Flyway Recompression Chamber (FARC). Additional capacity can be realized given special operations missions are pre-assigned to the ship prior to deployment load out, or embarked Marine assets are offloaded to create capacity space for SOF equipment. The ship’s design and primary mission make it an ideal platform to conduct SOF operations. The ability to land, fuel, outfit, and take off two heavy-lift or four medium-lift Vertical Take Off and Landing (VTOL) craft, simultaneously, lends itself to serving a variety of SOF supporting roles to include air cover for insertion, logistic support, medical evacuation, and rapid extrication of units and equipment. The well deck can be ballasted to eight feet of water over the sill for embarkation of Naval Special Warfare (NSW) displacement vehicles, such as the Mark V Special Operations Craft (SOC). The additional cargo, ammunition, and vehicle storage capacity allows for small to medium sized SOF operations to be conducted from the LPD-17 class ships (LPD-17 ORD, pp. 3-6).

3. Logistic Capabilities

The San Antonio class, just as any Navy ship, is capable of performing underway replenishments at sea via either Vertical Replenishment (VERTREP) or Connected Replenishment (CONREP). This fact alone gives Navy ships the ability to stay at sea for great lengths of time without compromising their location and/or mission by leaving the operational area and pulling into a local port. Unlike their combatant cousins, amphibious ships have an aerial and surface logistic delivery capability at their disposal. As previously mentioned, the LPD-17 is capable of handling two heavy lift or four medium lift VTOL aircraft at once. In particular, the CH-53E Sea Stallion with an exterior hook capacity of 20,000 pounds, the V-22 Osprey with an internal/external capacity of 20,000 pounds, and the CH-46 Sea Knight with an exterior hook capacity of 4,000 pounds give a significant amount of aerial logistics capability to project from the sea to land-based forces. The sea to shore logistics chain can be further extended by utilizing the Landing Craft Air Cushion (LCAC). This cargo carrying giant can haul 60 – 75 tons of material at speeds exceeding 40 knots over land or sea (Federation of

American Scientists website – LCAC). The combination of these air and surface logistic delivery mediums gives the LPD-17 the capability to support any small to medium sized SOF operation.

There are a few considerations when utilizing these assets. Operations that involve large amounts of SOF forces to stay ashore for extended periods of time may require a Forward Operating Base (FOB) to handle command and control and various logistics functions. Material requirements can then be stockpiled at the FOB to replenish the units as needed. This relieves some of the pressure on both the surface and aerial assets to fulfill logistic missions in direct support of the units, allowing them to support other critical missions such as search and rescue or air strike. Another consideration deals with the single-ship seabase supporting multiple segregate units ashore with only the logistic assets available aboard, and no FOB. The following scenario shows how the logistics support chain would break down, delaying the initiation of operations within the area of responsibility (AOR):

> Unit A is on an extended reconnaissance, and requires a resupply of materials to fulfill the mission. The mission is time sensitive, and without the supply delivery, it will miss the opportunity to capture its main objective. Unit B is preparing to initiate a direct assault mission on a small enemy military encampment. Something has occurred, and Unit B requires an emergency extraction of personnel and wounded. With two heavy lift air assets available, SOF operators in Unit B will require both assets to participate in the extraction. This leaves no air assets available to support Unit A's immediate material request, and thus compromises the reconnaissance mission.

The scenario above is a notional example to show that there are logistic limitations to supporting multiple SOF units from a single-ship seabase that must be considered by commanders prior to employment.

The tasks and risks our personnel face in the operating environments expose them to possible injury of any measurable degree. Medical facilities established in the FOB aid in supporting the care and well-being of ground forces under their cognizance. Depending on the geographic location and type of mission assigned to SOF units, a FOB may or may not be located within the logistic reach of the units. The reliance for medical support will then shift to the seabase as the primary care facility. The use of an amphibious assault ship as a seabase allows embarked units to take advantage of the larger medical facilities available as compared to other combatant ships in the fleet. The LPD-17 class contains two medical operating rooms, a 24-bed hospital ward, and a casualty overflow capacity of 100 (Federation of American Scientists – LPD-17). This allows small to larger sized SOF units to utilize the medical capability as a casualty receiving and treatment facility. (Defense Industry Daily) The combination of this and the aviation element capacity inherent on the LPD-17 makes this an effective platform to either handle or transfer personnel casualties to hospitals within theater.

C. HH-60G PAVE HAWK HELICOPTER

The HH-60G Pave Hawk is a medium lift, twin engine helicopter used primarily by the Army and Air Force. Its primary mission is to support the insertion, support, and extraction of Special Forces units engaged in a multitude of missions within hostile environments, through degraded weather conditions, day or night. It is a highly modified variant of the UH-60 Blackhawk helicopter fielded by the U.S. Army.

The Pave Hawk's extensive capability is realized through upgraded navigational, communications, operational endurance, combat, and tactical data systems. It utilizes an integrated inertial/global positioning/Doppler navigation system in directing the aircraft to its intended target. In addition, the forward-looking infrared and night vision compatibility of the cockpit extends the operational and navigational capabilities by allowing it to fly in low visibility conditions at very low altitudes. Satellite-based communications, secure voice, and Have Quick radio technologies allow the Pave Hawk to feed tactical and/or operational information to its supported forces. These communications technologies are also inherent within SOF, thus making the platform highly compatible to supporting special operations. The addition of two internal reserve fuel tanks and a retractable in-flight refueling probe gives the Pave Hawk the capability to remain on station for an extended amount of time. Two crew-served mounted 7.62mm or .50 caliber machine guns, electronic warfare technologies, and an externally mounted hoist allow the helicopter to support combat and rescue operations in any environment.

Installed tactical data systems allow for the receiving and transmission of real-time combat information, giving the Pave Hawk a limited capability in filling a C2 role. Search and rescue operations are enhanced by locator systems that interface with global positioning systems and personnel radios to triangulate and direct the helicopter to survivors or units requiring extraction (Air Force Link).

The HH-60G is capable of performing logistic support missions along with its combat capability. It is outfitted with an external cargo hook located on the helicopter's undercarriage. The hook's maximum load capacity is 8,000 pounds, and internal capacity is approximately 1,500 pounds (Air Force Link). According to subject matter experts, the limited aircraft maneuverability and restricted speeds associated with handling an external load lends this type of logistic operation to be infeasible in most combat scenarios the Pave Hawk will be involved in. Entering a hostile environment requires as much speed and maneuverability that's available from the helicopter. Pilots will therefore more frequently consider supporting units logistically using internal space vice external for cargo transport.

The Pave Hawk's versatile employment in missions supporting SOF gives JFCs the increased flexibility they require in planning operations within dynamic environments. The HH-60G, although Air Force owned, is capable of folding its rotor blades for maritime transport and operations (Air Force Link). This maritime-based adaptation gives the Pave Hawk the necessary means to operate from a seabase.

D. SPECIAL OPERATIONS FORCE (SOF) UNITS

1. SOF Warrior

The requirements to become a member of the Special Operations community are rigorous and extremely challenging. The initial phases of training potential special operators tests maturity, ingenuity, mental agility, physical strength, and the drive necessary to endure the rigors they will ultimately face in the operational environment. Unlike conventional forces that are specialized in one area of expertise, special operators are trained in a wide range of skills at an expert level of knowledge and capability. Skills such as demolition, multiple weapon specialization, guerilla tactics, cultural management, and foreign language training are a few examples given to special operators over a course of their two year initial training (SOF Posture Statement, p. 16). The intense training given initially and throughout a special operator's career, via programs such as Advanced Special Operations Technique (ASOT) training and the Joint Special Operations University located at Hulburt Field in Florida, empowers them to face and accomplish the rigors of assigned missions within any environment. Above all, the person, or operator, is the number one priority in the Special Operations community. This is evident in the first 'SOF Truth' being "Humans are more important than Hardware" (SOF Posture Statement, p. 1).

2. SOF Equipment

The SOF operator's equipment is the principal component assisting them in completing their assigned task or mission. There are two types of equipment, Standard Equipment and SOF Peculiar Equipment. Standard Equipment is the basic materials common to all military units requisitioned through logistic networks accessible by all. SOF Peculiar Equipment is designed to enhance the capabilities of a SOF unit to accomplish the sensitive and demanding missions assigned to it. In some cases, SOF Peculiar items are standard pieces of equipment that were modified to suit various mission requirements. An example of this is the M4A1 Special Operations Peculiar Modification (SOPMOD) rifle. The M4A1 SOPMOD is a modified variant of the M4, a shortened version of the M16A2 rifle, which utilizes Commercial Off-The-Shelf (COTS) items to enhance its capability. The SOPMOD kit includes: an M4A1 carbine, a Rail Interface System (RIS) hand guard developed by Knight's Armament Company, a shortened quick-detachable M203 grenade launcher and leaf sight, a KAC sound suppressor, a KAC back-up rear sight, an Insight Technologies AN/PEQ-2A visible laser/infrared designator, along with Trijicon's ACOG and Reflex sights, and a night vision sight" (GlobalSecurity.org).

There are many advantages in using COTS, one being the ease at acquisitioning the items through local contracts, while another being the fact these items possess the latest in cutting-edge technologies to leverage against an enemy's various capabilities.

The Special Operations community is unique in their responsibility of equipment acquisition and life-cycle management. United States Special Operations Command (USSOCOM) is the only unified combatant commander that has sole responsibility of acquisition and life-cycle management for its peculiar equipment. The imbedded full-service acquisition staff provides USSOCOM increased flexibility and responsiveness in supporting its operators through streamlined logistic networks. The staff utilizes a process known as Urgent Deployment Acquisition (UDA) to expedite the procurement and distribution of new technologies into the hands of the SOF units who operate in today's extremely dynamic combat environment (SOF Posture Statement, p. 20).

3. SOF Missions

Personnel, force capabilities, level of training, and applied equipment are just a few of the necessary ingredients in completing assigned mission objective(s). It is important to understand that, because of the ingredients mentioned, conventional forces cannot accomplish missions designed for SOF, nor can SOF accomplish missions designed for conventional forces. These missions are specifically tailored for the environment, target, and objective. There are eight different kinds of SOF-specific missions: Direct Action, Special Reconnaissance, Foreign Internal Defense, Unconventional Warfare, Counterterrorism, Counterproliferation of Weapons of Mass Destruction, Civil Affairs Operations/Psychological Operations, and Information Operations.

- *Direct Action (DA)* – DA missions are short-duration, politically sensitive, and combat intensive operations which require specially trained personnel to accomplish. Its primary purpose is to destroy, exploit, capture, damage, or recover the designated target with a high degree of precision and force employment.
- *Special Reconnaissance (SR)* – SR operations occur in politically sensitive and denied environments that collect or verify strategic and operational information needed in battle-space assessment. SOF operators utilize the latest innovations in surveillance technology to accomplish a variety of missions such as battle damage

assessment; location, detection, and tracking of enemy personnel and weaponry; or hydrological surveys prior to amphibious landings.

- *Foreign Internal Defense (FID)* – FID missions employ SOF to train, counsel, and organize allied foreign military or security forces in core competencies within the context of national and strategic objectives of the host nation. Political and cultural sensitivities are crucial between the U.S. and foreign nation in synchronizing the means and ways to the end-state of creating a properly trained and equipped force. Stabilization efforts against insurgent or terrorist threats, reducing the need for future U.S. intervention, and maintaining U.S. relations and influence within the region are a few of the goals FID accomplishes. Typical FID missions are long in duration and have variable combat intensities dependent on level of insurgent activity in the region.

- *Unconventional Warfare (UW)* – UW missions cover a broad range of military and paramilitary warfare. It is conducted mainly by indigenous guerilla forces with all levels of support and training taken care of by an external SOF entity. In other words, SOF operates in varying degrees of directing or assisting the indigenous force in accomplishing its objectives. Types of UW missions include guerilla warfare; covert, sabotage, disruption, and intelligence gathering operations; and evasion and recovery operations. UW is highly intensive in terms of combat and political risk and usually longer in duration than DA, for example.

- *Counterterrorism (CT)* – CT missions require the entire range of Special Operations capabilities. These capabilities are used either in response to actions, threats, or hostage situations or as intelligence-gathering operations against terrorist cells and capabilities. The length and combat intensity of the missions are dependent on the stated objective(s) given to the SOF units.

- *Counterproliferation of Weapons of Mass Destruction (CPWMD)* – These missions involve locating, identifying, seizing, destroying, rendering safe, and transporting WMD from identified sources anywhere in the world. The tasks required to complete this mission may involve the entire spectrum of SOF capabilities, and may also require the injection of WMD handling capabilities specific to certain qualified personnel into the units.

- *Civil Affairs Operations / Psychological Operations (CAO/PSYOP)* – SOF units do not perform CAO/PSYOP directly. Rather, they fill a supporting role to the units performing these particular missions. USSOCOM manages CAO and PSYOPS as a separate entity from its Special Operations forces, and uses them to integrate and synchronize both capabilities to achieve the desired end-state effects.
- *Information Operations (IO)* – Information superiority within the battle space is achieved through the degradation or destruction of enemy information infrastructure while protecting and leveraging U.S. information and information capabilities. SOF provides support to larger IO campaigns through different inherent capabilities. IO may also be integrated as sub-objectives to other missions listed previously.

Once integrated into a Joint Task Force (JTF), SOF can provide the enhanced combat capabilities required to counter enemy operations across all spectrums of military action. The flexibility to act as either advisors; trainers to host nation forces; or as a weapon of stealth, speed, and precision; SOF continues to become the ‘force of choice’ in any operational environment.

4. SOF Unit Composition

SOF units are hierarchically organized similarly to conventional ground forces. Platoons, or teams, are anywhere in size from 10 to 14 operators and typically the mission deployment size. The composition of each unit is specifically tailored to the mission it is assigned, and therefore may only require a force smaller than a platoon such as a squad or fire-team (two person team). Equipment given to the unit is also adjusted based on the requirements of the mission. In the case of special operations, no two missions are the same, and thus the size, composition, and equipment a unit possesses is likewise never exactly the same. Due to the specific missions used in the model, this section will cover only Navy and Army Special Forces unit compositions.

a. Navy Sea, Air and Land (SEAL)

Navy SOF is comprised of four Naval Special Warfare Groups (NSWG) located either in Little Creek, Virginia or Coronado, California. NSWG-1 and NSWG-2 is comprised of four SEAL teams, a Logistics Support Unit (LOGSU), and Naval Special Warfare Units assigned to various geographic COCOMs which maintain administrative control over deployed forces entering the theater. NSWG-3 and NSWG-4 are the Special Boat Teams (SBT) and SEAL Delivery Vehicle (SDV) teams used as the primary insertion and extraction platform for amphibious-borne special operations. (NWP 3-05, pp. 2-2 thru 2-6) Navy SOF deploy as a Naval Special Warfare Task Group (NSWTG) to each of the COCOMs. NSWTGs are comprised of task units which handle C2, operational planning and execution, and a mobility element. The mobility element can either be ground-based, sea-based, or a combination of both. The operational component of each task unit is the SEAL platoon. Each platoon is comprised of 12 to 14 enlisted and 2 to 3 officers, each qualified in dive, demolition, parachute, maritime, and tactical small-unit operations. (NWP 3-05, p. 2-8) Figure 2 shows a notional SEAL platoon organization.

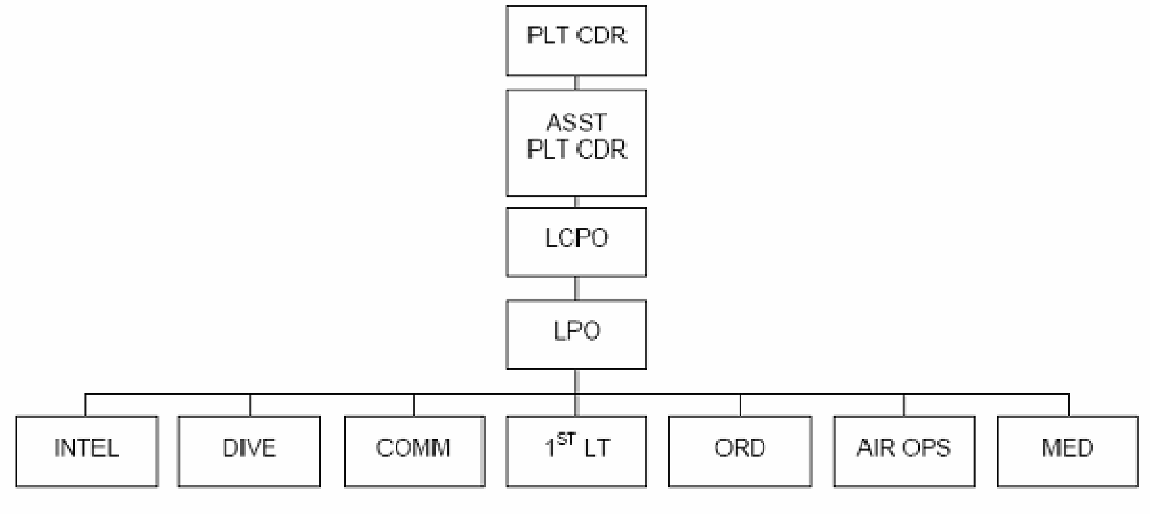

Figure 2. Notional SEAL platoon organization (From: NWP 3-05, p. 2-8)

These professionals are specialized in maritime-based special operations, but able, and are currently, working side-by-side with their Army counterparts in land-based operations supporting GWOT.

b. Army Special Forces

The leaders in large-scale land-based special operations, the United States Army Special Forces Command (Airborne) (USASFC(A)), a subordinate command under the United States Army Special Operations Command, is responsible for training, equipping, and employing the five active-duty and two National Guard Special Operations Groups (Airborne) to COCOMs in support of missions across the ROMO. Each group is comprised of four battalions and a company. Three of the four battalions are the line battalions which house the Special Forces, while the fourth battalion is the combat support element within the group. The headquarters company within each group is the C2 element coordinating all aspects of operations. The line battalions contain their own organic support and C2 structure along with three line companies. Each line company contains six Operational Detachment Alpha (ODA) teams. Two of the six teams within each company are specially trained in combat diving and free-fall parachuting as methods of infiltration. The ODAs are “the heart and soul of SF [Special Forces] operations” (U.S. Army Special Forces Command (A) Fact Sheet).

Each ODA is comprised of 12 Special Forces operators. An officer, normally a Captain, is the team commander with a Warrant Officer as second in command. The remaining members are non-commissioned officers specialized in a designated warfare area, to include weapons, demolition, medicine, communications, and intelligence. The ODA is a flexible tool that can be used by operational commanders to fulfill practically any mission (SpecialOperations.com). The scalability of personnel, skill set, and equipment allowed in the ODA units gives them the combat capability and advantage to quickly and decisively overpower the enemy. Figure 3 below gives a typical ODA unit composition.

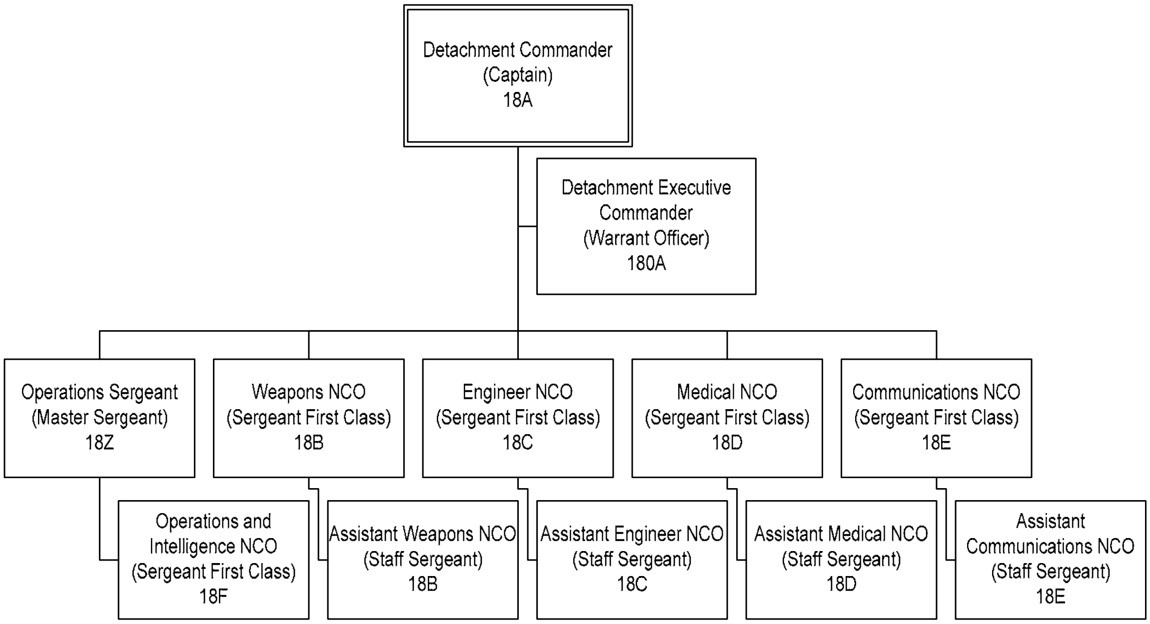

Figure 3. Typical ODA Composition (After: SpecialOperations.com)

E. CONCLUSION

Combining the agility of SOF with the highly mobile and self-supporting attributes of a single-ship seabase gives the JFC great flexibility in employing this revolutionary type of warfare in any combat environment. This concept, or model, is in its infancy and has yet to be fully tested and implemented within joint doctrine. Exploratory approaches in defining, shaping, and testing a model can bring to light either feasible or infeasible realities to existing concepts. The modeling approach being used in this thesis is Discrete Event Simulation (DES). The next chapter will discuss what DES is along with the tools and methodology used to build the simulation.

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III. METHODOLOGY

In the previous chapter, model components were discussed both as single independent entities and as an integrated system. The components were introduced in a detail necessary for the reader to frame the attributes and constraints each brings to the operational picture. In this chapter, the tools and methods used to model the components within a Discrete Event Simulation will be discussed.

A. DISCRETE EVENT SIMULATION (DES) MODELING

1. DES

Discrete Event Simulation is one of the many tools used to describe the behavior of one or many systems (see, e.g., Law and Kelton 2001 and Buss, April 2001). It is a collection of variables and events that produce state trajectories closely imitating the system being studied. These state trajectories refer to events occurring in the system that changes the state variables associated with it.

There are two types of variables associated with DES: parameters and state variables. Parameters are traits associated with a particular system that do not change when events occur. State variables describe a particular trait within the system that changes upon the occurrence of an event. To illustrate this, suppose a bank manager wants to study the arrival process of customers to a drive-thru teller service. The number of total drive-thru tellers available to the system does not change when a customer arrives (event); therefore it is a parameter. The arrival of a customer to the system changes the cumulative number of customer arrivals to the bank's drive-thru system for a given time period; therefore the cumulative number of customer arrivals is a state variable. Performance measures are derived from the collection of data, i.e., the changing values of state variables, as the simulation is executed.

Events describe what occurs when the value of a state variable changes. Events are scheduled based on an inherent time delay dictated by the system. Each event is placed on the Future Event List (FEL) according to the scheduled simulation time it will occur. The FEL sorts and initiates events based on the lowest scheduled time. Events occur instantaneously; state variables are changed; and future events are scheduled as appropriate to the behavior of the system. Once the FEL is empty, the system is thought of as being in an idle state. State variables are not changing when a system is idle, thus the simulation terminates.

2. Event Graphs

Event graphs are a visual medium to describe the interplay between scheduled events, parameters, and state variables. Nodes represent the events occurring within the system, and directed arcs joining the nodes represent the scheduling of a future event. Additional notation, such as arguments being passed between events, a conditional statement governing the scheduling of a future event, or the time delay between two events, is added to give the graph depth and a degree of robustness. Figure 4 shows an example of an event graph for two events A and B.

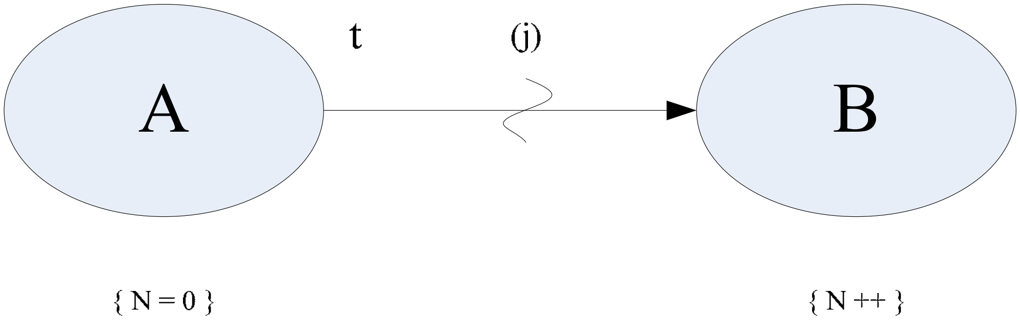


Figure 4. Fundamental Event Graph (From: Buss, April 2001, p. 2)

The above event graph can be interpreted as follows: Event A occurs, setting the state variable *N* to zero; if the conditional statement *(j)* is true, Event A schedules Event B with a time delay equal to the parameter *t*; Event B occurs which changes the state variable *N* by a value of one unit.

3. Listener Pattern

The establishment of listening patterns between two or more system components is a powerful tool within DES. The occurrence of an event in a source component is "heard" by all components listening to it. If the listener component contains the same event name and signature heard from the source, the event is executed as if explicitly scheduled (Buss and Sanchez, 2005, p. 996). The utilization of listener patterns allows components to be interchangeable to other systems without having to redesign the individual components. To illustrate this, suppose we have a school teacher, Mrs. Smith, calling class attendance. Mrs. Smith has three students, Billy, Bob, and Sue. Each of the three students listens for their name to be called, and responds "present" to indicate their attendance in class. Figure 5 is the event graph representing this system using listener patterns.

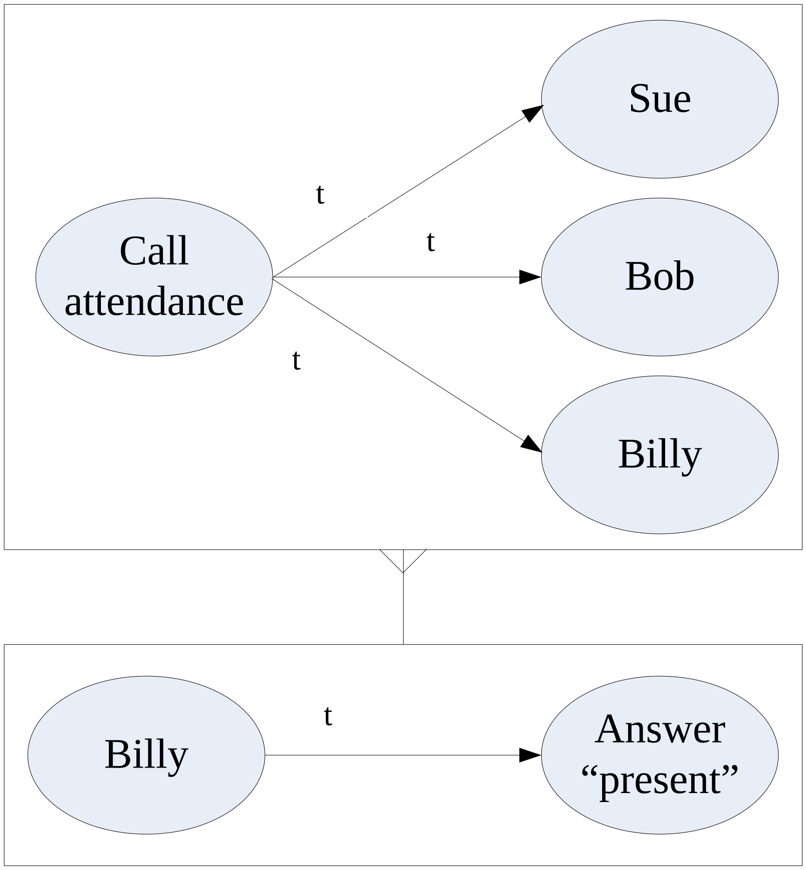


Figure 5. Use of Listener Patterns in DES

In the above example, the event 'Call Attendance' is executed, and schedules the three events: 'Sue', 'Bob', and 'Billy', with a time delay equal to the parameter *t*. Billy's listener component "hears" when the 'Sue' and 'Bob' events are executed, but does nothing until the 'Billy' event is executed. Upon this execution, Billy's listener component immediately executes the ‘Billy’ event and schedules the event ‘Answer “present”’ with a delay equal to the parameter *t*. At the completion of the delay, the ‘Answer “present”’ event is executed. Billy can now take his listener component to his next class and be able to answer the call of attendance.

4. Simkit

Simkit is an open source package, written in Java computer language, which uses the Listener Event Graph Object (LEGO) concept to generate objects that comprise a DES component framework. Additional information about LEGO can be found in Buss and Sanchez (2002). Simkit can be thought of as the medium in which event graphs are translated into a collection of components that encompass a computer simulation model. Table 2 summarizes the relationship between DES event graphs and Simkit implementations.

Event Graph	Simkit implementation
Parameters	*private* instance variables mapped into a read/write property of the class
State Variables	*protected* instance variables mapped into a read only property of the class
Events	classified by a method with the event’s name prefixed by ‘do’
Run Event	reset() method that initializes all state variables doRun() method updates the value of all state variables by firing a property change.
Event scheduling	use of waitDelay() method with the event name, time delay, and corresponding arguments as appropriate
State Variable change	the firing of a PropertyChangeEvent

Table 2. Relationship between Event Graphs and Simkit implementation (From: Buss, 2002, p. 244)

B. MODEL DESCRIPTION

1. Overview

The model is intended to determine the level of sustained logistic support required to individual or multiple SOF units performing a variety of land-based missions from a single-ship seabase. The model is written in the Java computer language using the Simkit package to drive different entities in performing various tasks. The structure of the model utilizes a rudimentary chain of command typically seen in most military units.

SOF units deploy initially from the seabase to randomly assigned mission waypoints within the battlespace. Each performs an assigned mission, randomly generated from a discrete list, upon arrival at the waypoint. Supplies are consumed at a rate based on a calculated consumption rate, mission length, mission intensity, and type of mission. Upon completion of the mission, the units will communicate the required amount of material to the seabase. The seabase commander checks the availability of a helicopter, and assigns the first available to deliver goods to the requesting unit. The requested quantity is loaded onto the helicopter and delivered to a waypoint other than the unit's location. This is necessary to maintain the covert state of the unit, and not allow the helicopter's presence to give away their position to enemy forces. Supplies are dropped by the helicopter, and subsequently picked up by the SOF unit once they arrive at the delivery waypoint. Upon completion of their resupply, the unit moves to their next assigned waypoint to perform another mission. If, upon completion of a mission, there are no helicopters available to perform a support mission, and the unit supply quantities fall below a stated threshold, the unit will remain at its current location until the first helicopter comes available and is assigned a delivery mission in support of this unit.

The seabase holds a finite amount of material for issue to the SOF units. Once the on-hand quantities fall below a stated threshold, based on a percentage of maximum capacity for each commodity, the seabase will request an underway replenishment to be performed by a resupply ship. The resupply ship will gather the requested material, and deliver the goods to the seabase within a time period of three days.

There are five classes that represent the military components modeled in the simulation. These five classes are: SOFUnitMoverManager, HeloMoverManager, Commander, SeabaseMoverManager, and ResupplyShipMoverManager. The remaining eight classes define the inherent behavioral states, supply commodities carried, and available missions to perform for each military component as applicable. Figure 6 is the listener pattern between the component classes.

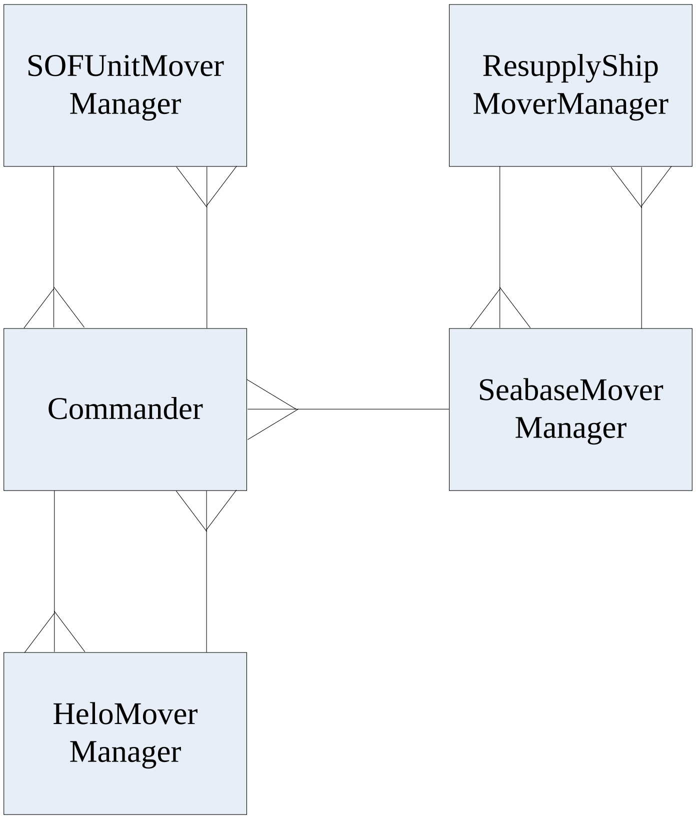


Figure 6. Model Listener Pattern

2. SOFUnitMoverManager Class

The SOFUnitMoverManager class creates and manages each unit's movement to a waypoint, mission assignment, and replenishment of supply commodities carried. Each unit is defined by fourteen different parameters listed below. Weights of individual items used in calculating the total weight, in pounds, of each supply commodity per unit are taken from (United States Marine Corps Systems Command).

- sofUnit – Utilizes the Mover class within Simkit that controls the movement and speed of each unit from waypoint to waypoint.

- baseLocation – The initial starting point of all units represented as an x-coordinate, y-coordinate pair.
- resupplyTime – An exponentially distributed random number that is generated each time the unit arrives at a supply drop, representing the length of time required to receive supplies and ready themselves for movement to the next mission waypoint.
- ammunitionQuantity – the total amount of ammunition carried by the unit. This parameter is calculated based on the weight of eight full magazines of 5.56 mm caliber rounds and a mixture of four explosive and smoke grenades, multiplied by the number of personnel in the unit:

  $$17 \times numberUnitPersonnel \text{ .}$$

- equipmentQuantity – the total amount of equipment carried by the unit. Equipment is defined generically to include weapons, communication and navigational gear, protective equipment, and body armor. The mix of equipment needed for the upcoming assigned mission is assumed to be optimal, e.g., body armor weight may be replaced by enhanced communication and intelligence gathering gear for a reconnaissance mission. Clothing, helmet, and other protective gear are not included in the weight, since it is unrealistic to account for a unit losing all their clothing during a mission. The weights used for communication gear are based on the AN/PRC-117F long-range radio, AN/PRC-126 short-range radio and spare batteries for each member of the unit, and computer navigation gear. One M249 Squad Automatic Weapon (SAW) and a M4A1 SOPMOD for each member of the unit other than the one carrying the M249 SAW are also included. Body armor is included as the mission dictates:

  $$15 + (7 \times (numberUnitPersonnel - 1)) + 39 \text{ .}$$

- medicalQuantity – the total amount of medical gear carried by the unit. In the model, it is assumed there is one member assigned as a medic. This parameter is therefore calculated based on the weight of one medic field pack per unit and a personal medical kit for each member of the unit:

$$30 + (1 \times numberUnitPersonnel) \text{ .}$$

- subsistenceQuantity – the total amount of Meal Ready-to-Eat (MRE) containers carried by the unit. The parameter is calculated based on eight MREs carried per unit member. The quantity of MREs carried per member is based on two MREs per day per person for four days, the maximum time length of the mission set:

$$10 \times numberUnitPersonnel \text{ .}$$

- waterQuantity – the total amount of water carried by the unit. The parameter is calculated based on each unit member carrying two gallons of water:

$$17 \times numberUnitPersonnel \text{ .}$$

- sofSupplies – Object of the SOFSupplies class that assists in managing the consumption and resupply of material to the units.
- sofUnitRandomMover – Object of the RandomPointGenerator class that generates random x and y-coordinates corresponding to the mission waypoints.
- missions – Object of the SOFMission class used to assign a mission once the unit has arrived at a mission waypoint.
- sofUnitName – The unit's name in the format: SOFUnit1, SOFUnit2, …, SOFUnit(numberOfUnits).

As the units move to mission waypoints, and perform the assigned missions, supplies are consumed and reported to the seabase in the form of a material requisition. Helicopters, if available, are loaded and sent to a supply drop point where the SOF units arrive, after the helicopter has departed, to receive the requisitioned material. If there are no helicopters available and a SOF unit's on-hand quantity of supplies is below the unitSupplyThreshold, then the unit will enter a 'Balk' state. A balk state prevents the corresponding SOF unit from continuing to its next mission waypoint until properly supplied.

3. SOFUnitState Class

The SOFUnitState class defines the six different states applicable to a SOF unit. Unit state changes occur at points in time when a scheduled event is executed that affects various state variables inherent to each unit. The six state changes are listed below.

- `IDLE` – This state occurs at two different instances within the simulation. The first is when a unit is created. The second occurrence is when a unit has completed the assigned mission and awaits further orders from the Commander.
- `MISSIONMOVEMENT` – This state indicates a unit was ordered by the Commander to move from its current location to the mission waypoint.
- `ENGAGED` – Occurs when a unit has completed movement to the mission waypoint and is engaged in the assigned mission.
- `RESUPPLYMOVEMENT` – This state indicates a unit was ordered by the Commander to move from its current location to the supply drop point.
- `RESUPPLY` – A unit has reached the supply drop point, and is currently resupplying its on-hand quantity of supplies with the supplies dropped by the supporting helicopter unit.
- `BALK` – Occurs when a unit's on-hand quantity of supplies is below the unitSupplyThreshold, and there are no helicopters available to deliver supplies.

4. HeloMoverManager Class

Helicopters assigned to the seabase are created and managed by this class. Movement and mission assignment are controlled by the class upon receipt of applicable orders from the Commander. Loading and unloading of supply materials to be delivered to the requesting unit are also controlled here through an interface with the SOFSupplies class. The parameters listed below define a helicopter at its creation within the simulation.

- helo – Object of the Mover class that controls the movement and speed of the helicopter as its assigned supply delivery missions.

- baseLocation – the location where each helicopter is based, deploys from, and returns to. This corresponds to the location of the seabase given as an x-coordinate, y-coordinate pair.
- heloLoadTime – An exponentially distributed random variable that corresponds to the preparation, loading, and deployment of a helicopter from the seabase as written in (LPD-17 ORD).
- heloOffloadTime – An exponentially distributed random variable that corresponds to the time required in offloading requisitioned unit material upon the helicopter's arrival at the supply drop point.
- totalCapacity – The maximum internal capacity of a helicopter as given by various subject matter experts within military aviation squadrons.
- sofSupplies – Object of the SOFSupplies class used to manage the supply material loaded onto and offloaded from the helicopter performing supply delivery missions.

5. LiftAssetState Class

The LiftAssetState class defines the five different states applicable to a helicopter. Helicopter state changes occur at points in time when a scheduled event is executed that affects various state variables inherent to each lift asset. The five state changes are listed below.

- `IDLE` – This state occurs two different times within the simulation. The first is at the creation of each helicopter assigned to the seabase. The second occurs when the helicopter returns to the seabase, from the supply drop point, and no units are awaiting the availability of a lift asset to deliver supplies.
- `INGRESS` – Indicates a helicopter assigned a supply delivery mission has loaded requisitioned supplies, departed the seabase, and is inbound to the supply drop point.

- `EGRESS` – Indicates a helicopter assigned a supply delivery mission has offloaded the requisitioned supplies, departed the supply drop point, and is inbound to the seabase's location.
- `LOADING` – Occurs when a helicopter is ordered on a delivery mission and is currently at the seabase loading requisitioned supplies.
- `UNLOADING` – Upon the helicopter's arrival to the supply drop point location, it enters this state to initiate the offloading of requisitioned material.

6. Commander Class

The Commander class is the main interface, via listener patterns, between the SOF units and the helicopter. The class mimics the N3 (Operations) or N4 (Logistics) staff on the seabase in coordinating the operations ashore with the logistic support and delivery needed via helicopter attached to the seabase. The creation of a Commander object is defined by a single parameter identifying the available helicopters to perform logistic support missions.

- embarkedHelos – List of all helicopters available to the Commander for logistic delivery mission assignment. This list is populated with all the helicopters assigned to the seabase at the initiation of the simulation.

7. SeabaseMoverManager Class

The seabase used as the logistic sustainment platform within the simulation is created and managed within this class. The use of maritime platforms as a sustainment piece brings two important constraints to the forefront of operational planning. The first is the total operational capacity of air and land-capable craft able to deliver material to forces operating ashore. The second constraint is the total capacity available to store material used by the operating forces. These two constraints are captured within the simulation as input parameters to this class. The minimum and maximum values for the number of helicopters to embark on the seabase, as well as the minimum square-foot area for SOF equipment storage and workspace, come from (LPD-17 ORD). Square-foot area is converted into pounds, within the model, based on the maximum weight per square foot within storage and cargo spaces as outlined in the (LPD-17 Ship Spec 130, p. 3). The allocation of total capacity distribution for each supply commodity carried by the seabase is calculated using the same ratio (total weight per commodity per unit divided by total weight of all commodities per unit) corresponding to the unit commodity capacity distribution. Once the reorder threshold is reached for any one of the carried commodities, a requisition is generated for all the commodities equaling the difference between current on-hand amount and maximum capacity for the respective commodity type. The parameters listed below define the properties of a seabase at creation and throughout the simulation.

- seabase – Object of the Mover class that manages the movement and speed of the seabase. Modeling effects of a mobile seabase is not within the scope of this thesis, but the addition of this parameter will allow movement in later expansions of the model.
- baseLocation – The location of the seabase represented as an x-coordinate, y-coordinate pair. The seabase remains at this location throughout the simulation. It performs all helicopter and underway replenishment evolutions here as well.
- seabaseAmmunitionCapacity – Maximum ammunition capacity carried by the seabase based on square-foot area allocated to SOF units:

  $$seabaseStorageCapacity \times seabaseDeckCargoWeight \times 0.181\,.$$

- seabaseEquipmentCapacity – Maximum equipment capacity carried by the seabase based on square-foot area allocated to SOF units:

  $$seabaseStorageCapacity \times seabaseDeckCargoWeight \times 0.496\,.$$

- seabaseMedicalCapacity – Maximum medical capacity carried by the seabase based on square-foot area allocated to SOF units:

  $$seabaseStorageCapacity \times seabaseDeckCargoWeight \times 0.037\,.$$

- seabaseSubsistenceCapacity – Maximum subsistence capacity carried by the seabase based on square-foot area allocated to SOF units:

  $$seabaseStorageCapacity \times seabaseDeckCargoWeight \times 0.106\,.$$

- seabaseWaterCapacity – Maximum water capacity carried by the seabase based on square-foot area allocated to SOF units:

$$seabaseStorageCapacity \times seabaseDeckCargoWeight \times 0.18 .$$

- sofSupplies – Uses an object of the SOFSupplies class as an interface to manage the issuing of material to requesting SOF units, adjusting the on-hand balance accordingly, and communicate to the resupply ship its requisition quantities for a scheduled underway replenishment.
- resupplyShipMoverManager – The resupply ship assigned to replenish the seabase.
- seabaseReorderThreshold – The percentage of maximum capacity for each supply commodity that triggers a requisition action for material delivered via underway replenishment.

8. SeabaseState Class

The SeabaseState class defines the two different states applicable to a seabase. Seabase state changes occur at points in time when a scheduled event is executed that affects various state variables inherent to the seabase. The two state changes are listed below.

- *`IDLE`* – This state occurs at the creation of the seabase, and remains the seabase's state throughout the simulation. The exception to this is when the seabase has requested an underway replenishment via a resupply ship.
- *`REPLENISHING`* – The seabase has initiated an underway replenishment request, and is either awaiting delivery of requisition or in an underway replenishment action with a resupply ship.

9. ResupplyShipMoverManager Class

The ResupplyShipMoverManager class creates and manages the movement and behavior of a resupply ship in the model. Movement and mission assignment is driven by the receipt of an underway replenishment request from the seabase, along with the requisitioned quantity per commodity. Requisitions are received and placed in a queue. If the ResupplyShipState is `IDLE`, the requisition will be processed, i.e., loaded onto the replenishment ship and delivered to the seabase. Requisitions received during any ResupplyShipState other than `IDLE` are placed in the queue to be processed upon the resupply ship's return to port.

- resupplyShip – Object of the Mover class that controls the movement and speed of the resupply ship as it is assigned underway replenishment missions.
- seabaseUnrepSupplies – Object of the SOFSupplies class that acts as an interface between the seabase and the resupply ship. This parameter is used to access the requisition and transferred quantities for each supply commodity from and to the seabase respectively.
- supplyPort – The location where the resupply ship is employed from and returns to given as an x-coordinate, y-coordinate pair. Material is loaded onto the resupply ship at this location for future transfer to the requesting seabase. Quantities of supply commodities on-hand available to transfer are considered infinite at this location.

10. ResupplyShipState Class

The ResupplyShipState class defines the four different states applicable to a resupply ship. Unit state changes occur at points in time when a scheduled event is executed that affects various state variables inherent to the resupply ship. The four state changes are listed below.

- `IDLE` – The state at which a resupply ship is at creation, and while awaiting a request for an underway replenishment.
- `LOADING` – Occurs when the resupply ship has received an underway replenishment request and is loading the requested material.
- `UNDERWAY` – The resupply ship has loaded requested material, and is moving to the seabase's location.

- `UNREP` – Occurs when the resupply ship arrives at the seabase's location and initiates an underway replenishment.
- `UNDERWAYRTP` – Occurs once the underway replenishment is complete and the resupply ship is returning to its baseLocation.

11. SOFSupplies Class

This particular class manages all activity for each supply commodity and each model component. In particular, it manages the amount of supplies consumed and received by the SOF units; manages the amount per commodity of supplies loaded onto and offloaded from the helicopter; and manages the amount per commodity issued and received by the seabase. The class uses twenty-one parameters in managing the supply flow of the simulation. All but one of the parameters correspond to a consumption rate calculated using the total weight for each commodity divided by the product of the maximum time and intensity for each mission.

- missions – Object of the SOFMissions class that is used to calculate the mission intensity and mission time corresponding to the type of mission passed to this class from the SOFUnitMoverManager class.
- Consumption rates – Five commodity types, by four mission types, equals twenty parameters listed within this class. Each parameter is identified by the name of the mission type and corresponding supply commodity type. For example, the parameter corresponding to the consumption of Ammunition during a DA mission is identified by the name daAmmoConsumptionRate. The consumption rate for this parameter is calculated using the following formula:

$$\frac{unitAmmunition}{daHighMissionIntensity \times daHighMissionTime}.$$

  The other nineteen consumption rate parameters are calculated similarly, using the appropriate unit commodity quantity in the numerator, and mission intensity and time in the denominator.

12. SOFSupplyType Class

The SOFSupplyType class lists the five different supply commodities types carried by a SOF unit. The five types are *Ammunition*, *Equipment*, *Medical*, *Subsistence*, and *Water*.

13. SOFMission Class

This class defines four missions, and the two associated properties of each mission, that SOF units are assigned randomly at each mission waypoint. The two properties of each mission are missionTime and missionIntensity. Both properties are randomly generated values using the Triangle distribution. The parameters associated with the two property's random distributions are defined in the TestCommander class and passed within this class's constructor.

14. TestCommander Class

The TestCommander class initiates all objects, assigns values to parameters, initiates the simulation, and collects data for each replication to further analyze.

C. CONCLUSION

This chapter discussed the tools and methodology used to model a single-ship seabase supporting SOF units ashore through the Discrete Event Simulation process. Once the various input parameters are selected and processed, at varying levels within a given range, by the simulation, data are produced that require exploratory analysis. The analysis methods used and results derived from the simulation model are discussed in the next chapter.

IV. DATA PRESENTATION AND ANALYSIS

This chapter discusses methods used to generate, extract, and analyze the model's data produced by the Discrete Event Simulation (DES). A Latin Hypercube is used to assign values to the simulation's input parameters. Input and output parameters used in the model are also discussed. The terms 'parameter' and 'variable' are used interchangeably throughout this chapter.

A. EXPERIMENTAL DESIGN

1. Measures of Effectiveness (MOE)

A common question managers ask their inventory control personnel is whether or not the range and depth of on-hand stock is suitable to meet all demand. Range refers to the individual types of stock held, whereas depth is defined as the amount held of each stock type. The degree at which these variables are kept is constrained by capacity. (Other constraints, such as cost or shelf-life, affect the level of range and depth, but are not discussed in this thesis). A measure of effectiveness the U.S. Navy uses in determining the range and depth of inventory carried by operating forces is Net Effectiveness. This measure is a ratio of issues, not including partial quantity issues, from supply stock and total issues performed by the operating unit. Net Effectiveness goals, set by both Atlantic and Pacific surface fleet commanders, range anywhere between 95 percent and 100 percent.

The utilization of assets available to a theater commander is an important measure of combat potential present at any point in time. In this particular model, the utilization of helicopters embarked on the seabase is used as an MOE. It would be an error to believe one hundred percent utilization is optimal for embarked helicopters. Helicopters, or any system for that matter, require an allocation of non-operational time, referred to as idle time in the model, to perform upkeep, maintenance, and training for the crews operating it. One hundred percent utilization does not take into account this non-operational time needed, is unrealistic to maintain a long-term operational tempo, and should be analyzed further if this is a result of the DES. In this model, a helicopter's operational utilization and maximal use of its mission capability is deemed effective if:

$$0.2 \le heloUtilization < 0.6$$

2. Design Parameters

Design parameters include both the input and output variables of the DES. The combinations of input variables at various levels represent an individual design point. These design points are derived using a nearly orthogonal Latin Hypercube (NOLH) developed by Cioppa and Lucas (2006). NOLHs are very efficient for experiments with many input variables, and allow the analyst flexibility in fitting regression models to the results. The near orthogonality of NOLHs means that little pairwise correlation exists between all two-variable combinations, which make it easier to assess the contributions of the variables. At the Same time, by examining multiple variables in a single experiment, the analyst can identify interactions (or "synergies") among these variables (Sanchez 2006). The NOLH are designed for continuous variables; if some variables have a smaller number of potential settings, then the orthogonality properties should be checked prior to experimentation.

a. Input Parameters

Six input variables were used to initialize parameters within the DES at varying levels generated by the NOLH. A brief description of each input parameter is given below, and the associated ranges of values used as inputs to the NOLH are given in Table 3. Settings for the first two input parameters are rounded to the nearest 0.1; settings for the remaining input parameters are rounded to the nearest integer.

- seabaseReorderThreshold – the percentage of total max capacity for each supply commodity carried which triggers a requisition and underway replenishment event.
- unitSupplyThreshold – the percentage of total max capacity for each supply commodity carried which triggers a requisition and logistic delivery event.

- numberUnitPersonnel – the number of personnel assigned to each unit.
- seabaseStorageCapacity – total square feet area on the seabase allocated for storage of supply commodities used by Special Operations Forces (SOF).
- numberOfUnits – the number of SOF units under the control of and being sustained by the seabase.
- numberOfHelos – the number of helicopters assigned to the seabase to perform logistic support missions.

Input Parameter	Range of Values
seabaseReorderThreshold	0.2 - 0.7
unitSupplyThreshold	0.3 - 1.0
numberUnitPersonnel	4 - 12
seabaseStorageCapacity	400 - 2000
numberOfUnits	1 - 10
numberOfHelos	1 - 4

Table 3. NOLH Input Parameter Settings

Three other input parameters, not included in the above list, are used to manage each simulation run. They are:

- numberOfReplications – The number of replications per design point the simulation will be run. The number is fixed at 100 for each design point in the case of this experiment.
- verboseOutput – A ‘true’ or ‘false’ value that manages the type of output string the user of the simulation desires.

- randomSeedString – A randomly generated number using a Mersenne twister. Each random number is set as the seed for which all random numbers generated within the simulation are based from. Each design point is assigned a different seed value to create independency between design point runs of the simulation.

b. Output Parameters

The collection of output information is done through the statistical data packages within Simkit. Each data point has four output variables, described as single values. Analysis performed on the four output variables listed below test the model against MOEs previously mentioned in this chapter.

- numberOfUnitBalks – the total number of balks occurring across all units assigned to the seabase.
- averageBalkTime – the mean time all units controlled by the seabase remain in a balk state.
- helicopterUtilization – Utilization measures the quantity of helicopters idle over the simulation's time length.
- seabaseNetEffectiveness – measures the effectiveness of inventory management as a ratio of completed issues, not including partial issues, and total issues of all types.

3. Design of Experiment

A spreadsheet developed by Professor Susan Sanchez, Naval Postgraduate School (available from the SEED Center for Data Farming web pages at http://harvest.nps.edu), is designed to build the NOLH matrix with the designs of Cioppa and Lucas (2006) based on the number of input parameters to the experiment and their low and high values. Each parameter is assigned a column within the matrix, and its values are rescaled based on the applicable value range given for that parameter. The more parameters there are in the experiment, the more design points are needed to create orthogonality amongst the columns, but more design points improves the space-filling of data points within the data space.

If an individual simulation run takes a long time, then the smallest NOLH capable of exploring the factors is preferred. Quick run times of a simulation allows flexibility in choosing which type, based on number of factors, of NOLH will be used to design the experiment. In the case of this thesis, a NOLH with 129 different design points is used. (This would be suitable for exploring up to 22 factors; six factors could be explored in the smallest NOLH with 17 design points). Each design point is then replicated 100 times, giving a total of 12,900 data points within the data space to analyze.

B. ANALYSIS AND RESULTS PRESENTATION

Analysis is performed using a program developed by SAS Institute Inc. known as JMP. It has a graphical user interface designed to facilitate both statistical and data analysis methods on qualitative and quantitative types of data.

Correlation matrices show the degree of relationship between two variables. Numbers closer to 1.000 indicate high values of variable x are paired with high values of variable y and tend to form a linear relationship having a positive slope, whereas numbers closer to -1.000 indicate high values of variable x are paired with low values of variable y and tend to form a linear relationship having a negative slope. Correlation values close to zero indicate no linear relationship exists between the two variables being compared. Calculation of the correlation is not dependent on the units of measure each of the two variables are stated in (Devore p. 540).

Scatter plots aid in visually inspecting if a pair of variables has a linear relationship or not, and can also verify the values listed in the correlation matrix with regard to their sign. Red lines appearing on the scatter plot represent density ellipses. These ellipses show the region where most of the data points lie, and can further validate the correlation value’s sign for a particular pairwise comparison by looking at the slope or trending direction of the elliptic curve.

Linear regression models can be used to describe data relationships or behavior within a data set, to estimate parameter values through determination of the model coefficients, to predict and estimate a response variable given a set of predictor variables, or as a process to investigate the values of a predictor variable which produces response variable values within a controlled threshold (Montgomery, p. 11). The regression models within this thesis are generated by first using a stepwise variable elimination technique and then performing residual analysis using standard least squares. P-values for a predictor term indicate the statistical significance of that term. If a P-value for a predictor value is less than the desired statistical significance level α, we will reject the null hypothesis of a regression model which states: the value of this predictor variable has no effect on the value of the decision variable (i.e., the coefficient associated with the predictor variable is zero). Mathematical transformation, e.g., logarithm, square root, or squaring, of either the predictor variables or the decision variable may be required if the underlying assumptions of normally distributed errors and homoscedasticity are not met. Fortunately, the estimated regression coefficients are robust to heteroscedastic error variance, and replicating the runs at each design point mitigates the problems that can arise when errors are not normally distributed.

1. Net Effectiveness

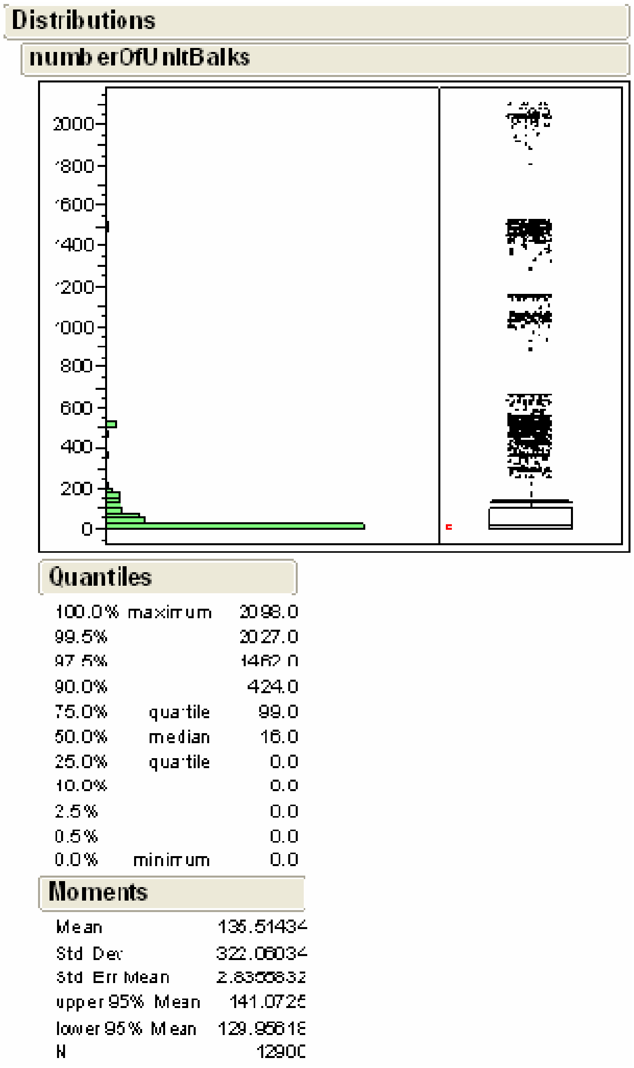
Net Effectiveness was equal to 100% for all 129 design points and corresponding replications. This indicates the seabase fulfilled the requested amount of each supply commodity by the employed SOF units and did not issue any partial quantities.

2. Number of Unit Balks

A unit balks when the on-hand quantity of any supply commodity type is below the stated unitSupplyThreshold and there are no helicopters available to perform a logistic delivery mission to this unit. The number is calculated by summing over all units the number of times each unit has entered a balk state over a period of three years simulation time.

$$\sum_{i=1}^{n} numberOfUnitBalks_i \qquad n = numberOfUnits$$

The distribution of numberOfUnitBalks across the 129 design points examined is shown below in Figure 7. It is heavily skewed right, and the clear bands of responses indicate there are thresholds where changes in one or more input variables may lead to large changes in the response.



Quantiles

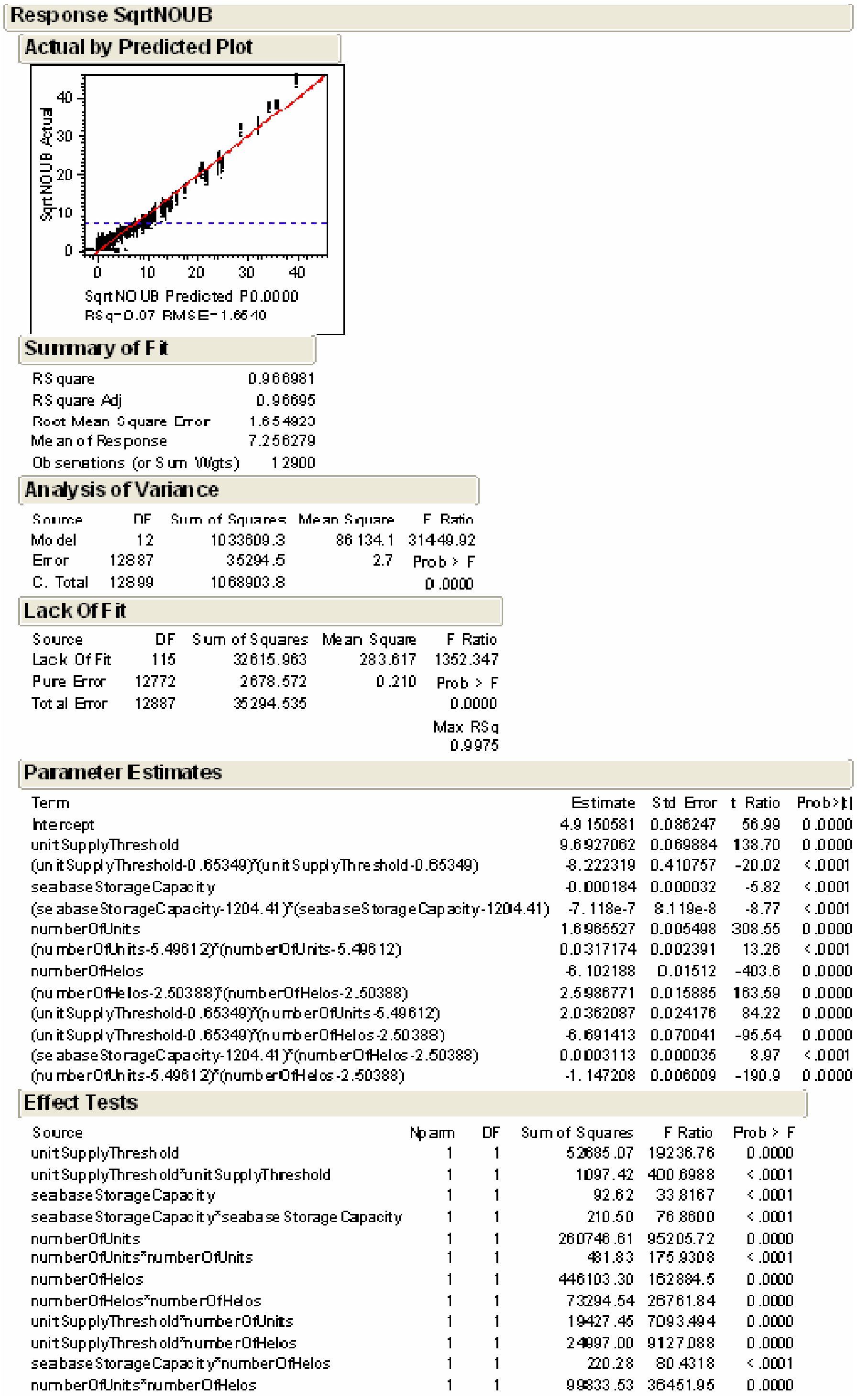
100.0%	maximum	2098.0
99.5%		2027.0
97.5%		1462.0
90.0%		424.0
75.0%	quartile	99.0
50.0%	median	16.0
25.0%	quartile	0.0
10.0%		0.0
2.5%		0.0
0.5%		0.0
0.0%	minimum	0.0

Moments

Mean	135.51434
Std Dev	322.06034
Std Err Mean	2.8355832
upper 95% Mean	141.0725
lower 95% Mean	129.95618
N	12900

Figure 7. JMP Distribution of numberOfUnitBalks

A regression model is used to explain the relationship between the response variable numberOfUnitBalks, and the predictor variables: seabaseReorderThreshold, unitSupplyThreshold, numberUnitPersonnel, seabaseStorageCapacity, numberOfUnits, and numberOfHelos. The response variable is mathematically transformed by taking its square root in order to stabilize the variance. Figure 8 is the linear regression model generated in JMP. The R^2 value associated with this model is 0.967, indicating the model accounts for 96.7% of the variability within the response variable numberOfUnitBalks. The predictor variables seabaseReorderThreshold and numberUnitPersonnel, and all associated interaction and polynomial terms, were insignificant in effecting the value of the response variable, and thus removed from the model during the stepwise variable elimination process. The predictor variable seabaseStorageCapacity is statistically significant, as seen by a small P-value, but can be argued as not being practically significant. The small coefficient value listed in the Estimate column of the Parameter Estimates section shows that for every increasing change in seabaseStorageCapacity, the response variable is decreased by 1.84×10^{-4}. The R^2 value of the model with seabaseStorageCapacity and all corresponding interaction and polynomial terms removed, is 0.966 (Figure 9), indicating the model accounts for essentially the same amount of variability within the response variable as the model shown in Figure 8.



Response SqrtNOUB

Actual by Predicted Plot

Summary of Fit

RSquare	0.966981
RSquare Adj	0.96695
Root Mean Square Error	1.654920
Mean of Response	7.256279
Observations (or Sum Wgts)	12900

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	12	1033609.3	86134.1	31449.92
Error	12887	35294.5	2.7	Prob > F
C. Total	12899	1068903.8		0.0000

Lack Of Fit

Source	DF	Sum of Squares	Mean Square	F Ratio
Lack Of Fit	115	32615.963	283.617	1352.347
Pure Error	12772	2678.572	0.210	Prob > F
Total Error	12887	35294.535		0.0000
				Max RSq
				0.9975

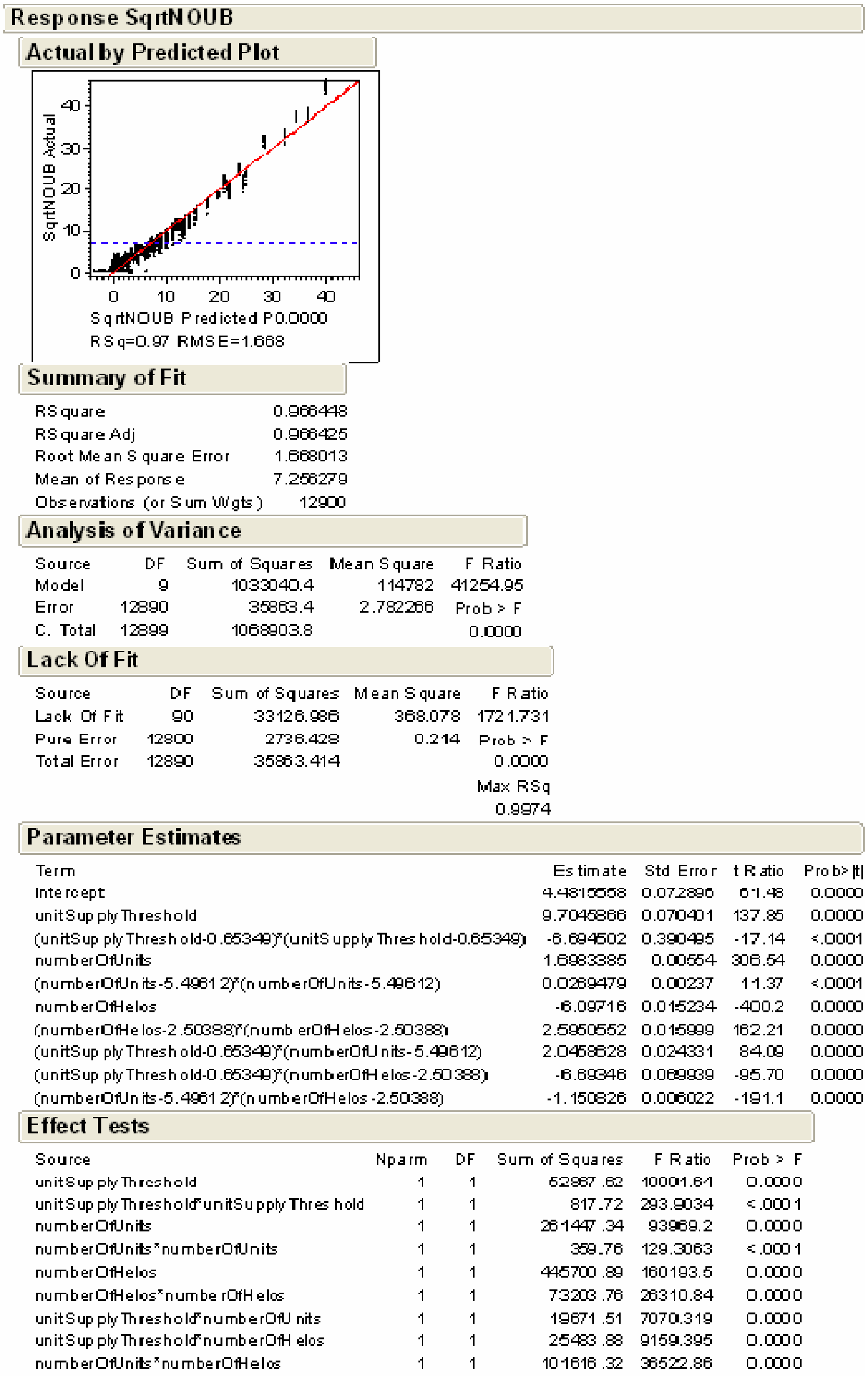
Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	4.9150581	0.086247	56.99	0.0000
unitSupplyThreshold	9.6927062	0.069884	138.70	0.0000
(unitSupplyThreshold-0.65349)*(unitSupplyThreshold-0.65349)	-8.222319	0.410757	-20.02	<.0001
seabaseStorageCapacity	-0.000184	0.000032	-5.82	<.0001
(seabaseStorageCapacity-1204.41)*(seabaseStorageCapacity-1204.41)	-7.118e-7	8.119e-8	-8.77	<.0001
numberOfUnits	1.6965527	0.005498	308.55	0.0000
(numberOfUnits-5.49612)*(numberOfUnits-5.49612)	0.0317174	0.002391	13.26	<.0001
numberOfHelos	-6.102188	0.01512	-403.6	0.0000
(numberOfHelos-2.50388)*(numberOfHelos-2.50388)	2.5986771	0.015885	163.59	0.0000
(unitSupplyThreshold-0.65349)*(numberOfUnits-5.49612)	2.0362087	0.024176	84.22	0.0000
(unitSupplyThreshold-0.65349)*(numberOfHelos-2.50388)	-6.691413	0.070041	-95.54	0.0000
(seabaseStorageCapacity-1204.41)*(numberOfHelos-2.50388)	0.0003113	0.000035	8.97	<.0001
(numberOfUnits-5.49612)*(numberOfHelos-2.50388)	-1.147208	0.006009	-190.9	0.0000

Effect Tests

Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
unitSupplyThreshold	1	1	52685.07	19236.76	0.0000
unitSupplyThreshold*unitSupplyThreshold	1	1	1097.42	400.6988	<.0001
seabaseStorageCapacity	1	1	92.62	33.8167	<.0001
seabaseStorageCapacity*seabase Storage Capacity	1	1	210.50	76.8600	<.0001
numberOfUnits	1	1	260746.61	95205.72	0.0000
numberOfUnits*numberOfUnits	1	1	481.83	175.9308	<.0001
numberOfHelos	1	1	446103.30	162884.5	0.0000
numberOfHelos*numberOfHelos	1	1	73294.54	26761.84	0.0000
unitSupplyThreshold*numberOfUnits	1	1	19427.45	7093.494	0.0000
unitSupplyThreshold*numberOfHelos	1	1	24997.00	9127.088	0.0000
seabaseStorageCapacity*numberOfHelos	1	1	220.28	80.4318	<.0001
numberOfUnits*numberOfHelos	1	1	99833.53	36451.95	0.0000

Figure 8. JMP Linear Regression Model for Square-Root of numberOfUnitBalks

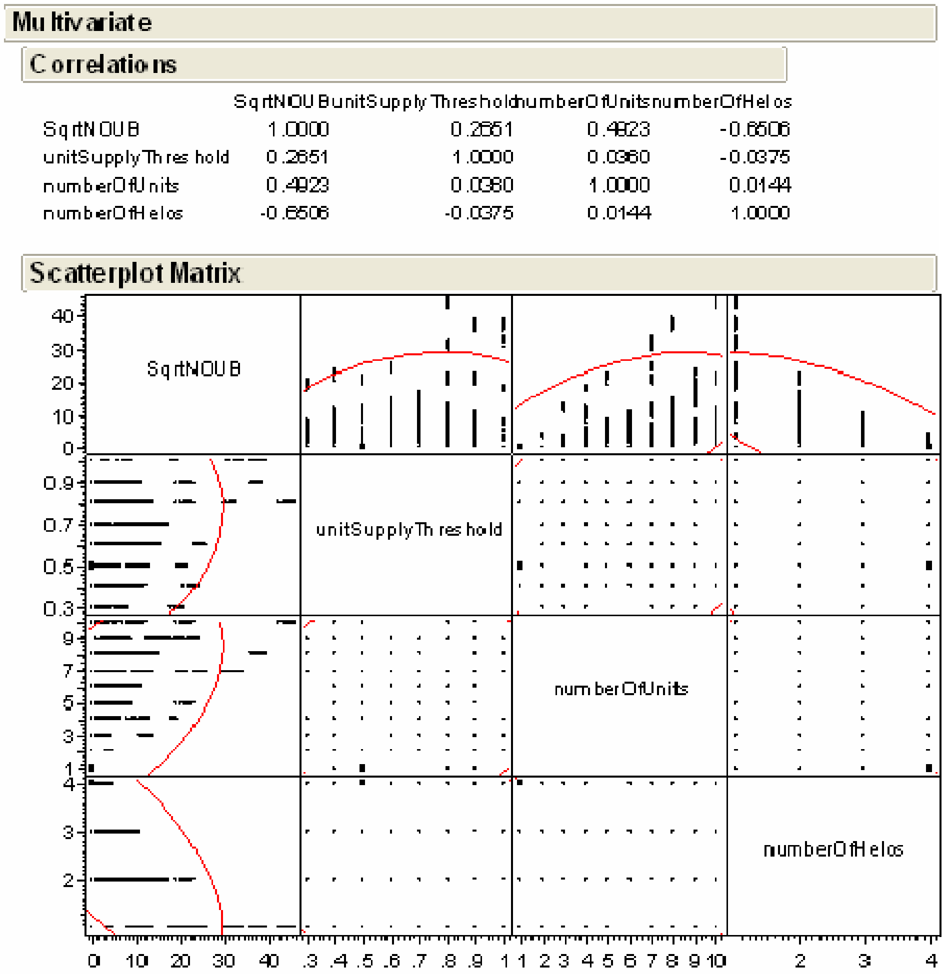


```
Response SqrtNOUB
Actual by Predicted Plot

Summary of Fit
RSquare                          0.966448
RSquare Adj                      0.966425
Root Mean Square Error           1.668013
Mean of Response                 7.256279
Observations (or Sum Wgts)          12900

Analysis of Variance
Source        DF   Sum of Squares   Mean Square    F Ratio
Model          9        1033040.4        114782   41254.95
Error      12890          35863.4      2.782266   Prob > F
C. Total   12899        1068903.8                   0.0000

Lack Of Fit
Source          DF   Sum of Squares   Mean Square    F Ratio
Lack Of Fit     90        33126.986       368.078   1721.731
Pure Error   12800         2736.428         0.214   Prob > F
Total Error  12890        35863.414                   0.0000
                                                     Max RSq
                                                      0.9974

Parameter Estimates
Term                                                                  Estimate   Std Error   t Ratio   Prob>|t|
Intercept                                                            4.4815558    0.072896     61.48     0.0000
unitSupplyThreshold                                                  9.7045866    0.070401    137.85     0.0000
(unitSupplyThreshold-0.65349)*(unitSupplyThreshold-0.65349)          -6.694502    0.390495    -17.14     <.0001
numberOfUnits                                                        1.6983385     0.00554    306.54     0.0000
(numberOfUnits-5.49612)*(numberOfUnits-5.49612)                      0.0269479     0.00237     11.37     <.0001
numberOfHelos                                                         -6.09716    0.015234    -400.2     0.0000
(numberOfHelos-2.50388)*(numberOfHelos-2.50388)                      2.5950552    0.015999    162.21     0.0000
(unitSupplyThreshold-0.65349)*(numberOfUnits-5.49612)                2.0458628    0.024331     84.09     0.0000
(unitSupplyThreshold-0.65349)*(numberOfHelos-2.50388)                 -6.69346    0.069939    -95.70     0.0000
(numberOfUnits-5.49612)*(numberOfHelos-2.50388)                      -1.150826    0.006022    -191.1     0.0000

Effect Tests
Source                                     Nparm   DF   Sum of Squares    F Ratio   Prob > F
unitSupplyThreshold                            1    1        52967.62    10001.64     0.0000
unitSupplyThreshold*unitSupplyThreshold        1    1          817.72    293.9034     <.0001
numberOfUnits                                  1    1       261447.34     93969.2     0.0000
numberOfUnits*numberOfUnits                    1    1          359.76    129.3063     <.0001
numberOfHelos                                  1    1       445700.89    160193.5     0.0000
numberOfHelos*numberOfHelos                    1    1        73203.76    26310.84     0.0000
unitSupplyThreshold*numberOfUnits              1    1        19671.51    7070.319     0.0000
unitSupplyThreshold*numberOfHelos              1    1        25483.88    9159.395     0.0000
numberOfUnits*numberOfHelos                    1    1       101616.32    36522.86     0.0000
```

Figure 9. JMP Linear Regression Model for Square-Root of numberOfUnitBalks without seabaseStorageCapacity

More detailed information about the model effects can be found by looking at plots along with the signs and magnitudes of regression coefficients (Montgomery, p. 530). Graphs shown in Appendix C, Figures 35, 36, 37, and 38 show increases in the unitSupplyThreshold lead to increases in the numberOfUnitBalks; validating the positive coefficient in the model. Figure 11 show increases in both numberOfHelos and numberOfUnits lead to a decrease and increase, respectively, in the numberOfUnitBalks; so the negative coefficient for numberOfHelos and the positive coefficient for numberOfUnits (Figure 9) dominate any interaction effects with opposite signs. The magnitude of numberOfHelos and numberOfUnits can also be validated by looking at Figure 11. The parameter numberOfHelos has a greater effect in decreasing the numberOfUnitBalks than does the degree of effect increasing numberOfUnits has on numberOfUnitBalks; validating the absolute value of numberOfHelo's coefficient is greater than the absolute value of numberOfUnit's coefficient.

The correlation matrix and scatter plot for the pairwise comparison of numberOfUnitBalks to the three predictor variables: unitSupplyThreshold, numberOfUnits, and numberOfHelos are shown below as Figure 10. The scatter plot verifies the positive relationship, indicated by the estimate value listed in the Parameter Estimates block of Figure 9 and the correlation value shown in Figure 10, between the response variable and the two predictor variables unitSupplyThreshold and numberOfUnits, as well as verifying the negative relationship between the response variable, numberOfUnitBalks, and the predictor variable numberOfHelos.



Multivariate

Correlations

	SqrtNOUB	unitSupplyThreshold	numberOfUnits	numberOfHelos
SqrtNOUB	1.0000	0.2651	0.4923	-0.8506
unitSupplyThreshold	0.2651	1.0000	0.0380	-0.0375
numberOfUnits	0.4923	0.0380	1.0000	0.0144
numberOfHelos	-0.8506	-0.0375	0.0144	1.0000

Scatterplot Matrix

Figure 10. JMP Correlation Matrix and Scatter Plot for numberOfUnitBalks

A majority of the unit balks occurs with the larger amount of units under the seabase’s control with high unitSupplyThreshold values, regardless of the number of helicopters. The maximum average values of unit balks, across all units, for each number of helicopters performing logistic delivery missions, and the corresponding percentage change in maximum average value by adding an additional helicopter are summarized in Table 4 below. The benefit of adding additional helicopters in order to decrease the amount of unit balks is graphically shown in Figure 11 below for numberOfHelos equal to one, two, three, and four respectively. Diagrams detailing the benefit of adding an additional helicopter as a function of both numberOfUnits and unitSupplyThreshold are found in Appendix C, Figures 35, 36, 37, and 38 for numberOfHelos equal to one, two, three, and four respectively.

numberOfHelos	Maximum average numberOfUnitBalks	Percentage change with addition of one helicopter
1	2026.52	81.43%
2	376.32	80.04%
3	75.13	82.12%
4	13.43	-

Table 4. Percent change of numberOfUnitBalks by the addition of one helicopter

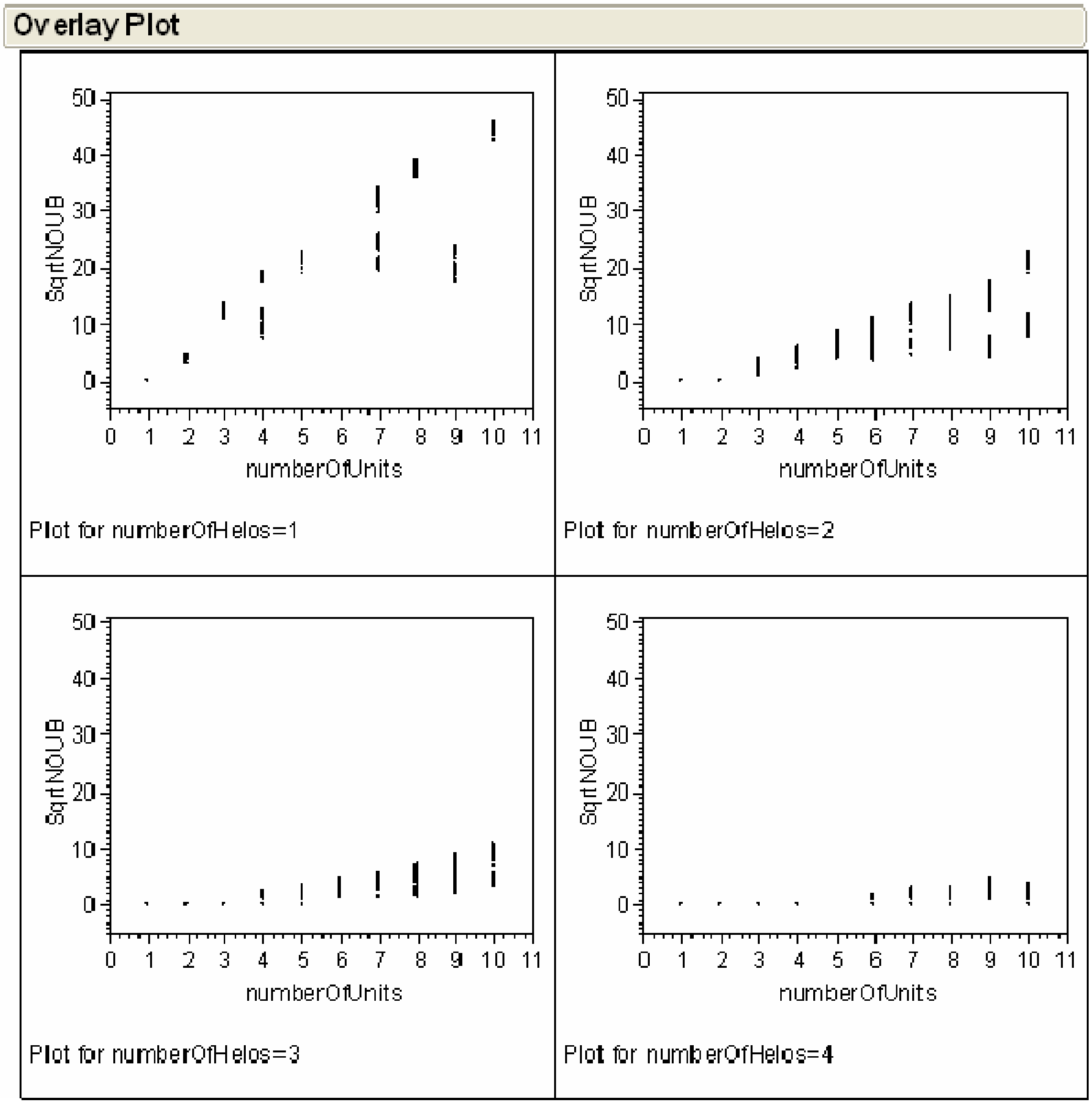


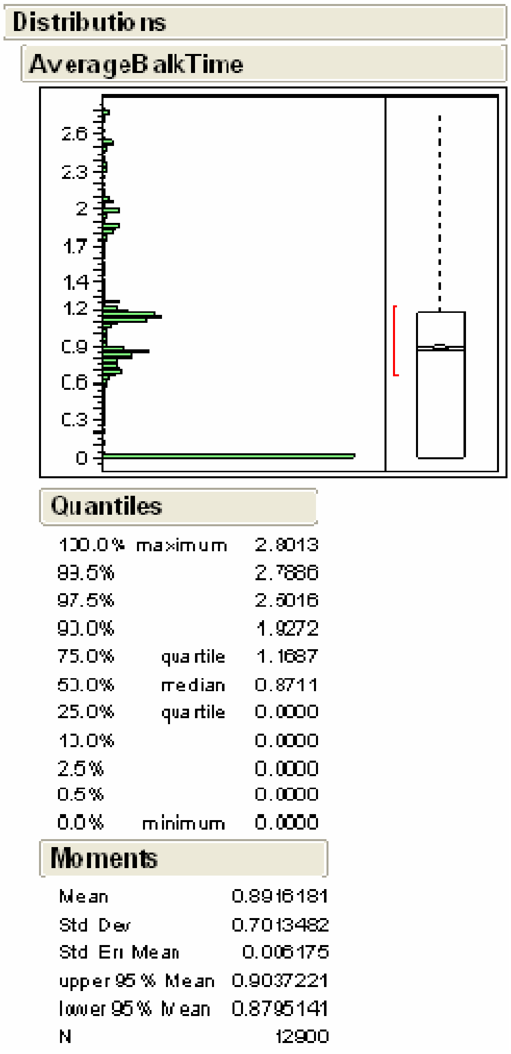
Figure 11. Overlay Plot for Square-Root of numberOfUnitBalks vs. numberOfUnits when numberOfHelos = {1,2,3,4}

3. Average Balk Time

The purpose of this parameter is to identify the average time any single unit is spending in a balk state, in units of hours, given the values of input parameters assigned to the simulation design point. The number is calculated by summing the balk times over all unit balk instances and dividing by numberOfUnitBalks

$$\sum_{i=1}^{n} \frac{unitBalkTime_i}{numberOfUnitBalks} \qquad n = numberOfUnitBalks \, .$$

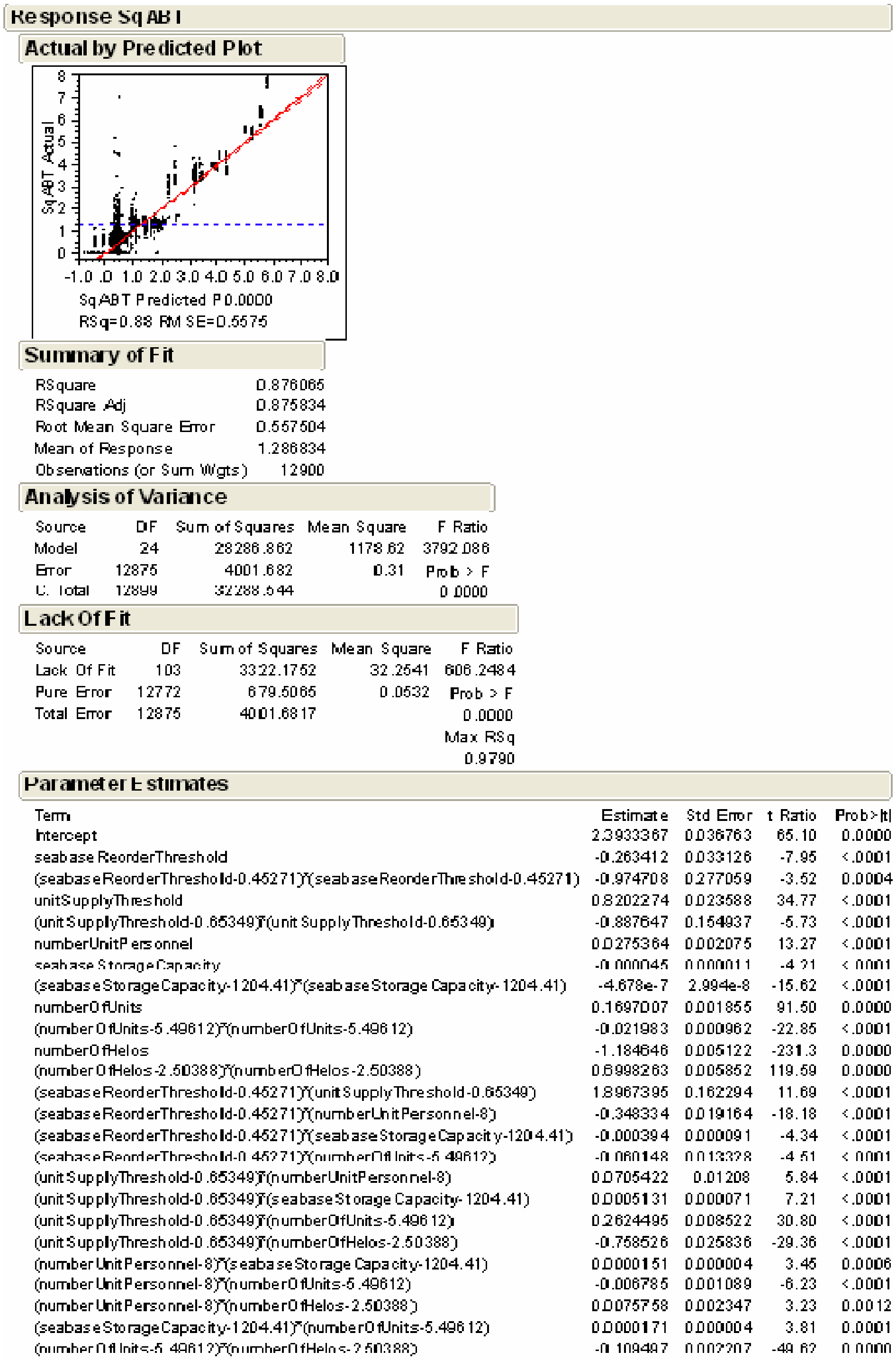
The distribution of averageBalkTime is given in Figure 12 below.



```
Quantiles
100.0%  maximum   2.8013
99.5%             2.7886
97.5%             2.5016
90.0%             1.9272
75.0%   quartile  1.1687
50.0%   median    0.8711
25.0%   quartile  0.0000
10.0%             0.0000
2.5%              0.0000
0.5%              0.0000
0.0%    minimum   0.0000
Moments
Mean              0.8916181
Std Dev           0.7013482
Std Err Mean       0.006175
upper 95% Mean    0.9037221
lower 95% Mean    0.8795141
N                     12900
```

Figure 12. JMP Distribution of averageBalkTime

A regression model is used to explain the relationship between the response variable averageBalkTime, and the predictor variables: seabaseReorderThreshold, unitSupplyThreshold, numberUnitPersonnel, seabaseStorageCapacity, numberOfUnits, and numberOfHelos. The response variable is transformed by taking the square root. Recall the variance of the response variable is stabilized through a mathematical transformation of the variable. The differences and degrees predictor variables have on the response variable will be more dramatic if a mathematical transformation of the predictor variable does not occur. Figure 13 is the linear regression model generated in JMP. The R^2 value associated with this model is 0.876, indicating the model accounts for 87.6% of the variability within the response variable averageBalkTime. All predictor variables were statistically significant in rejecting the null hypothesis: all predictor effects, i.e. the corresponding coefficient, equals zero. The predictor variable seabaseStorageCapacity, as identified in the numberOfUnitBalks linear regression model, can be argued as not being practically significant. The small coefficient value listed in the Estimate column of the Parameter Estimates section shows that for every increasing change in seabaseStorageCapacity, the response variable is decreased by 4.5×10^{-5}. The R^2 value of the model with seabaseStorageCapacity and all corresponding interacation and polynomial terms removed is 0.873 (Figure 14), indicating the model accounts for essentially the same amount of variability within the response variable, than shown in Figure 13.



```
Response Sq ABT
Actual by Predicted Plot
    Sq ABT Predicted P 0.0000
    RSq=0.88 RMSE=0.5575
Summary of Fit
  RSquare                          0.876065
  RSquare Adj                      0.875834
  Root Mean Square Error           0.557504
  Mean of Response                 1.286834
  Observations (or Sum Wgts)          12900
Analysis of Variance
  Source       DF   Sum of Squares   Mean Square    F Ratio
  Model        24        28286.862       1178.62   3792.086
  Error     12875         4001.682          0.31   Prob > F
  C. Total  12899        32288.544                   0.0000
Lack Of Fit
  Source          DF   Sum of Squares   Mean Square    F Ratio
  Lack Of Fit    103        3322.1752       32.2541   606.2484
  Pure Error   12772         679.5065        0.0532   Prob > F
  Total Error  12875        4001.6817                   0.0000
                                                       Max RSq
                                                        0.9790
Parameter Estimates
  Term                                                                Estimate   Std Error  t Ratio  Prob>|t|
  Intercept                                                          2.3933367   0.036763    65.10    0.0000
  seabaseReorderThreshold                                            -0.263412   0.033126    -7.95    <.0001
  (seabaseReorderThreshold-0.45271)*(seabaseReorderThreshold-0.45271) -0.974708  0.277059    -3.52    0.0004
  unitSupplyThreshold                                                0.8202274   0.023588    34.77    <.0001
  (unitSupplyThreshold-0.65349)*(unitSupplyThreshold-0.65349)        -0.887647   0.154937    -5.73    <.0001
  numberUnitPersonnel                                                0.0275364   0.002075    13.27    <.0001
  seabaseStorageCapacity                                             -0.000045   0.000011    -4.21    <.0001
  (seabaseStorageCapacity-1204.41)*(seabaseStorageCapacity-1204.41)  -4.678e-7   2.994e-8   -15.62    <.0001
  numberOfUnits                                                      0.1697007   0.001855    91.50    0.0000
  (numberOfUnits-5.49612)*(numberOfUnits-5.49612)                    -0.021983   0.000962   -22.85    <.0001
  numberOfHelos                                                      -1.184646   0.005122   -231.3    0.0000
  (numberOfHelos-2.50388)*(numberOfHelos-2.50388)                    0.6998263   0.005852   119.59    0.0000
  (seabaseReorderThreshold-0.45271)*(unitSupplyThreshold-0.65349)    1.8967395   0.162294    11.69    <.0001
  (seabaseReorderThreshold-0.45271)*(numberUnitPersonnel-8)          -0.348334   0.019164   -18.18    <.0001
  (seabaseReorderThreshold-0.45271)*(seabaseStorageCapacity-1204.41) -0.000394   0.000091    -4.34    <.0001
  (seabaseReorderThreshold-0.45271)*(numberOfUnits-5.49612)          -0.060148   0.013328    -4.51    <.0001
  (unitSupplyThreshold-0.65349)*(numberUnitPersonnel-8)              0.0705422    0.01208     5.84    <.0001
  (unitSupplyThreshold-0.65349)*(seabaseStorageCapacity-1204.41)     0.0005131   0.000071     7.21    <.0001
  (unitSupplyThreshold-0.65349)*(numberOfUnits-5.49612)              0.2624495   0.008522    30.80    <.0001
  (unitSupplyThreshold-0.65349)*(numberOfHelos-2.50388)              -0.758526   0.025836   -29.36    <.0001
  (numberUnitPersonnel-8)*(seabaseStorageCapacity-1204.41)           0.0000151   0.000004     3.45    0.0006
  (numberUnitPersonnel-8)*(numberOfUnits-5.49612)                    -0.006785   0.001089    -6.23    <.0001
  (numberUnitPersonnel-8)*(numberOfHelos-2.50388)                    0.0075758   0.002347     3.23    0.0012
  (seabaseStorageCapacity-1204.41)*(numberOfUnits-5.49612)           0.0000171   0.000004     3.81    0.0001
  (numberOfUnits-5.49612)*(numberOfHelos-2.50388)                    -0.109497   0.002207   -49.62    0.0000
```

Figure 13. JMP Linear Regression Model for Square-Root of averageBalkTime

Response SqABT

Actual by Predicted Plot

SqABT Predicted P0.0000
RSq=0.87 RMSE=0.5646

Summary of Fit

RSquare	0.872825
RSquare Adj	0.872658
Root Mean Square Error	0.56459
Mean of Response	1.286834
Observations (or Sum Wgts)	12900

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	17	28182.260	1657.78	5200.693
Error	12882	4106.284	0.32	Prob > F
C. Total	12899	32288.544		0.0000

Lack Of Fit

Source	DF	Sum of Squares	Mean Square	F Ratio
Lack Of Fit	110	3426.7773	31.1525	585.5426
Pure Error	12772	679.5065	0.0532	Prob > F
Total Error	12882	4106.2838		0.0000
				Max RSq
				0.9790

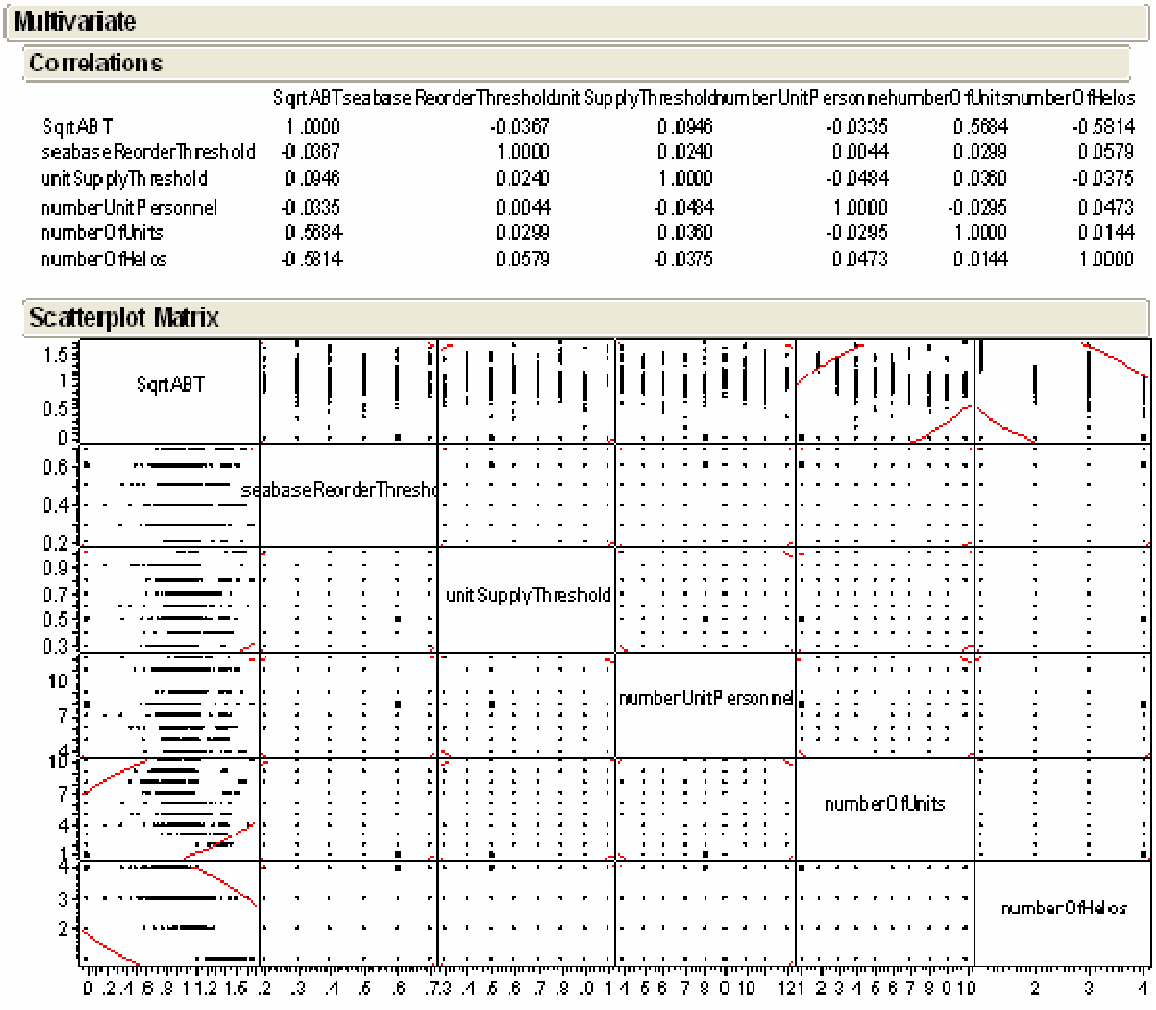
Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	2.2147832	0.033881	65.37	0.0000
seabaseReorderThreshold	-0.269373	0.033502	-8.04	<.0001
(seabaseReorderThreshold-0.45271)*(seabaseReorderThreshold-0.45271)	-0.738183	0.247126	-2.99	0.0028
unitSupplyThreshold	0.8228246	0.023869	34.47	<.0001
(unitSupplyThreshold-0.65349)*(unitSupplyThreshold-0.65349)	-0.584083	0.143418	-4.07	<.0001
numberUnitPersonnel	0.0267437	0.0021	12.74	<.0001
numberOfUnits	0.1700844	0.001878	90.57	0.0000
(numberOfUnits-5.49612)*(numberOfUnits-5.49612)	-0.02022	0.000898	-22.51	<.0001
numberOfHelos	-1.181244	0.00518	-228.1	0.0000
(numberOfHelos-2.50388)*(numberOfHelos-2.50388)	0.6884321	0.005756	119.61	0.0000
(seabaseReorderThreshold-0.45271)*(unitSupplyThreshold-0.65349)	1.5187445	0.15623	9.72	<.0001
(seabaseReorderThreshold-0.45271)*(numberUnitPersonnel-8)	-0.355225	0.019179	-18.52	<.0001
(seabaseReorderThreshold-0.45271)*(numberOfUnits-5.49612)	-0.078013	0.013088	-5.96	<.0001
(unitSupplyThreshold-0.65349)*(numberOfUnits-5.49612)	0.2664449	0.008395	31.74	<.0001
(unitSupplyThreshold-0.65349)*(numberOfHelos-2.50388)	-0.74045	0.025468	-29.07	<.0001
(numberUnitPersonnel-8)*(numberOfUnits-5.49612)	-0.003147	0.00105	-3.00	0.0027
(numberUnitPersonnel-8)*(numberOfHelos-2.50388)	0.0074494	0.002354	3.16	0.0016
(numberOfUnits-5.49612)*(numberOfHelos-2.50388)	-0.113969	0.00215	-53.02	0.0000

Figure 14. JMP Linear Regression Model for Square-Root of averageBalkTime without seabaseStorageCapacity

As performed for the previous regression model, validation was done by analyzing the model coefficients' sign and magnitude. Graphs shown in Appendix C, Figures 39, 40, 41, and 42 show increases in the unitSupplyThreshold lead to increases in the averageBalkTime; validating the positive coefficient in the model. Figure 16 show increases in both numberOfHelos and numberOfUnits lead to a decrease and moderate increase, respectively, in the averageBalkTime; validating the negative coefficient for numberOfHelos and the small positive coefficient for numberOfUnits listed in Figure 15. The magnitude of numberOfHelos and numberOfUnits can also be validated by looking at Figure 16. The parameter numberOfHelos has a greater effect in decreasing the averageBalkTime than does the degree of effect increasing numberOfUnits has on averageBalkTime; validating the absolute value of numberOfHelo's coefficient is greater than the absolute value of numberOfUnit's coefficient. Figures 17 and 18 display the averageBalkTime across applicable levels of seabaseReorderThreshold and numberUnitPersonnel. The lack of correlation between these two parameters and averageBalkTime accounts for the variablility in averageBalkTime values as either seabaseReorderThreshold or numberOfUnitPersonnel increase. The sign related to these two coefficients is difficult to validate with only Figures 17 and 18, and will require deeper analysis to confirm their values.

The correlation matrix and scatter plot for the predictor variables listed in Figure 14 are shown in Figure 15 below. The predictor variables numberOfUnits and numberOfHelos are moderately related to the response variable with correlation values of 0.5684 and -0.5814, respectively. The remaining three predictors, seabaseReorderThreshold, unitSupplyThreshold, and numberUnitPersonnel, show practically no relation to averageBalkTime with correlation values near zero.



Multivariate

Correlations

	SqrtABT	seabaseReorderThreshold	unitSupplyThreshold	numberUnitPersonnel	numberOfUnits	numberOfHelos
SqrtABT	1.0000	-0.0367	0.0946	-0.0335	0.5684	-0.5814
seabaseReorderThreshold	-0.0367	1.0000	0.0240	0.0044	0.0299	0.0579
unitSupplyThreshold	0.0946	0.0240	1.0000	-0.0484	0.0360	-0.0375
numberUnitPersonnel	-0.0335	0.0044	-0.0484	1.0000	-0.0295	0.0473
numberOfUnits	0.5684	0.0299	0.0360	-0.0295	1.0000	0.0144
numberOfHelos	-0.5814	0.0579	-0.0375	0.0473	0.0144	1.0000

Scatterplot Matrix

Figure 15. JMP Correlation Matrix and Scatter Plot for averageBalkTime

The fact that each unit which enters a balk state increases the numberOfUnitBalks and the time spent in the balk state used in calculating averageBalkTime means they are dependent on one another. It follows then for this model that, as shown for numberOfUnitBalks, a majority of balk time instances for each number of helicopters occurs with the larger amount of units under the seabase's control with high unitSupplyThreshold values. The maximum average value of averageBalkTime, across all units, for each number of helicopters performing logistic delivery missions, and the corresponding percentage change in maximum average value by adding an additional helicopter is summarized in Table 5 below. The benefit of adding additional helicopters, as a function of numberOfUnits, in order to decrease the averageBalkTime is shown in

Figure 16 below for numberOfHelos equal to one, two, three, and four respectively. Graphs detailing the benefit of adding an additional helicopter as a function of both numberOfUnits and unitSupplyThreshold are found in Appendix C, Figures 39, 40, 41, and 42 for numberOfHelos equal to one, two, three, and four respectively.

numberOfHelos	Maximum averageBalkTime	Percentage change with addition of one helicopter
1	2.786115	56.15%
2	1.22175	24.43%
3	0.92330	24.73%
4	0.695013	-

Table 5. Percent change of averageBalkTime by the addition of one helicopter

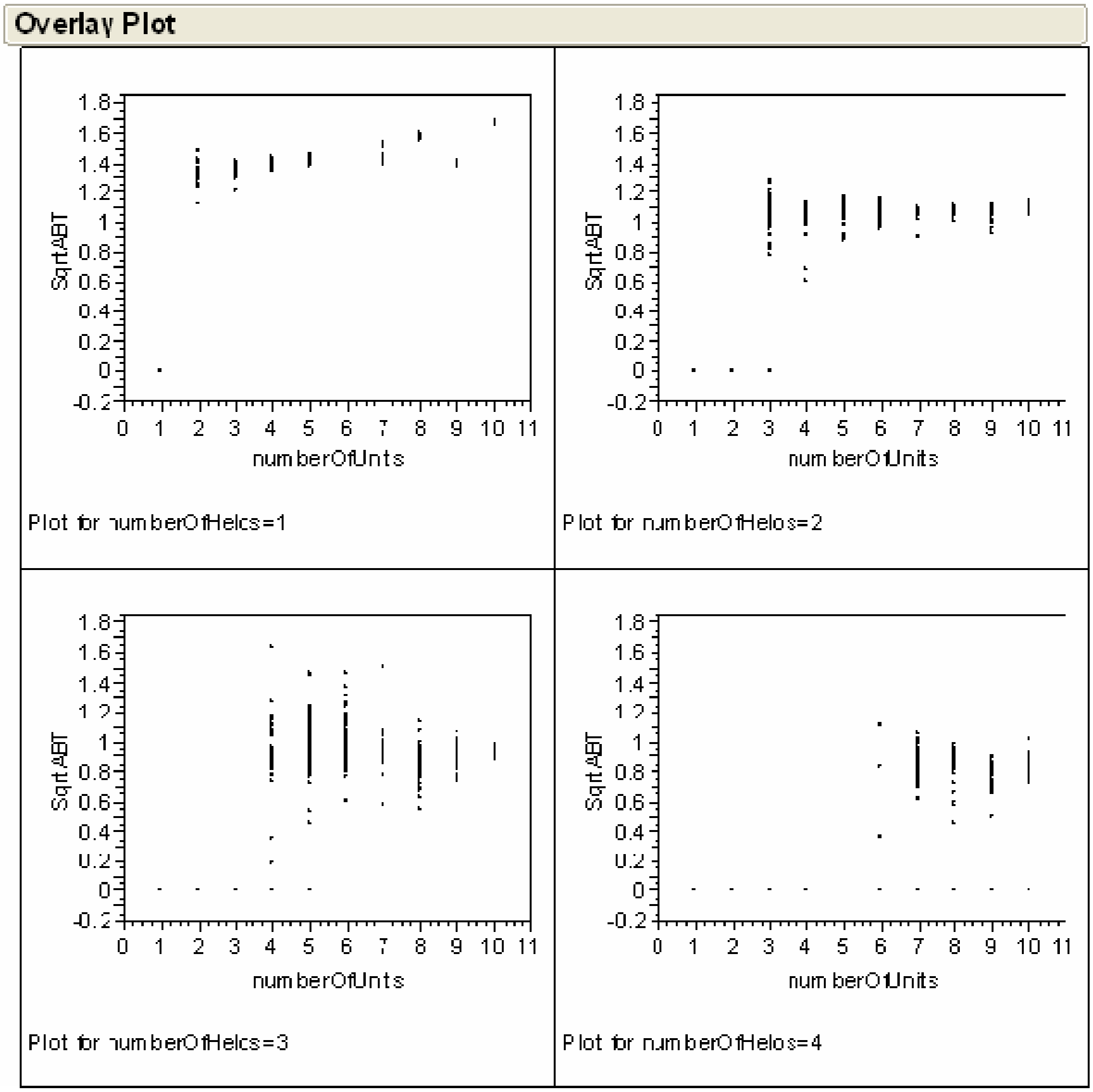


Figure 16. Overlay Plot for Square-Root of averageBalkTime vs. numberOfUnits with numberOfHelos = {1, 2, 3, 4}

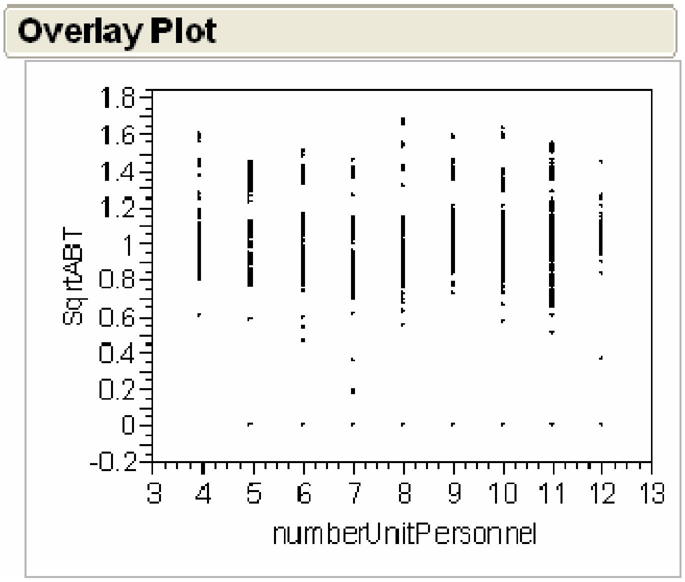


Figure 17. Overlay Plot for Square-Root of averageBalkTime vs. numberUnitPersonnel

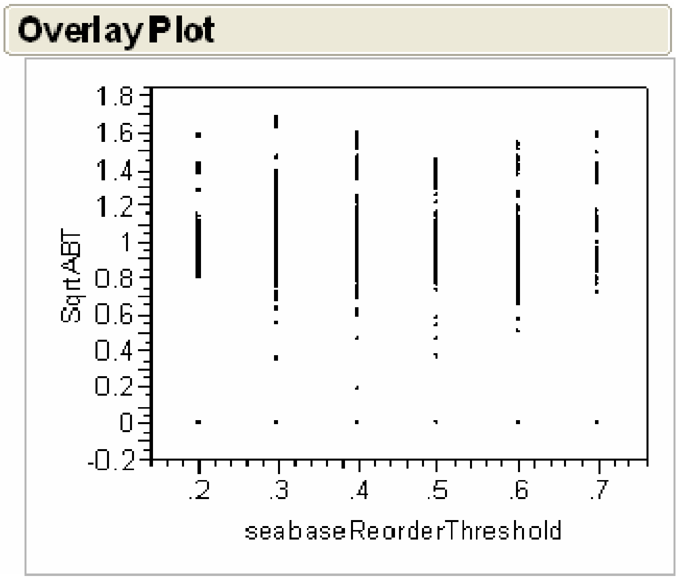


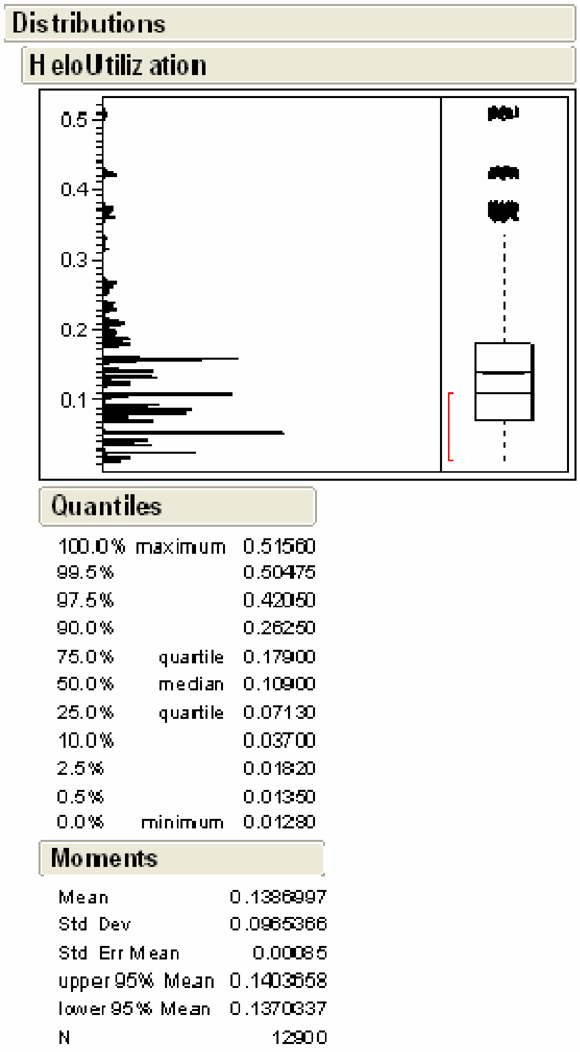
Figure 18. Overlay Plot for Square-Root of averageBalkTime vs. seabaseReorderThreshold

4. Helicopter Utilization

Helicopter utilization measures the number of helicopters idle, i.e., not performing a logistic delivery mission, over the three year simulated time period. The utilization value is derived by dividing the average helicopters idle over a time period by the total number of helicopters assigned to the seabase, and then subtracting one from this quotient.

$$1-\left(\frac{mean\ number\ of\ \ idle\ helicopters\ over\ time}{numberOfHelos}\right)$$

The distribution of heloUtilization is given in Figure 19 below. Once again, in the upper tail of the distribution there are clear thresholds where heloUtilization jumps from one level to another



Distributions

HeloUtilization

Quantiles

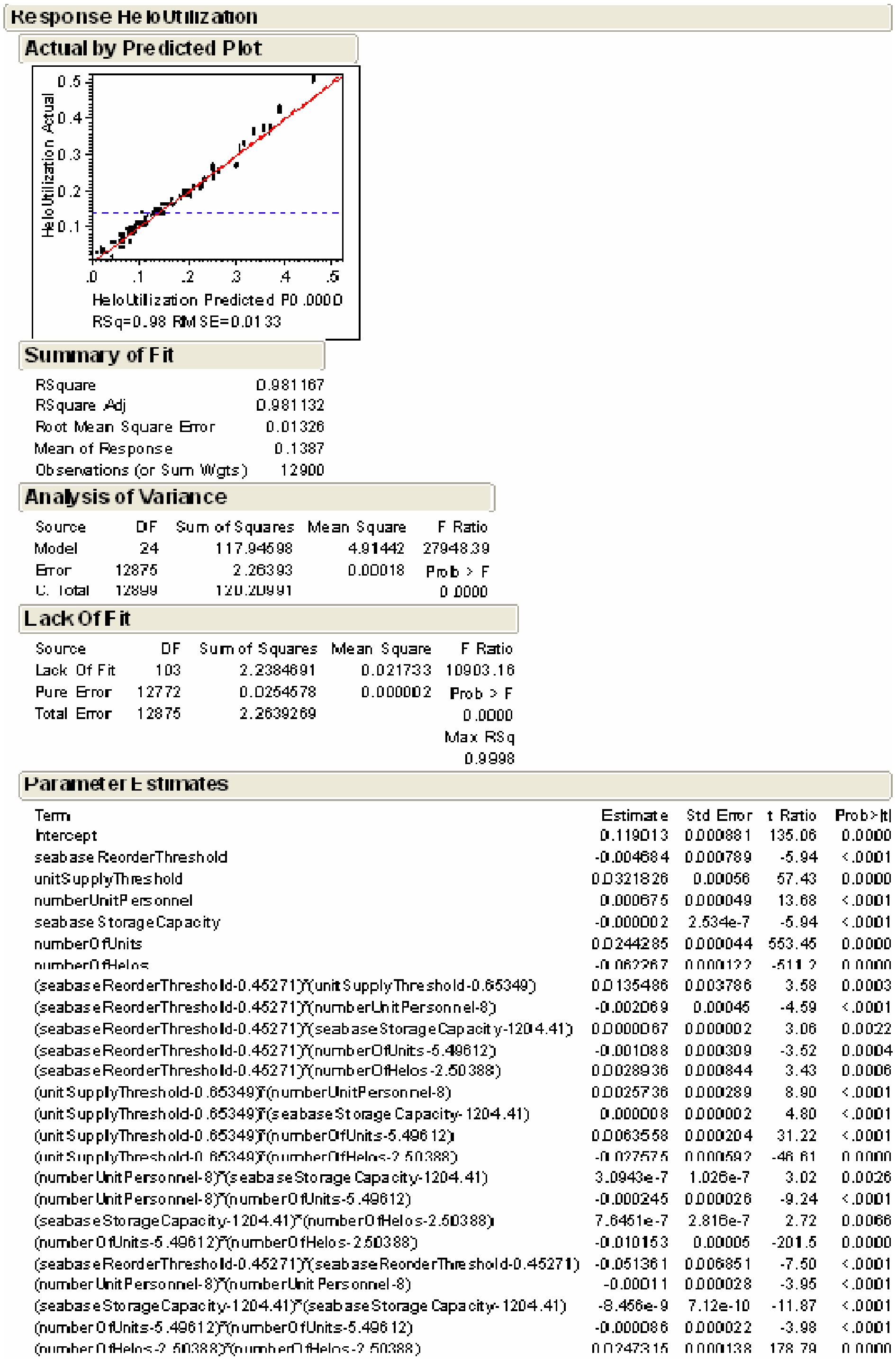
100.0%	maximum	0.51560
99.5%		0.50475
97.5%		0.42050
90.0%		0.26250
75.0%	quartile	0.17900
50.0%	median	0.10900
25.0%	quartile	0.07130
10.0%		0.03700
2.5%		0.01820
0.5%		0.01350
0.0%	minimum	0.01280

Moments

Mean	0.1386997
Std Dev	0.0965366
Std Err Mean	0.00085
upper 95% Mean	0.1403658
lower 95% Mean	0.1370337
N	12900

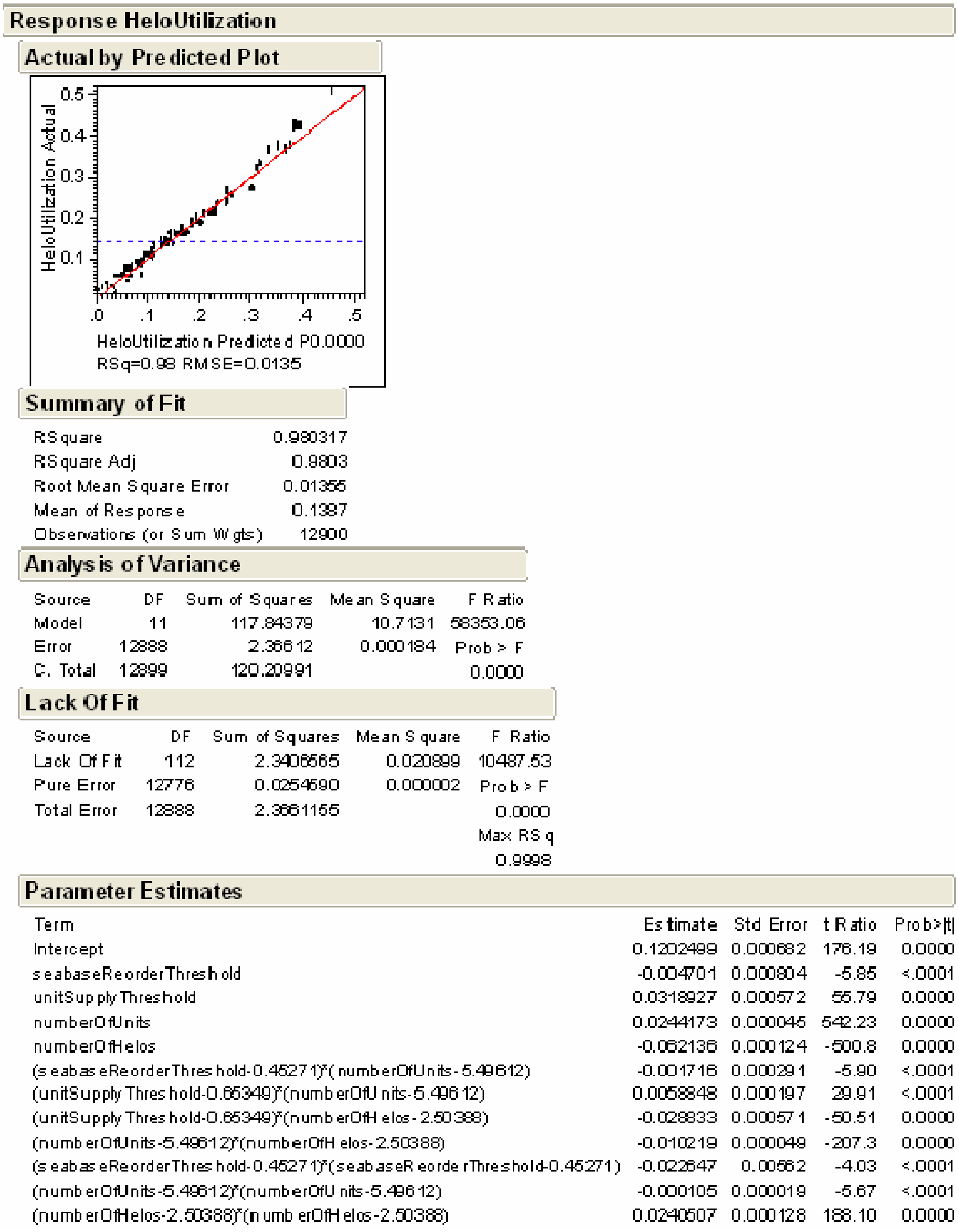
Figure 19. JMP Distribution of heloUtilization

A regression model is used to explain the relationship between the response variable heloUtilization, and the predictor variables: seabaseReorderThreshold, unitSupplyThreshold, numberUnitPersonnel, seabaseStorageCapacity, numberOfUnits, and numberOfHelos. Figure 20 is the linear regression model generated in JMP. The R^2 value associated with this model is 0.981, indicating the model accounts for 98.1% of the variability within the response variable heloUtilization. All predictor variables were statistically significant, but the predictor variables seabaseStorageCapacity and numberUnitPersonnel can be argued as not being practically significant. The small coefficient value listed in the Estimate column of the Parameter Estimates section shows that for every increasing change in seabaseStorageCapacity and numberUnitPersonnel, the response variable is decreased by 2.0×10^{-6} and increased by 6.75×10^{-4}, respectively. The R^2 value of the linear regression model with seabaseStorageCapacity, numberUnitPersonnel, and all corresponding interaction and polynomial terms removed is 0.980 (Figure 21), indicating the model accounts for essentially the same variability within the response variable, as the model shown in Figure 20.



```
Response HeloUtilization
Actual by Predicted Plot
Summary of Fit
RSquare                         0.981167
RSquare Adj                     0.981132
Root Mean Square Error           0.01326
Mean of Response                  0.1387
Observations (or Sum Wgts)         12900
Analysis of Variance
Source        DF   Sum of Squares   Mean Square    F Ratio
Model         24        117.94598       4.91442   27948.39
Error      12875          2.26393       0.00018   Prob > F
C. Total   12899        120.20991                   0.0000
Lack Of Fit
Source           DF   Sum of Squares   Mean Square    F Ratio
Lack Of Fit     103        2.2384691      0.021733   10903.16
Pure Error    12772        0.0254578      0.000002   Prob > F
Total Error   12875        2.2639269                   0.0000
                                                      Max RSq
                                                       0.9998
Parameter Estimates
Term                                                                     Estimate  Std Error  t Ratio  Prob>|t|
Intercept                                                                0.119013   0.000881   135.06    0.0000
seabaseReorderThreshold                                                 -0.004684   0.000789    -5.94    <.0001
unitSupplyThreshold                                                     0.0321826    0.00056    57.43    0.0000
numberUnitPersonnel                                                      0.000675   0.000049    13.68    <.0001
seabaseStorageCapacity                                                  -0.000002   2.534e-7    -5.94    <.0001
numberOfUnits                                                           0.0244285   0.000044   553.45    0.0000
numberOfHelos                                                           -0.062267   0.000122   -511.2    0.0000
(seabaseReorderThreshold-0.45271)*(unitSupplyThreshold-0.65349)         0.0135486   0.003786     3.58    0.0003
(seabaseReorderThreshold-0.45271)*(numberUnitPersonnel-8)               -0.002069    0.00045    -4.59    <.0001
(seabaseReorderThreshold-0.45271)*(seabaseStorageCapacity-1204.41)      0.0000067   0.000002     3.06    0.0022
(seabaseReorderThreshold-0.45271)*(numberOfUnits-5.49612)               -0.001088   0.000309    -3.52    0.0004
(seabaseReorderThreshold-0.45271)*(numberOfHelos-2.50388)               0.0028936   0.000844     3.43    0.0006
(unitSupplyThreshold-0.65349)*(numberUnitPersonnel-8)                   0.0025736   0.000289     8.90    <.0001
(unitSupplyThreshold-0.65349)*(seabaseStorageCapacity-1204.41)           0.000008   0.000002     4.80    <.0001
(unitSupplyThreshold-0.65349)*(numberOfUnits-5.49612)                   0.0063558   0.000204    31.22    <.0001
(unitSupplyThreshold-0.65349)*(numberOfHelos-2.50388)                   -0.027575   0.000592   -46.61    0.0000
(numberUnitPersonnel-8)*(seabaseStorageCapacity-1204.41)                3.0943e-7   1.026e-7     3.02    0.0026
(numberUnitPersonnel-8)*(numberOfUnits-5.49612)                         -0.000245   0.000026    -9.24    <.0001
(seabaseStorageCapacity-1204.41)*(numberOfHelos-2.50388)                7.6451e-7   2.816e-7     2.72    0.0066
(numberOfUnits-5.49612)*(numberOfHelos-2.50388)                         -0.010153    0.00005   -201.5    0.0000
(seabaseReorderThreshold-0.45271)*(seabaseReorderThreshold-0.45271)     -0.051361   0.006851    -7.50    <.0001
(numberUnitPersonnel-8)*(numberUnitPersonnel-8)                          -0.00011   0.000028    -3.95    <.0001
(seabaseStorageCapacity-1204.41)*(seabaseStorageCapacity-1204.41)       -8.456e-9   7.12e-10   -11.87    <.0001
(numberOfUnits-5.49612)*(numberOfUnits-5.49612)                         -0.000086   0.000022    -3.98    <.0001
(numberOfHelos-2.50388)*(numberOfHelos-2.50388)                         0.0247315   0.000138   178.79    0.0000
```

Figure 20. JMP Linear Regression Model for heloUtilization



Response HeloUtilization

Actual by Predicted Plot

HeloUtilization Predicted P0.0000
RSq=0.98 RMSE=0.0135

Summary of Fit

RSquare	0.980317
RSquare Adj	0.9803
Root Mean Square Error	0.01356
Mean of Response	0.1387
Observations (or Sum Wgts)	12900

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	11	117.84379	10.7131	58353.06
Error	12888	2.36612	0.000184	Prob > F
C. Total	12899	120.20991		0.0000

Lack Of Fit

Source	DF	Sum of Squares	Mean Square	F Ratio
Lack Of Fit	112	2.3406565	0.020899	10487.53
Pure Error	12776	0.0254590	0.000002	Prob > F
Total Error	12888	2.3661155		0.0000
				Max RSq
				0.9998

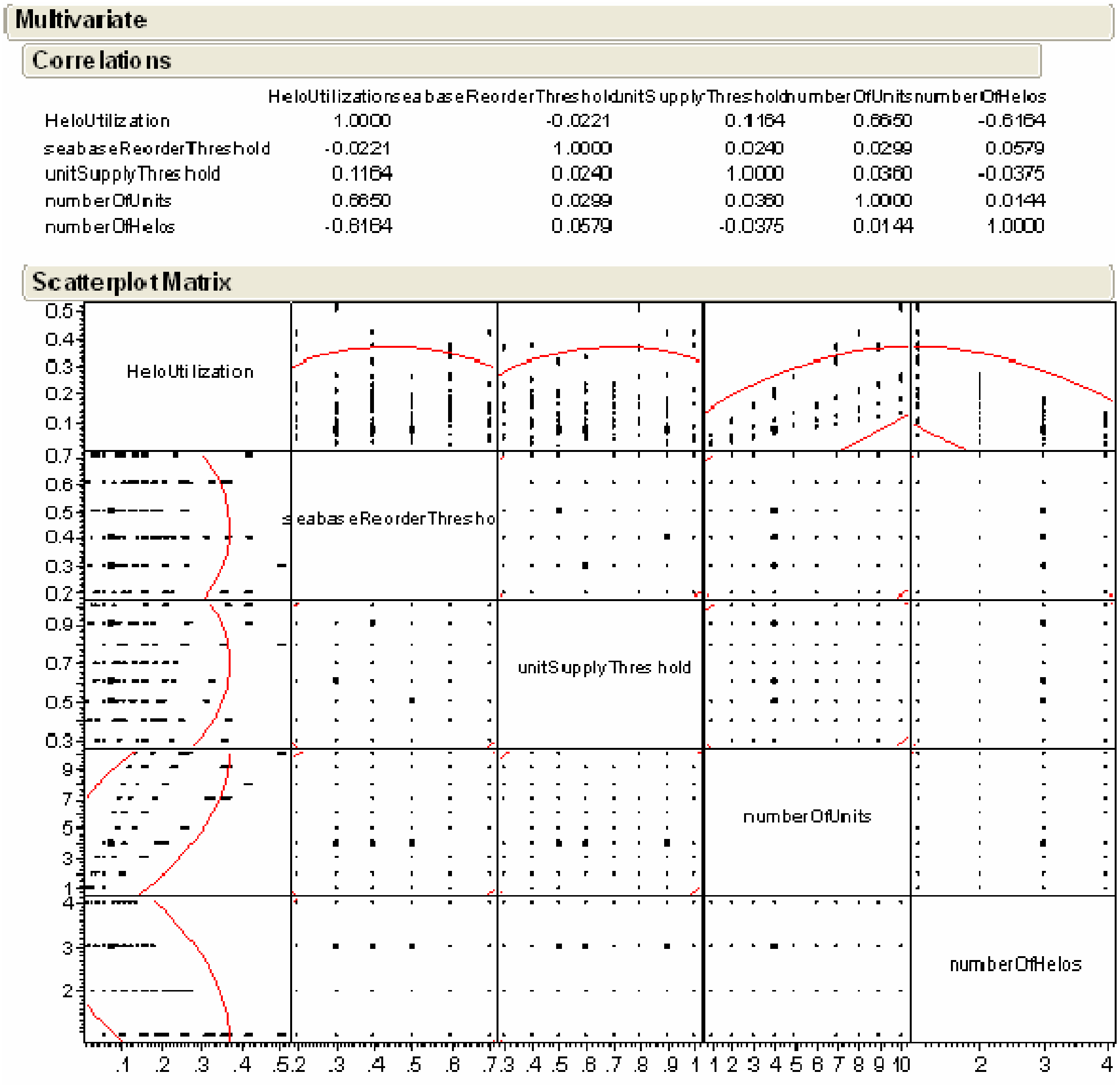
Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	0.1202499	0.000682	176.19	0.0000
seabaseReorderThreshold	-0.004701	0.000804	-5.85	<.0001
unitSupplyThreshold	0.0318927	0.000572	55.79	0.0000
numberOfUnits	0.0244173	0.000045	542.23	0.0000
numberOfHelos	-0.062136	0.000124	-500.8	0.0000
(seabaseReorderThreshold-0.45271)*(numberOfUnits-5.49612)	-0.001716	0.000291	-5.90	<.0001
(unitSupplyThreshold-0.65349)*(numberOfUnits-5.49612)	0.0058848	0.000197	29.91	<.0001
(unitSupplyThreshold-0.65349)*(numberOfHelos-2.50388)	-0.028833	0.000571	-50.51	0.0000
(numberOfUnits-5.49612)*(numberOfHelos-2.50388)	-0.010219	0.000049	-207.3	0.0000
(seabaseReorderThreshold-0.45271)*(seabaseReorderThreshold-0.45271)	-0.022647	0.00562	-4.03	<.0001
(numberOfUnits-5.49612)*(numberOfUnits-5.49612)	-0.000105	0.000019	-5.67	<.0001
(numberOfHelos-2.50388)*(numberOfHelos-2.50388)	0.0240507	0.000128	188.10	0.0000

Figure 21. JMP Linear Regression Model for heloUtilization without seabaseStorageCapacity and numberUnitPersonnel

As performed for the previous regression models, validation was done by analyzing the model coefficients' sign and magnitude. Graphs shown in Appendix C, Figures 43, 44, 45, and 46 show increases in the unitSupplyThreshold lead to moderate increases in the heloUtilization as numberOfUnits increase; validating the coefficient's positive sign and magnitude in the model. Figure 23 shows increases in both numberOfHelos and numberOfUnits lead to a moderate decrease and moderate increase, respectively, in the heloUtilization; validating the negative coefficient for numberOfHelos, the small positive coefficient for numberOfUnits, and their respective small coefficient magnitudes listed in Figure 21. Figures 24 and 25 are overlay plots displaying heloUtilization across applicable levels of seabaseReorderThreshold and unitSupplyThreshold. The lack of correlation between seabaseReorderThreshold, unitSupplyThreshold and heloUtilization accounts for the variablility in heloUtilization values as both are increased. The sign related to both seabaseReorderThreshold;s and unitSupplyThreshold's coefficient are difficult to validate with information interpreted from Figures 24 and 25, and will require deeper analysis to confirm their values.

The correlation matrix and scatter plot for the predictor variables listed in Figure 21 is shown below in Figure 22. The predictor variables numberOfUnits and numberOfHelos are moderately related to the response variable with correlation values of 0.6650 and -0.6164, respectively. The remaining predictors, seabaseReorderThreshold and unitSupplyThreshold, show practically no relation to heloUtilization with correlation values near zero.



Multivariate

Correlations

	HeloUtilization	seabaseReorderThreshold	unitSupplyThreshold	numberOfUnits	numberOfHelos
HeloUtilization	1.0000	-0.0221	0.1164	0.6650	-0.6164
seabaseReorderThreshold	-0.0221	1.0000	0.0240	0.0299	0.0579
unitSupplyThreshold	0.1164	0.0240	1.0000	0.0360	-0.0375
numberOfUnits	0.6650	0.0299	0.0360	1.0000	0.0144
numberOfHelos	-0.6164	0.0579	-0.0375	0.0144	1.0000

Scatterplot Matrix

Figure 22. Correlation Matrix and Scatter Plot for heloUtilization

Figure 23 below shows the average heloUtilization across all units for numberOfHelos equal to one, two, three, and four respectively. In terms of this model, as the number of helicopters assigned to the seabase increases, the average heloUtilization decreases for all values of numberOfUnits. Fixing the value of numberOfHelos, the average heloUtilization increases as the numberOfUnits increase.

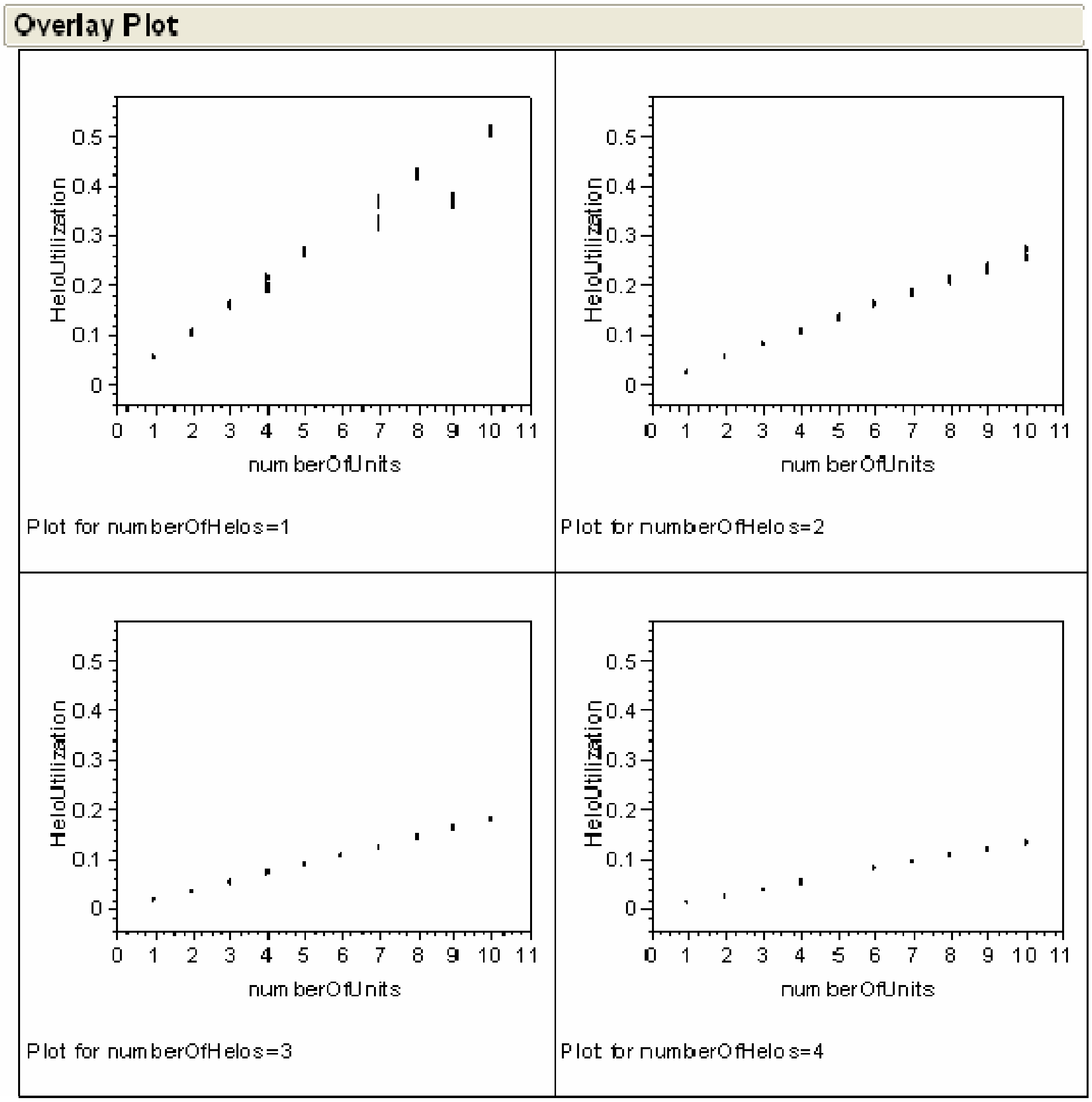


Figure 23. Overlay Plot of heloUtilization vs. numberOfUnits for numberOfHelos = {1, 2, 3, 4}

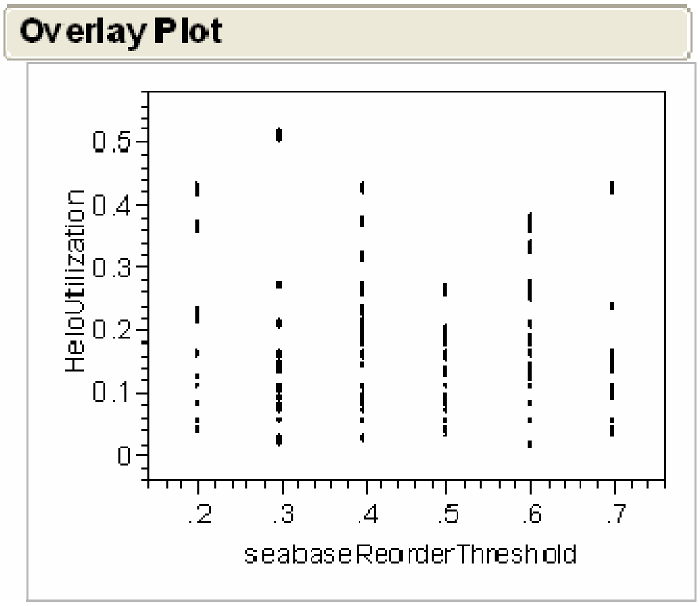


Figure 24. Overlay Plot of heloUtilization vs. seabaseReorderThreshold

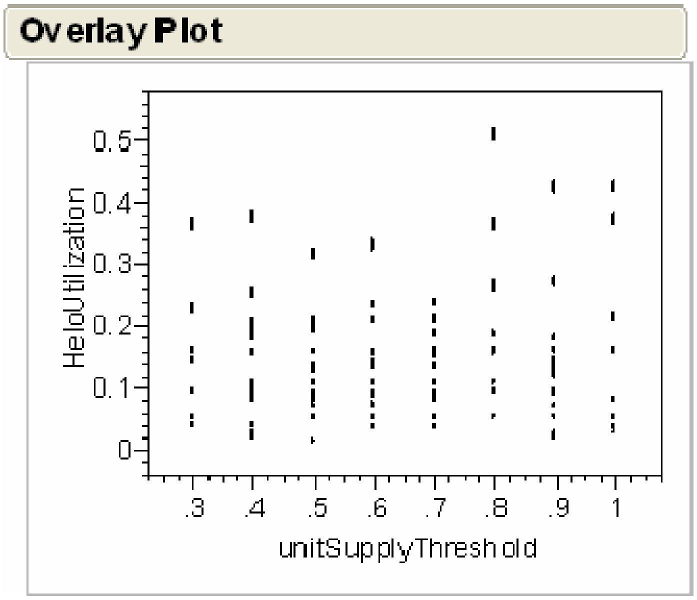


Figure 25. Overlay Plot of heloUtilization vs. unitSupplyThreshold

The average heloUtilization, across all values of numberOfHelos, ranges from 0.506, for numberOfHelos equal to one and numberOfUnits equal to ten, to 0.0135, for numberOfHelos equal to four and numberOfUnits equal to one. Utilizing the formula to calculate heloUtilization, the average number of idle helicopters over the simulated time period can be calculated using the average heloUtilization values. Table 6 summarizes the average number of idle helicopters for each level of numberOfHelos and numberOfUnits equaling one and ten (the parameter's minimum and maximum level).

numberOfHelos	numberOfUnits = 1	numberOfUnits = 10
1	0.946	0.494
2	1.946	1.473
3	2.946	2.464
4	3.946	3.463

Table 6. Calculated Average Number of Idle Helicopters

The values in Table 6 indicate that embarking additional helicopters on the seabase to perform logistic delivery missions only increases the average number of idle helicopters by the same degree. In the case where numberOfUnits equals one, regardless of the numberOfHelos embarked, only one helicopter on average is employed a fraction of the simulated time; whereas for numberOfUnits equaling ten, regardless of the numberOfHelos embarked, the single helicopter is employed more frequently over the simulated time period to support the larger numberOfUnits.

5. Seabase Storage Capacity

Is the square-foot area allocated to SOF, per (LPD-17 ORD), adequate to successfully perform Special Operations from a LPD-17 class seabase? The minimum square foot area on a LPD-17 allocated to SOF and/or EOD personnel is 400 square feet. The engineering of design points within a Nearly Orthogonal Latin Hypercube (NOLH) uses both the small and large value of a parameter's range along with permutated values between these two figures. Table 7 shows the design point with capacity set to 400 along with other input parameter settings.

seabaseReorder Threshold	unitSupply Threshold	numberUnit Personnel	seabaseStorage Capacity	numberOf Units	numberOf Helos
0.6	0.5	10	400	10	4

Table 7. Design Point Containing Minimum seabaseStorageCapacity

Despite having the maximum allowed helicopters embarked, the maximum number of units employed by the seabase, and the SOF units ordering supplies each time their on-hand quantities are at 50% their maximum capacity, the LPD-17 class ship is able to achieve a Net Effectiveness of 100% in sustaining units ashore with the minimum SOF-allocated square-foot area it is designed to contain.

C. CONCLUSION

This chapter discussed the results of the simulation through a variety of analytical techniques. Linear regression for the numberOfUnitBalks, averageBalkTime, and heloUtilization output parameters accounted for much of the variability and led to good predictive models. Net effectiveness for supply commodities issued was 100% for all design points within the simulation, indicating no partial quantity issues were performed by the seabase. Helicopter utilization appeared to remain fairly constant with the addition of one or several helicopters to the seabase.

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V. CONCLUSIONS AND RECOMMENDATIONS

The objective of this thesis was to identify what level of support and capability is required to logistically sustain a varied amount of SOF units from a single-ship Seabase. A Discrete Event Simulation (DES), written in Java computer language utilizing the Simkit package, was used to model the notional seabasing scenario. Key components were identified and built into the DES as objects that interact based on their particular roles within the scenario. The interactions created data points that were analyzed using regression and marginal benefit analysis. Analysis models within this thesis apply only to the predictor variables, as defined in Chapter IV, along with their respective range of values. Conclusions and recommendations stated in this chapter identified through analysis and interpretation of data relationships are within the scope and boundaries of this model.

A. MODEL CONCLUSIONS

1. Net Effectiveness and Seabase Capacity

Recall from Chapter IV that Net Effectiveness is a function of, among other things, capacity. Net Effectiveness was 100% for all combinations of design factors input to the simulation. In other words, regardless of: the number of helicopters embarked, the number of Special Operations Forces (SOF) units employed, the number of personnel within each unit, how frequent the seabase and SOF units request material, and the square foot area allocated as storage to the SOF units above the minimum area per ship design, the LPD-17 class ship is able to fully sustain SOF units operating ashore without compromising mission success by issuing partial supply quantities. This is contingent on the availability of a resupply ship to sustain the seabase.

Regression models associated with the number of unit balks, the average balk time, and helicopter utilization indicate the seabase storage capacity is not practically significant in affecting the values of these three response variables, validating the range of capacity set within the model is adequate in supporting SOF units operating ashore. The results of the model also validates the adequacy of the square-foot area SOF units require to successfully perform the LPD-17 secondary mission of Naval Special Warfare outlined in (LPD-17 ORD).

2. Helicopter Utilization

Analysis results found in Table 6 of Chapter IV suggests that adding more than one helicopter to the seabase has a minimal affect on improving utilization. It would appear that one helicopter is able to support the model's maximum number of SOF units employed by the seabase and still maintain an average utilization of 0.463. If a theater commander had to use this single data point to decide how many helicopter assets to assign to the seabase, only one would be allocated. This brings up a flaw in using utilization by itself as a measure of effectiveness. Figures 11 and 16, along with Tables 4 and 5, in Chapter IV shows the substantial marginal benefit of adding additional helicopters to minimize both the number of times a unit enters a balk state and the time spent in that state. Taking away helicopter resources from the seabase may free up equipment to be used elsewhere in the theater, but will greatly affect the ability of SOF units operating ashore to perform their missions in a timely manner when operationally required.

The law of diminishing returns will play a role in deciding how many additional helicopters to embark on the seabase. The benefit realized through the objective value of minimizing the frequency which a unit enters a balk state, and the associated time spent in the balk state, will decrease as the number of helicopters embarked increases. Figure 26 below uses numeric data from Table 4. The knee in the curve represents the value of numberOfHelos where a diminishing marginal benefit exists in further seeking to minimize the numberOfUnitBalks. The decision to limit the number of helicopters used to support SOF ashore based solely on marginal benefit analysis can be detrimental to the operational effectiveness of the campaign. The additional cost of increasing the number of helicopters may in reality be inconsequential to the importance of SOF mission timing and operational advantage. For example, the increased cost in adding a fourth helicopter to the seabase has a diminishing return (Figure 26), but decreases the unit balk occurrences by 82% over a three year period (Table 4). This can mean the difference in waging a successful Special Operations campaign. Figure 27 shows a similar argument for averageBalkTime data drawn from Table 5.

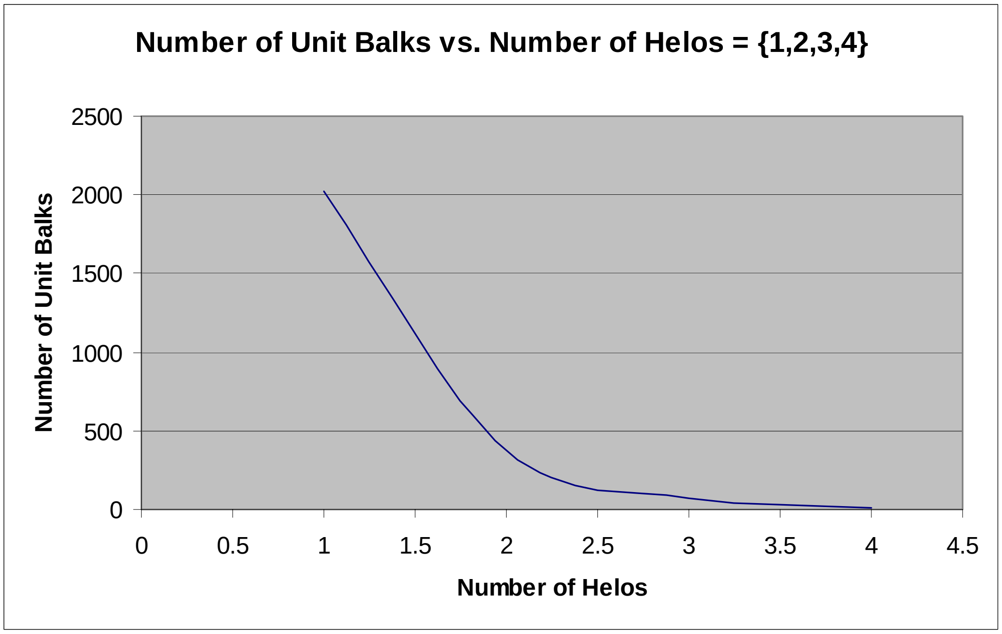

Figure 26. Relationship Between numberOfUnitBalks vs. numberOfHelos

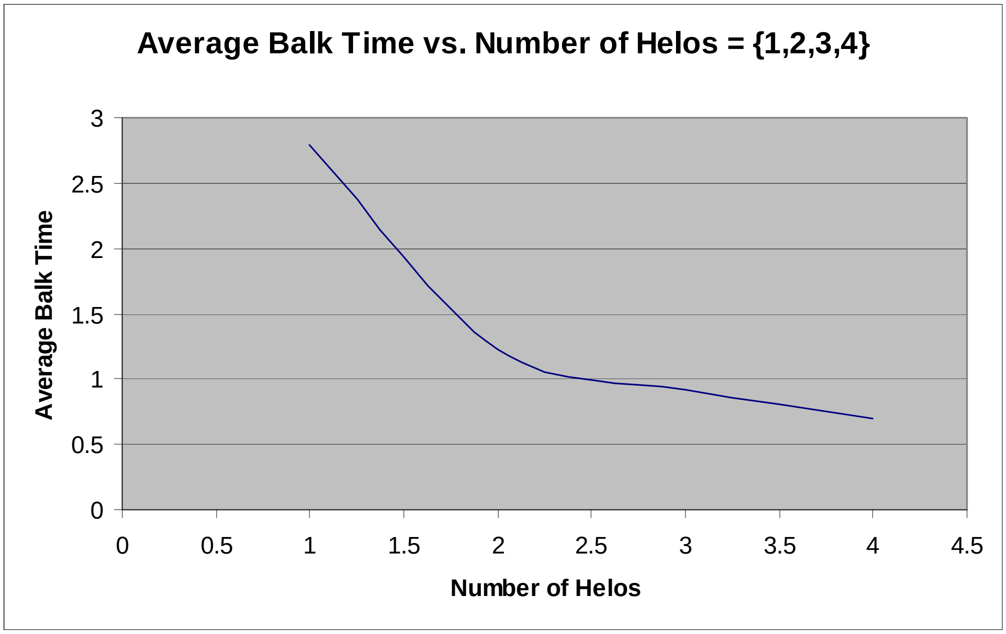

Figure 27. Relationship Between averageBalkTime vs. numberOfHelos

The low utilization numbers resulting from the model do lead to benefits. Helicopters remaining idle for a given period of time on the seabase give the operational commander flexibility in employing these assets in support of other mission areas. Maritime Interdiction Operations, maritime-borne Search and Rescue, and crew training are some examples of mission areas a commander can assign idle helicopters to as the operational environment dictates. On occasion, SOF units performing highly combat intensive Direct Action missions may require aerial extraction upon mission completion. This process would require multiple armed air assets to enter a ‘hot’ landing zone for personnel and casualty extraction. A seabase commander would be able to answer this short-notice request by having idle air assets available to deploy.

Flexibility in performing a variety of missions is crucial in meeting the concepts defining Seabasing. A commander with a given level of capability must strike a delicate balance between capability allocation among forces and risk associated with accomplishing missions; this is crucial in achieving objectives across the range of military operations. Using utilization of a capability as a measurement for decision-making by itself must be taken with extreme caution. Greater insight, and better decisions, can be drawn by using other measures of effectiveness and capability utilization together.

B. RECOMMENDATIONS FOR FURTHER RESEARCH

Potential follow-on studies may include researching the effects of:

- Modeling randomness in the availability of a resupply ship to sustain the seabase;
- Incorporating missions, to include maintenance downtime, designed for the embarked helicopters to perform besides logistic support; and.
- Implementing a repair process on the Equipment supply commodity, and modeling the associated delays.

Further enhancements to the Discrete Event Simulation model may include:

- Implementing an algorithm, such as traveling salesman, to model the helicopter supporting multiple units within one supply delivery mission;
- Modeling various types of terrain the SOF units will traverse to vary the consumption rates of each supply commodity; and
- Modeling the supply commodities carried by the SOF units in greater detail.

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APPENDIX A – EQUIPMENT SPECIFICATIONS

A. USS SAN ANTONIO (LPD-17)

Figure 28. USS SAN ANTONIO (LPD-17)

- Length: 684 ft (208 m)
- Beam: 105 ft (32 m)
- Draft: 23 ft (7 m)
- Speed: 22+ knots
- Crew: 363
- Troop: 699
- Vehicle Deck Space: 25,000 sq ft (2,323 sq m)
- Cargo / Ammunition Magazines: 25,000 cu ft (708 cu m)
- Ship – Shore Lift: Two Landing Craft Air Cushion (LCAC); 14 Advanced Amphibious Assault Vehicles (AAAV)
- Flight Deck: Landing for 2 CH-53E, or 4 AH/UH-1s, or 4 CH-46, or 2 MV-22
- Hangar Facilities: 1 CH-53E, or 2 CH-46, or 1 V-22, or 3 UH/AH-1s
- Cargo Fuel: JP-5 (42,000 cu ft); MOGAS (1,342 cu ft)
- Medical: 4 operating theaters (two medical, two dental), 24 bed ward, 100 casualty overflow beds
- Propulsion: 4 medium speed, turbocharged marine diesels (40,000 hp)
- Combat Systems:
  - Two Mk 31 Mod 0 RIM – 116A Rolling-Airframe Missile (RAM) system
  - Two Mk 46 Mod 1 30mm Close In Gun System

(Source: Federation of American Scientists website http://www.fas.org/man/dod-101/sys/ship/lpd-17.htm accessed June 2006)

B. HH – 60G PAVE HAWK

Figure 29. HH – 60G Pave Hawk Helicopter

- Primary Function: Infiltration, exfiltration, and resupply of Special Operations Forces in day, night or marginal weather conditions.
- Builder: Sikorsky Aircraft Corp.
- Power Plant: Two General Electric T700 – GE – 701C engines
- Thrust: 1,560 – 1,940 shaft horsepower each engine
- Length: 64 feet, 8 inches (17.1 meters)
- Height: 16 feet, 8 inches (4.4 meters)
- Rotary Diameter: 53 feet, 7 inches (14.1 meters)
- Speed: 184 mph (294.4 kph)
- Maximum Takeoff Weight: 22,000 pounds (9,979 kilograms)
- External Cargo Capacity: 8,000 pounds (3628.7 kilograms)
- Range: 445 statute miles (504 nautical miles); unlimited with air refueling
- Armament: Two 7.62mm mini-guns

(Source: Air Force Link website http://www.af.mil/factsheets/factsheet.asp?fsID=107 accessed January 2007)

APPENDIX B – MODEL EVENT GRAPHS

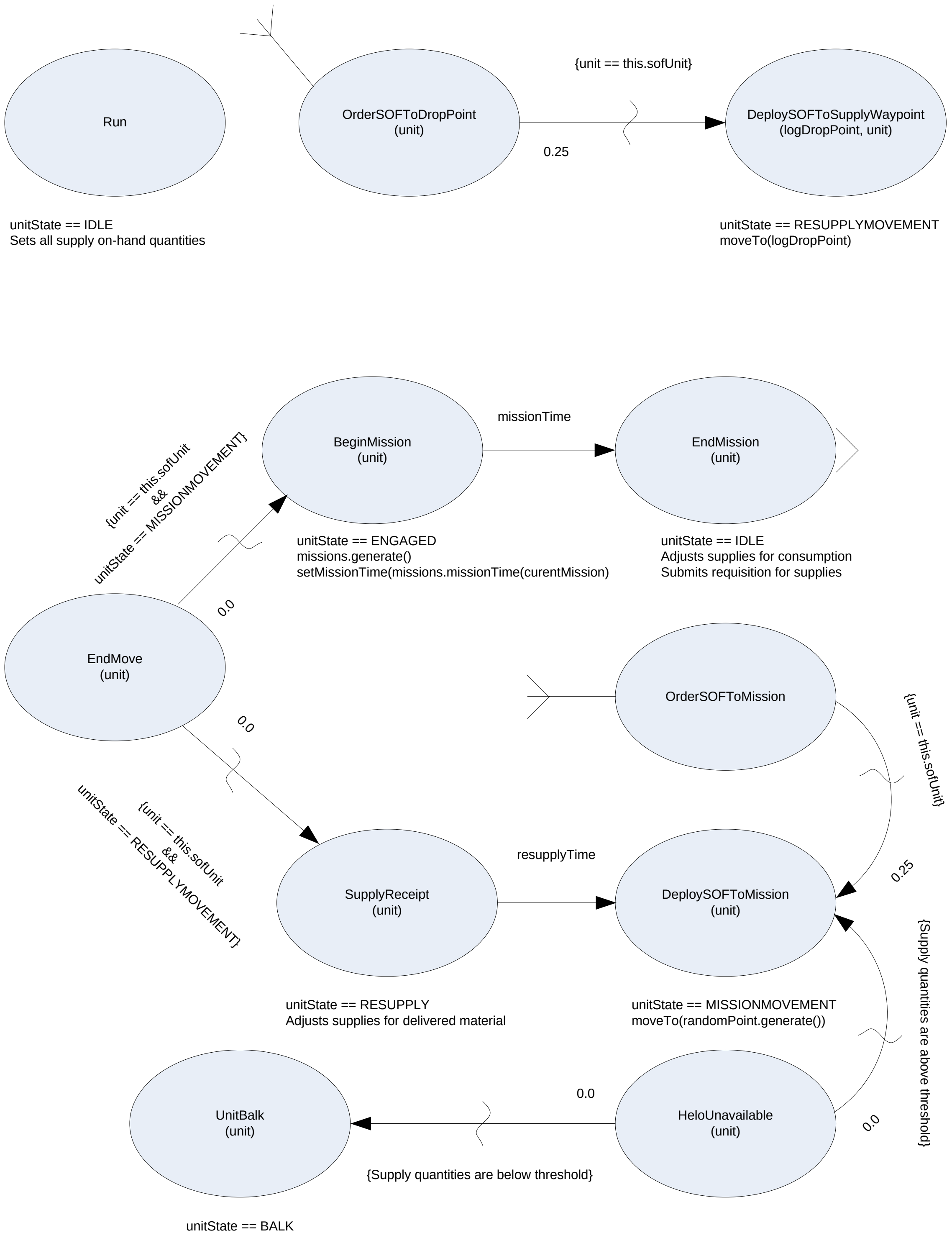

Figure 30. SOFUnitMoverManager Event Graph

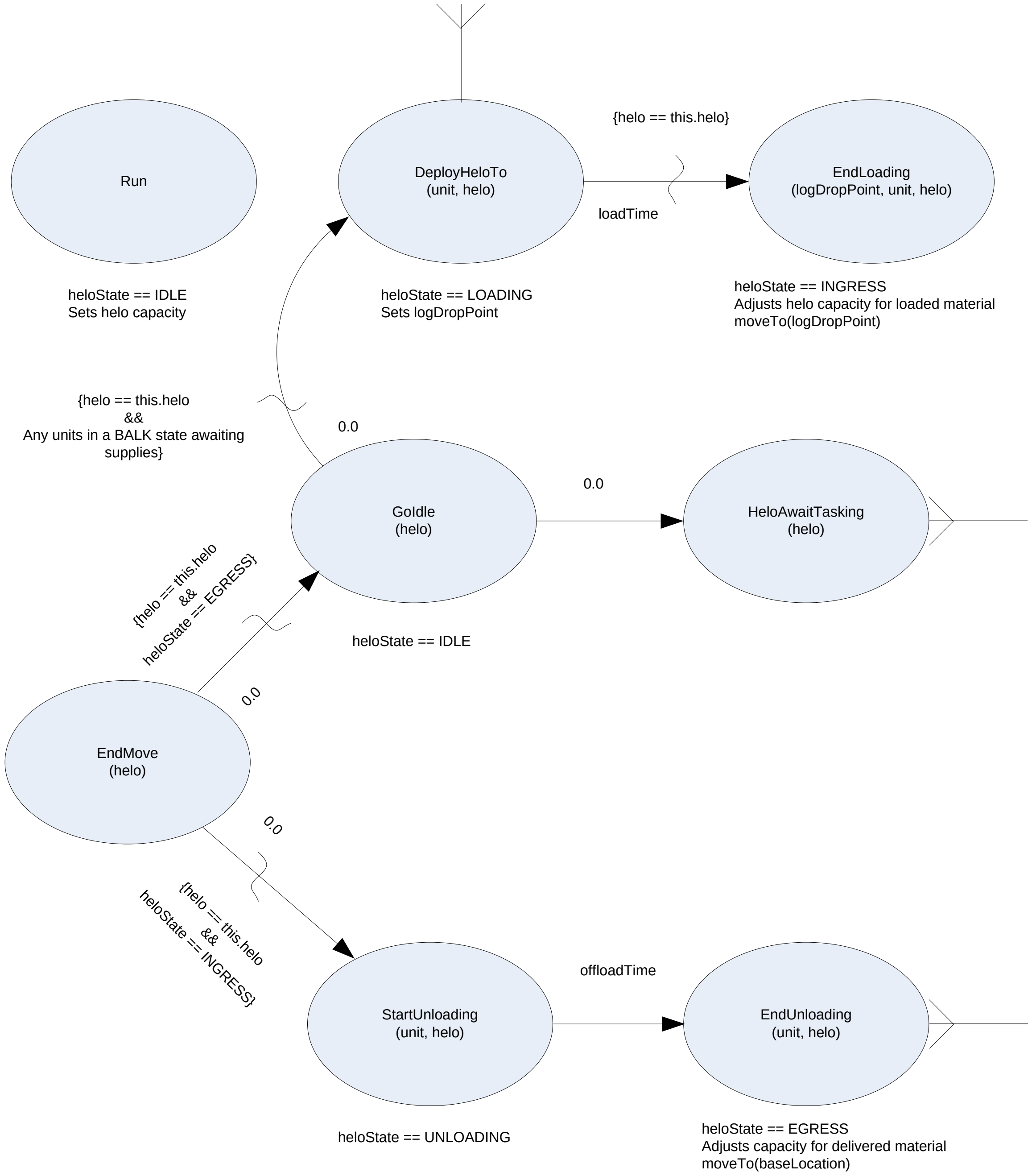

Figure 31. HeloMoverManager Event Graph

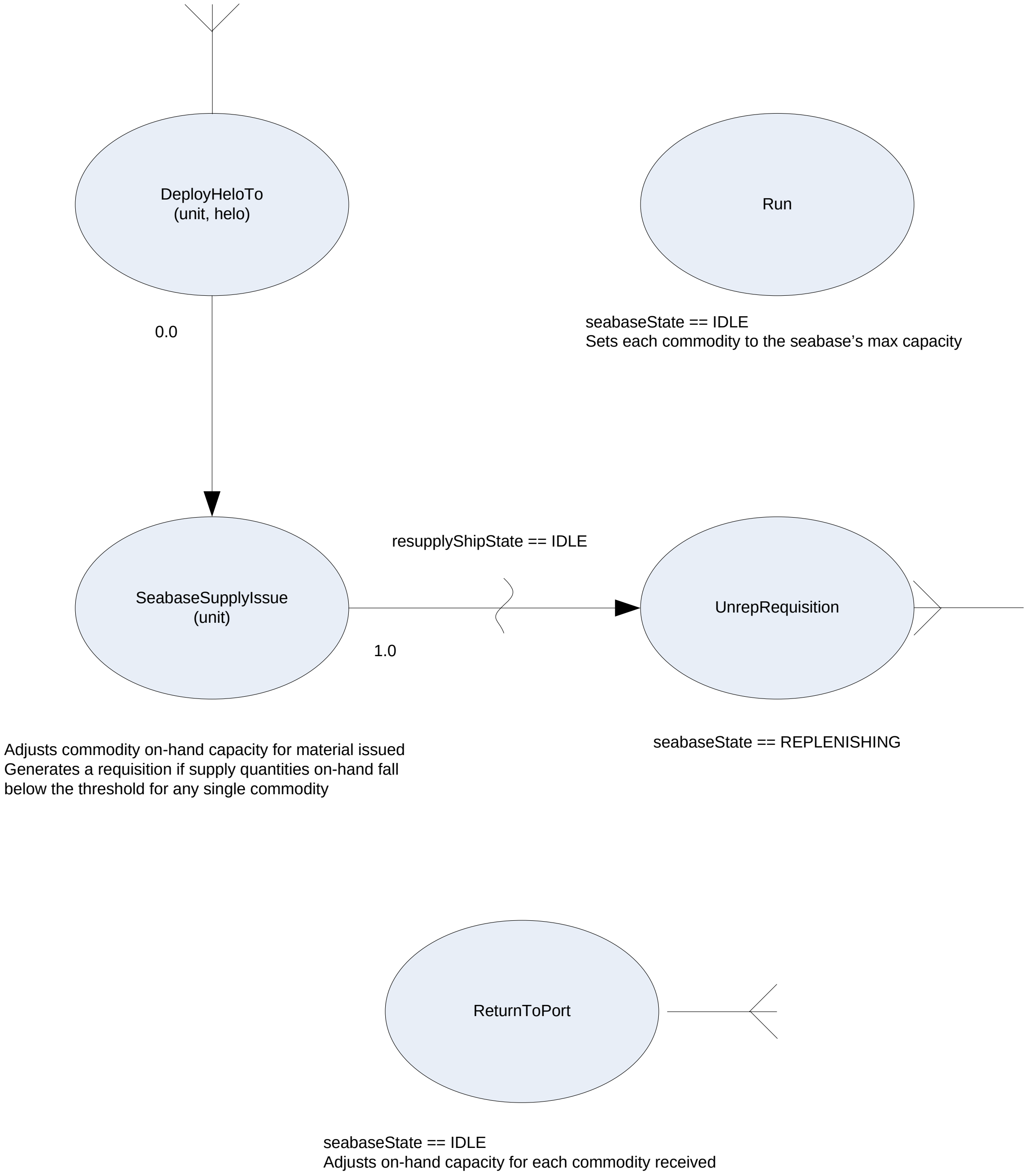

Figure 32. SeabaseMoverManager Event Graph

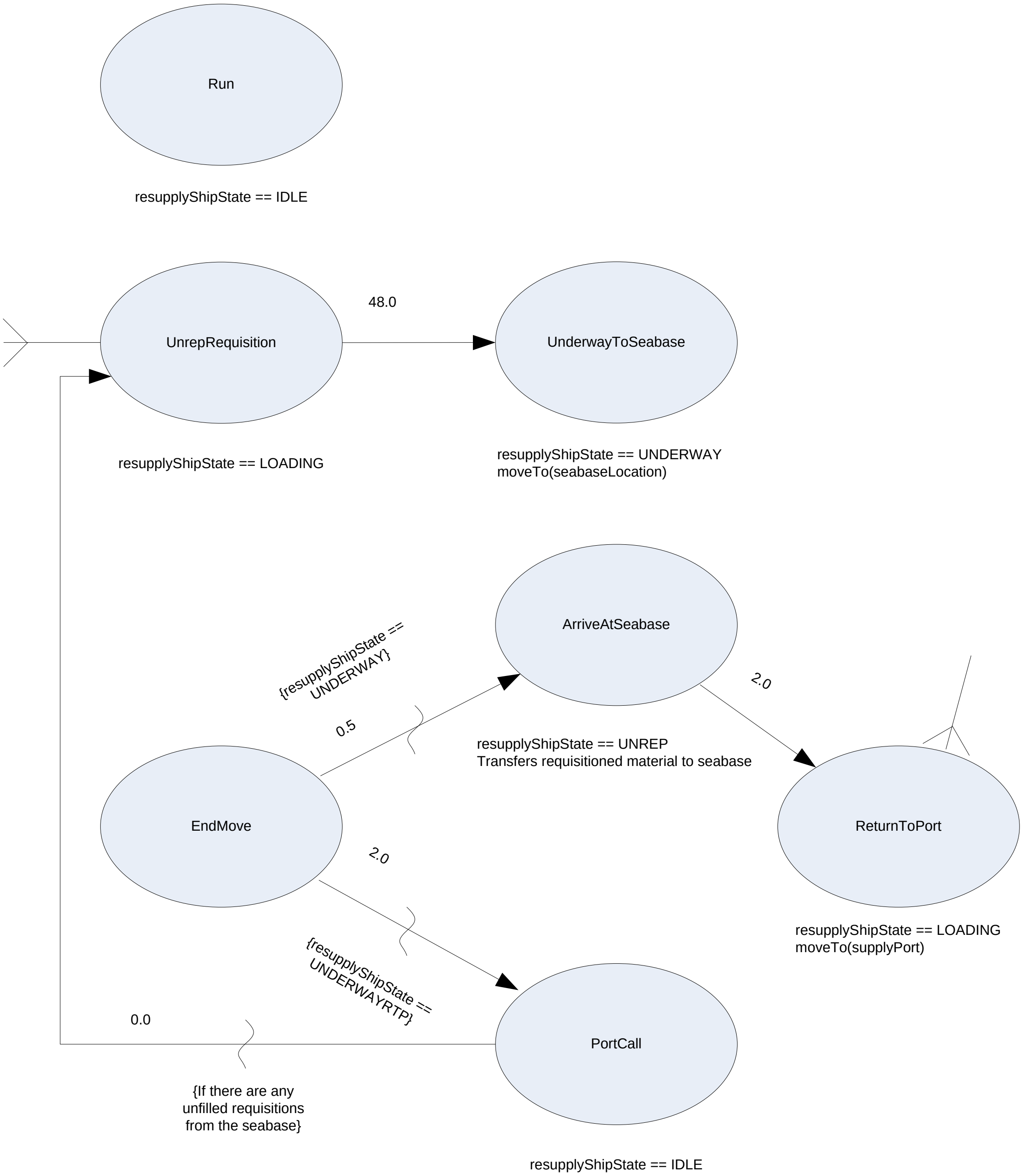

Figure 33. ResupplyShipMoverManager Event Graph

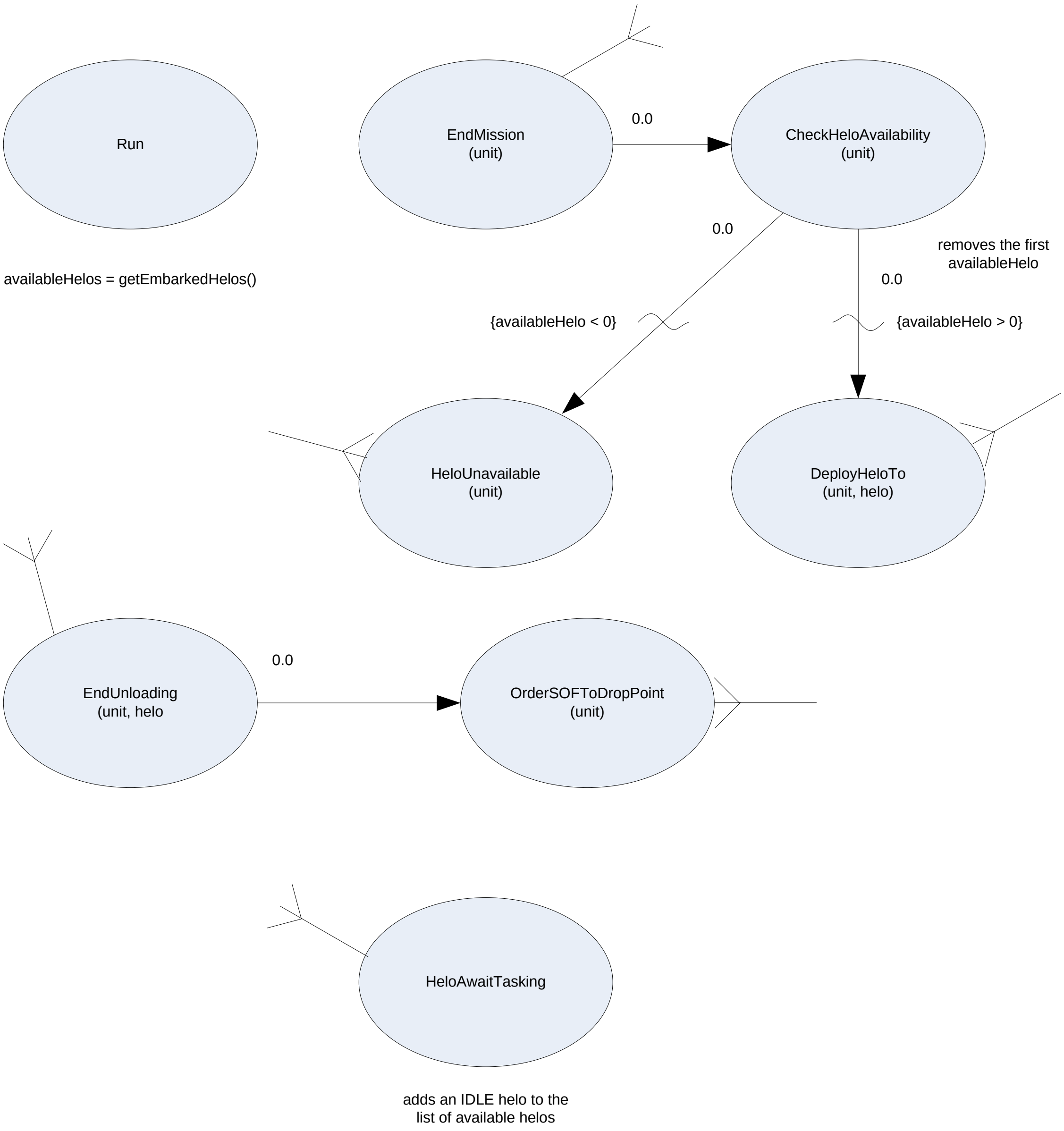

Figure 34. Commander Event Graph

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APPENDIX C – DATA ANALYSIS GRAPHS

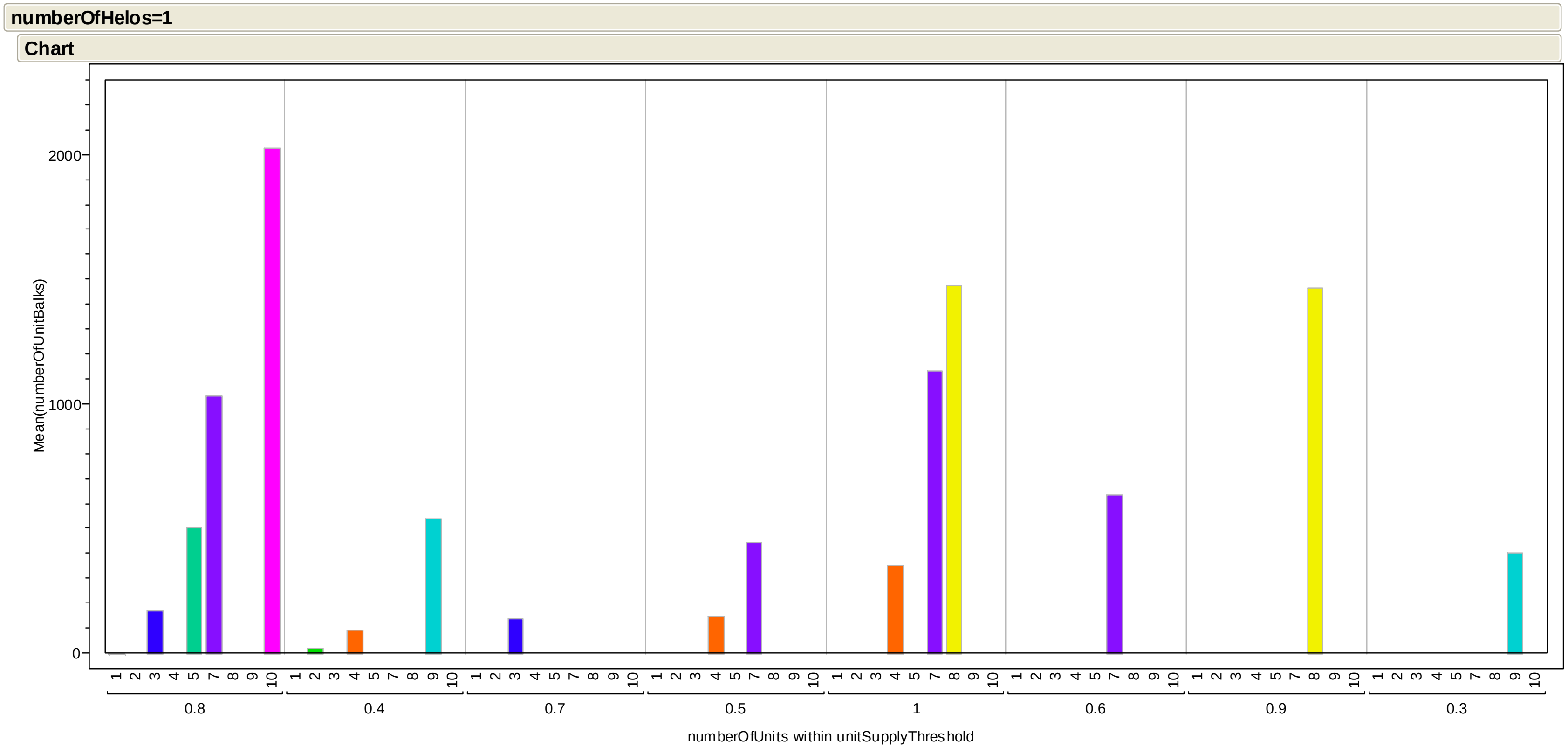

Figure 35. numberOfUnitBalks for numberOfHelicopter = 1 with numberOfUnits within unitSupplyThreshold

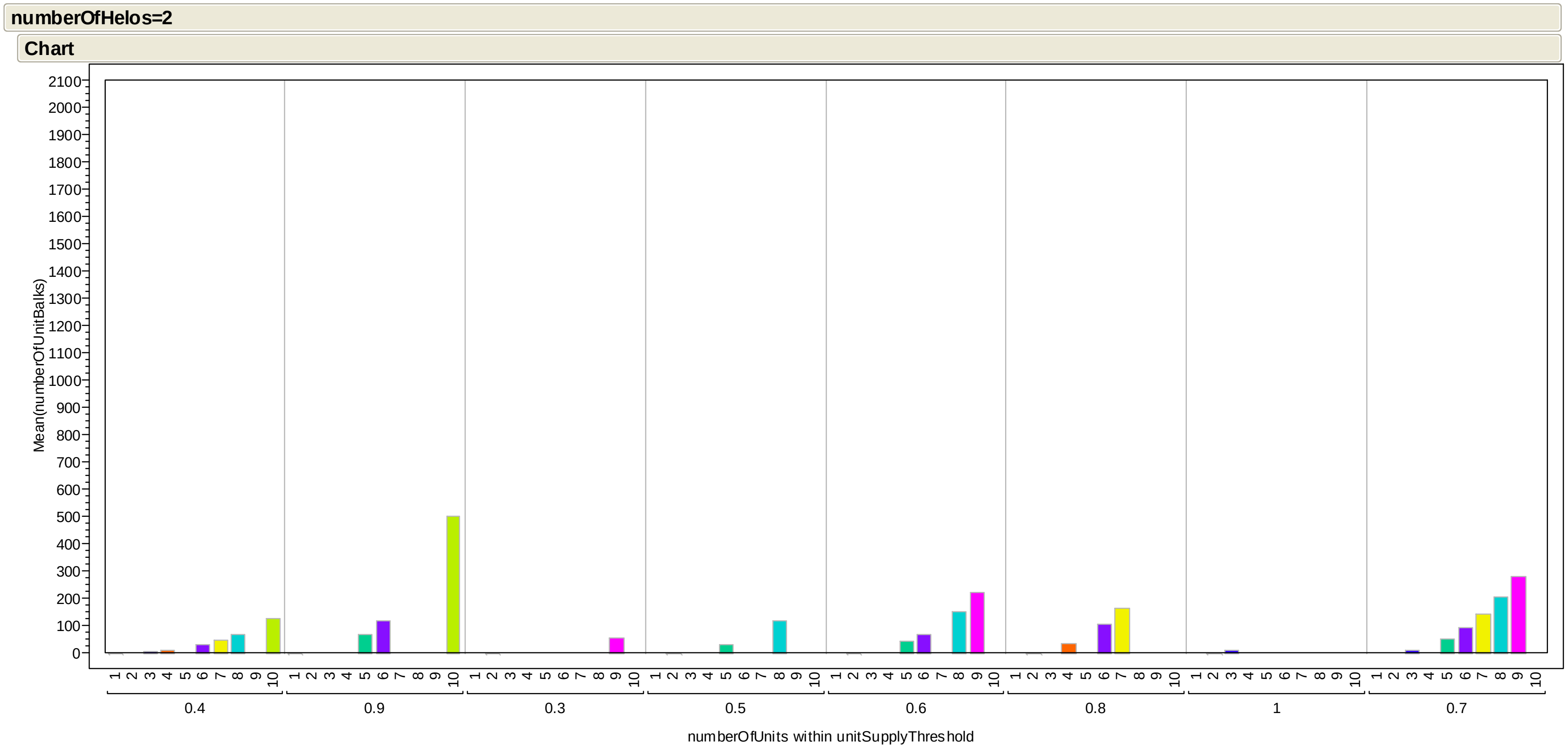

Figure 36. numberOfUnitBalks for numberOfHelicopter = 2 with numberOfUnits within unitSupplyThreshold

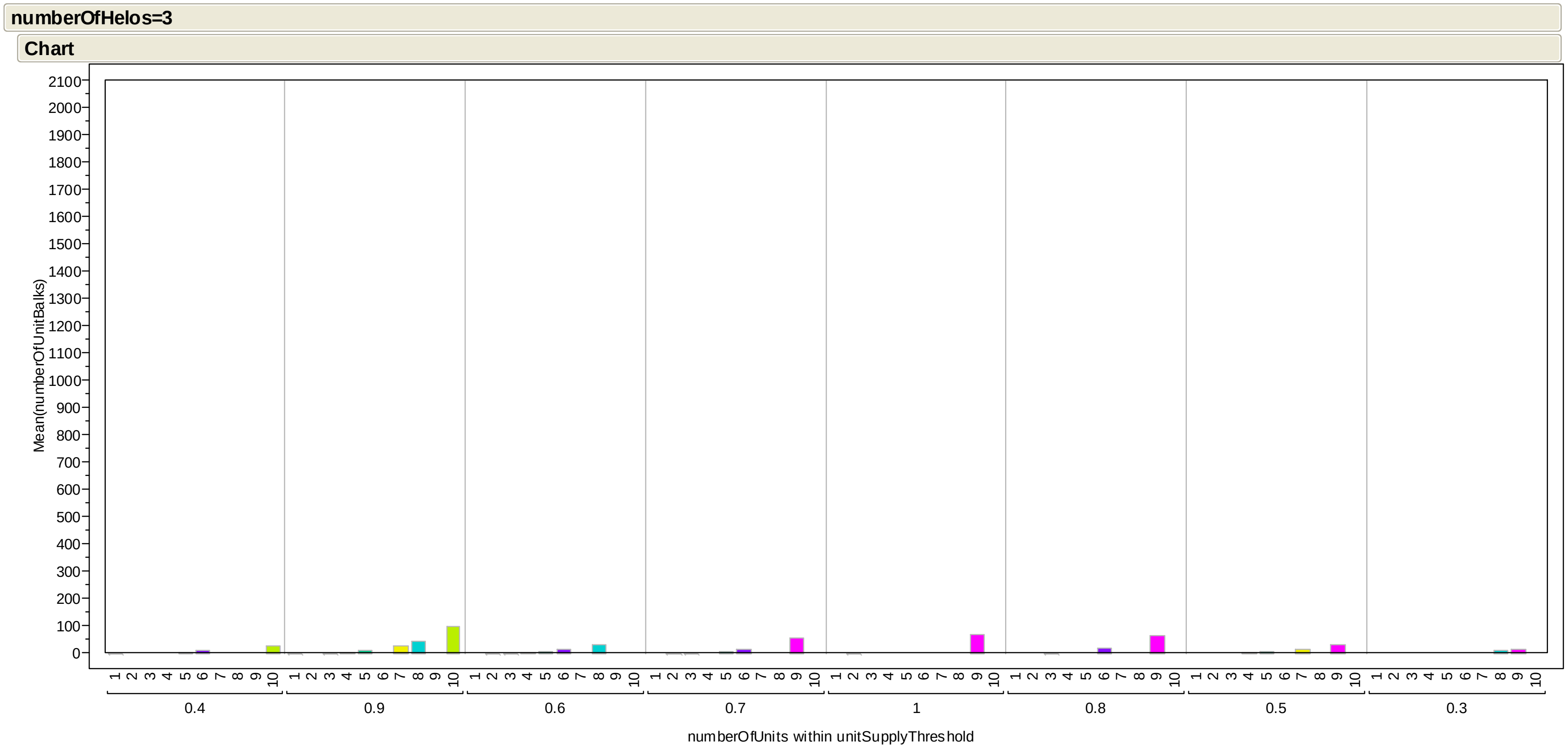

Figure 37. numberOfUnitBalks for numberOfHelicopter = 3 with numberOfUnits within unitSupplyThreshold

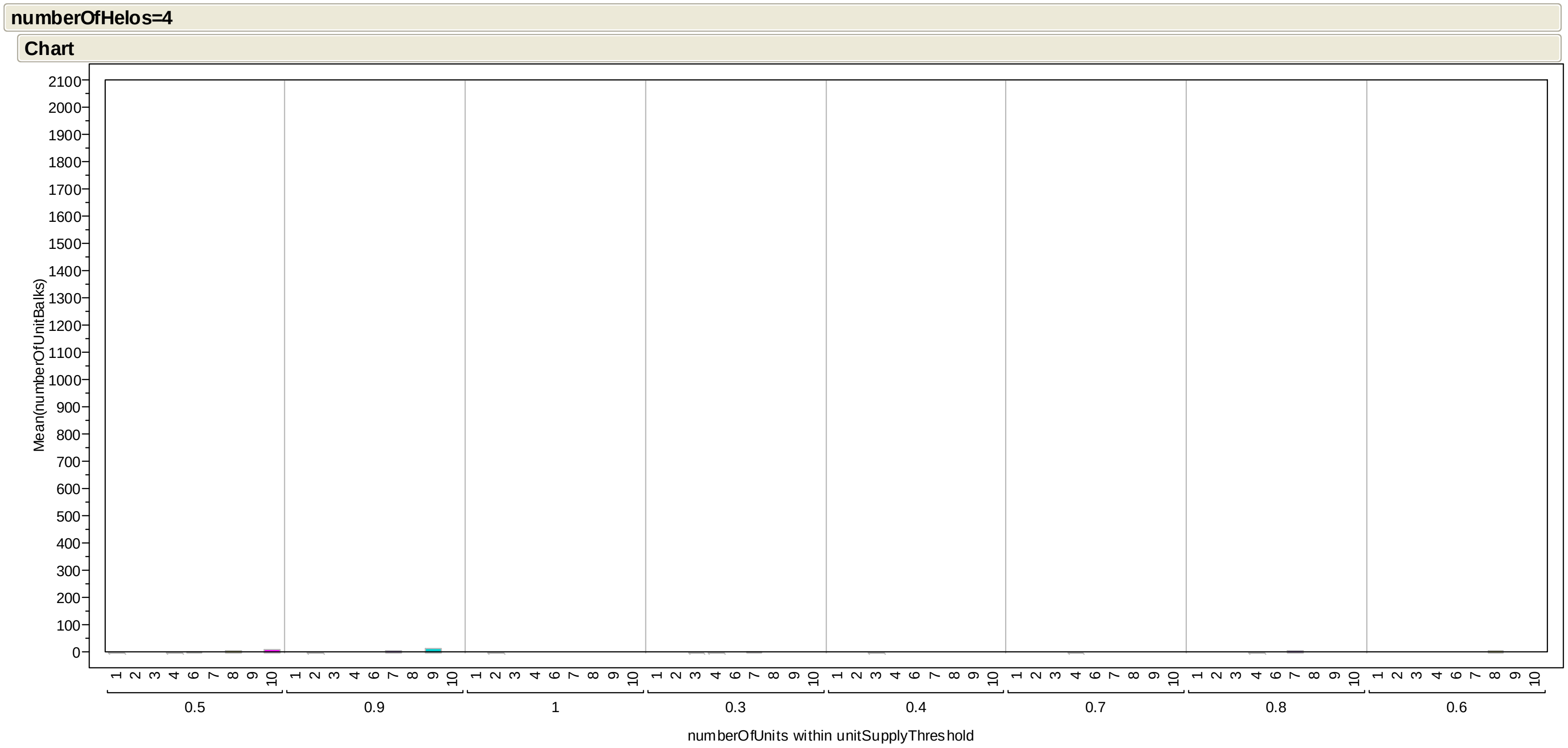

Figure 38. numberOfUnitBalks for numberOfHelicopter = 4 with numberOfUnits within unitSupplyThreshold

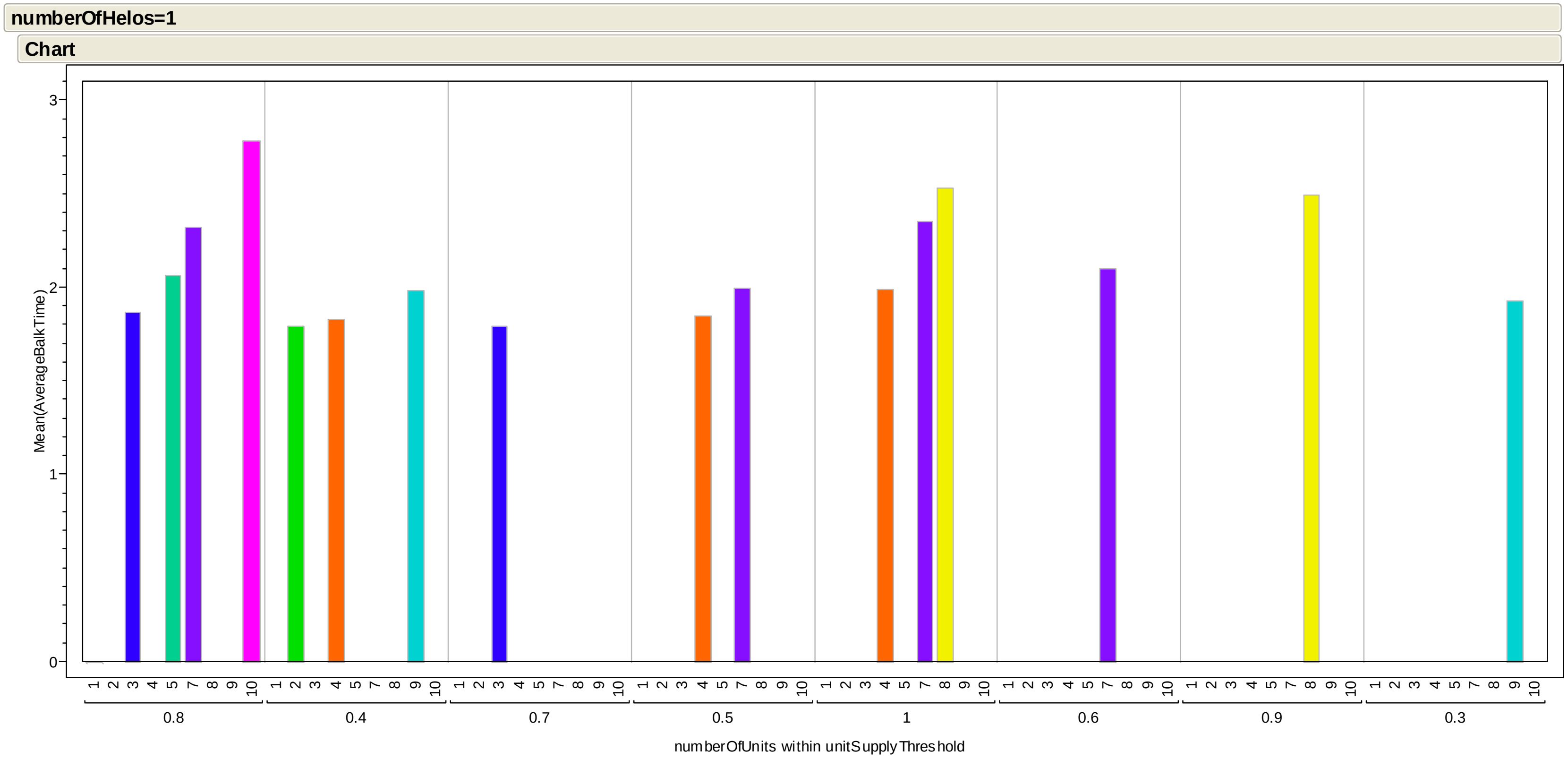

Figure 39. averageBalkTime for numberOfHelicopter = 1 with numberOfUnits within unitSupplyThreshold

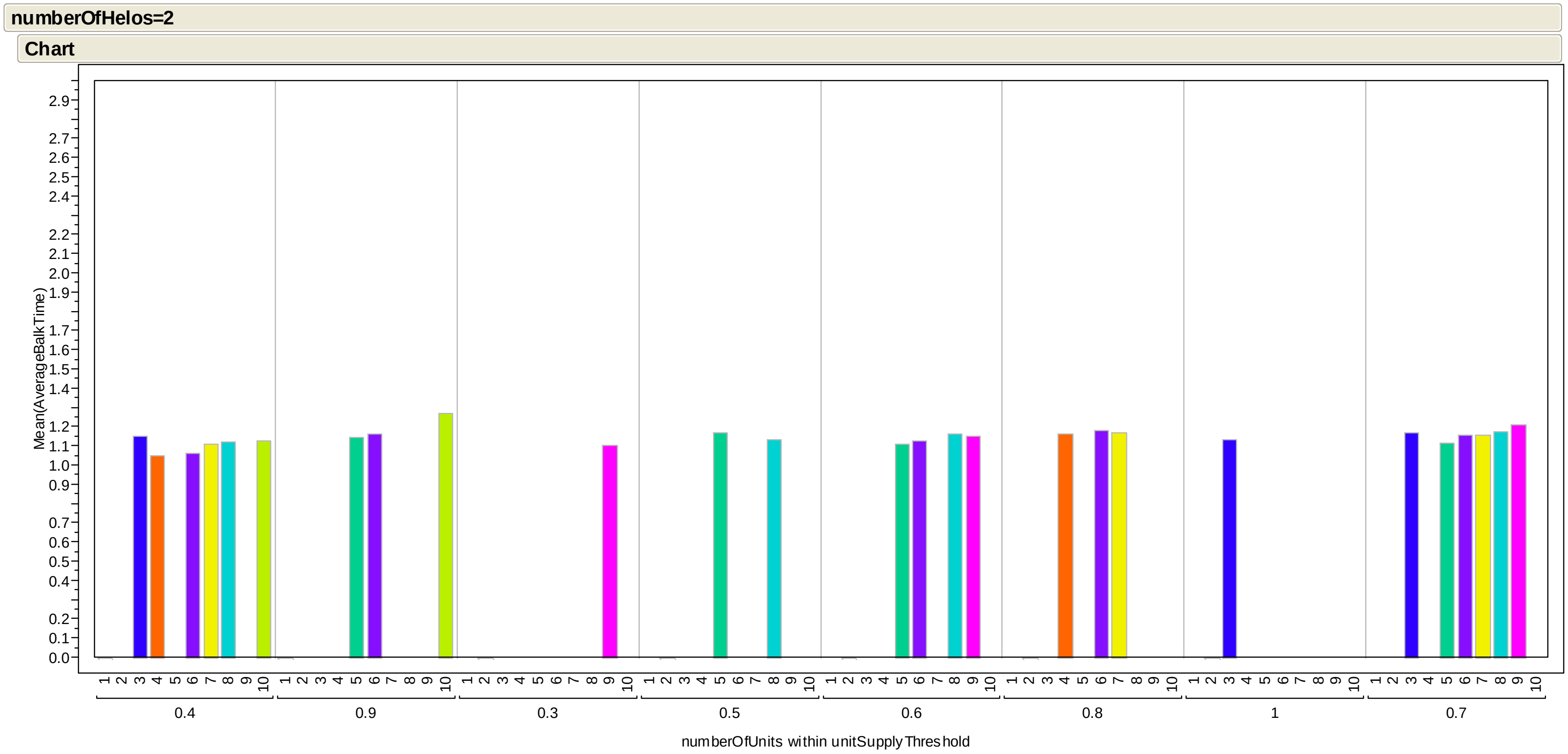

Figure 40. averageBalkTime for numberOfHelicopter = 2 with numberOfUnits within unitSupplyThreshold

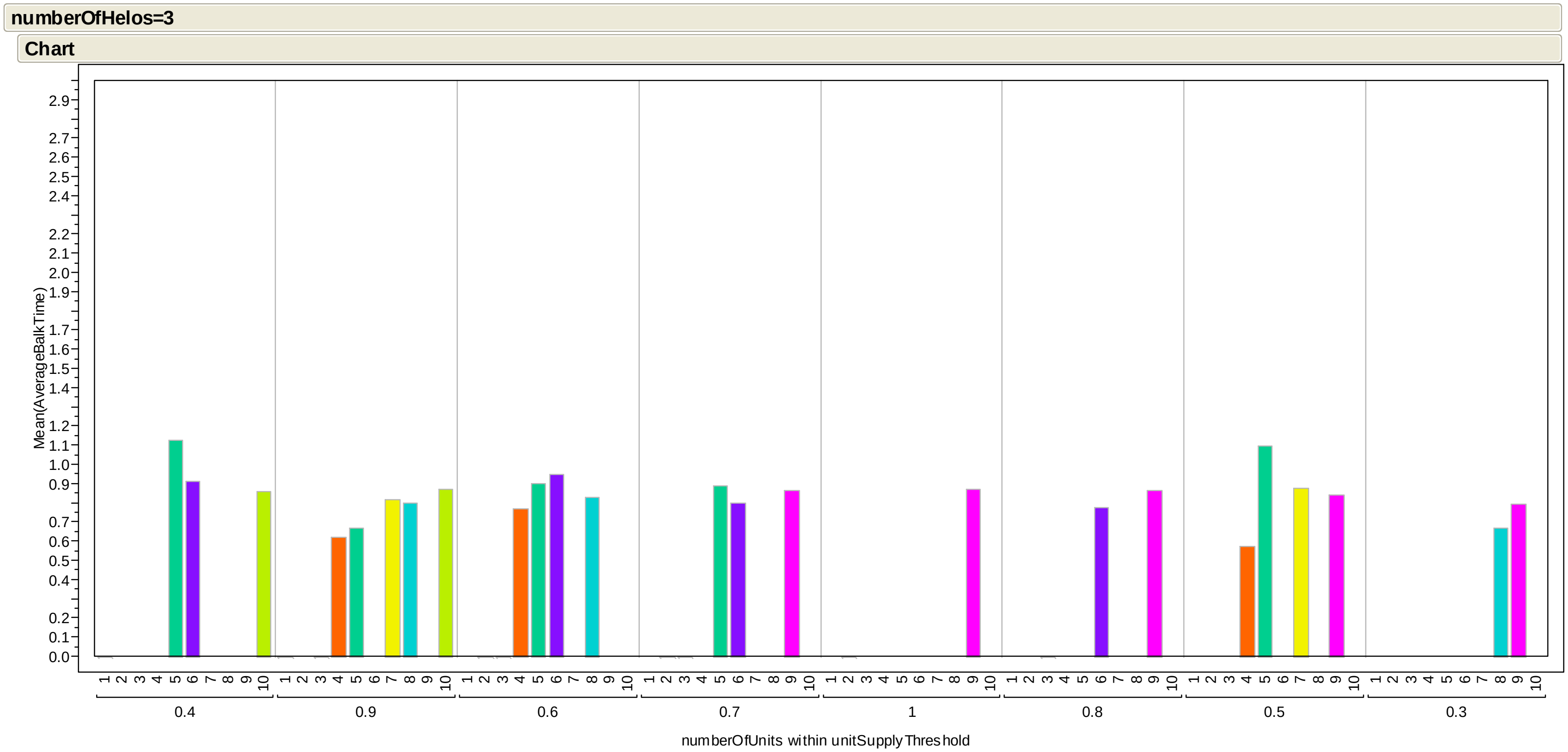

Figure 41. averageBalkTime for numberOfHelicopter = 3 with numberOfUnits within unitSupplyThreshold

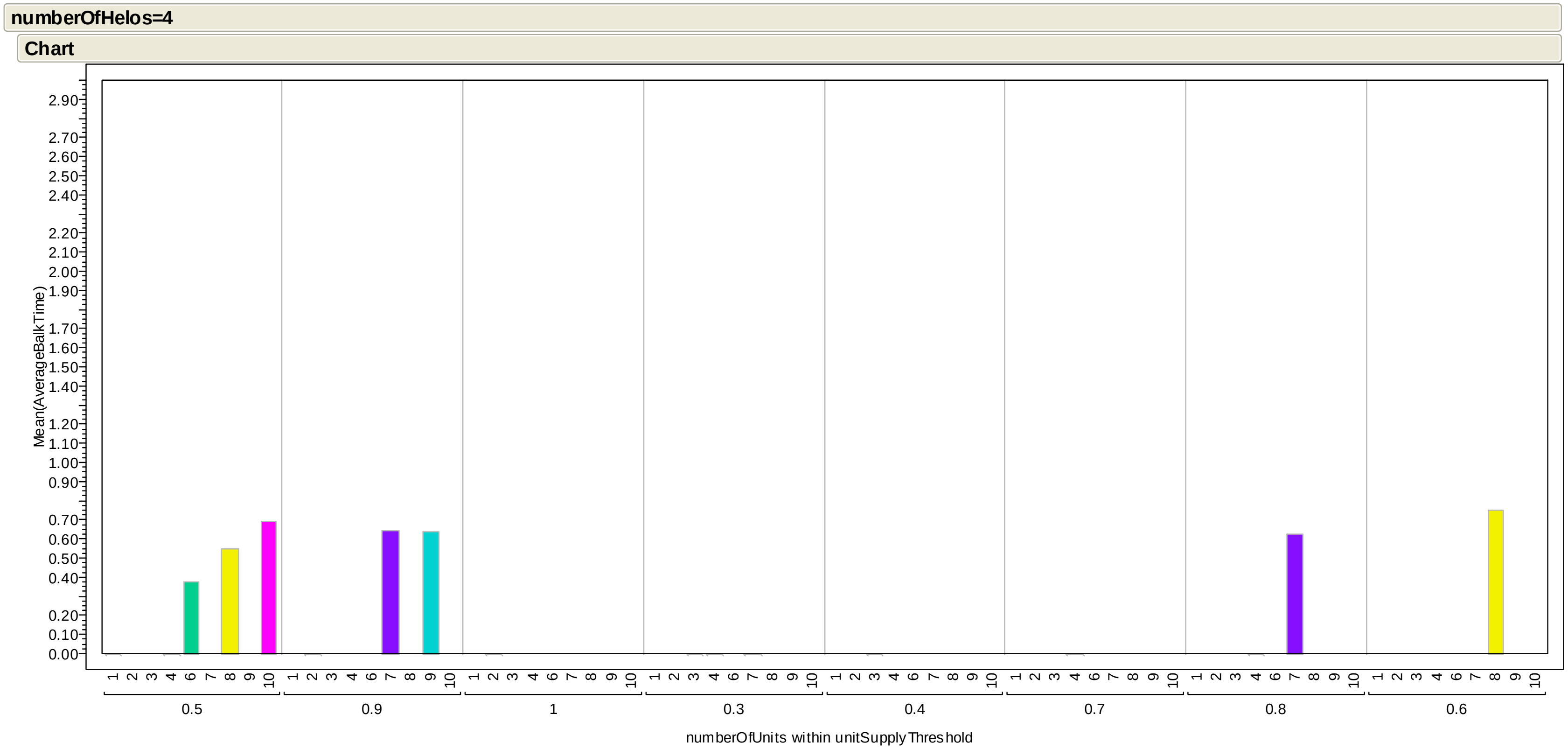

Figure 42. averageBalkTime for numberOfHelicopter = 4 with numberOfUnits within unitSupplyThreshold

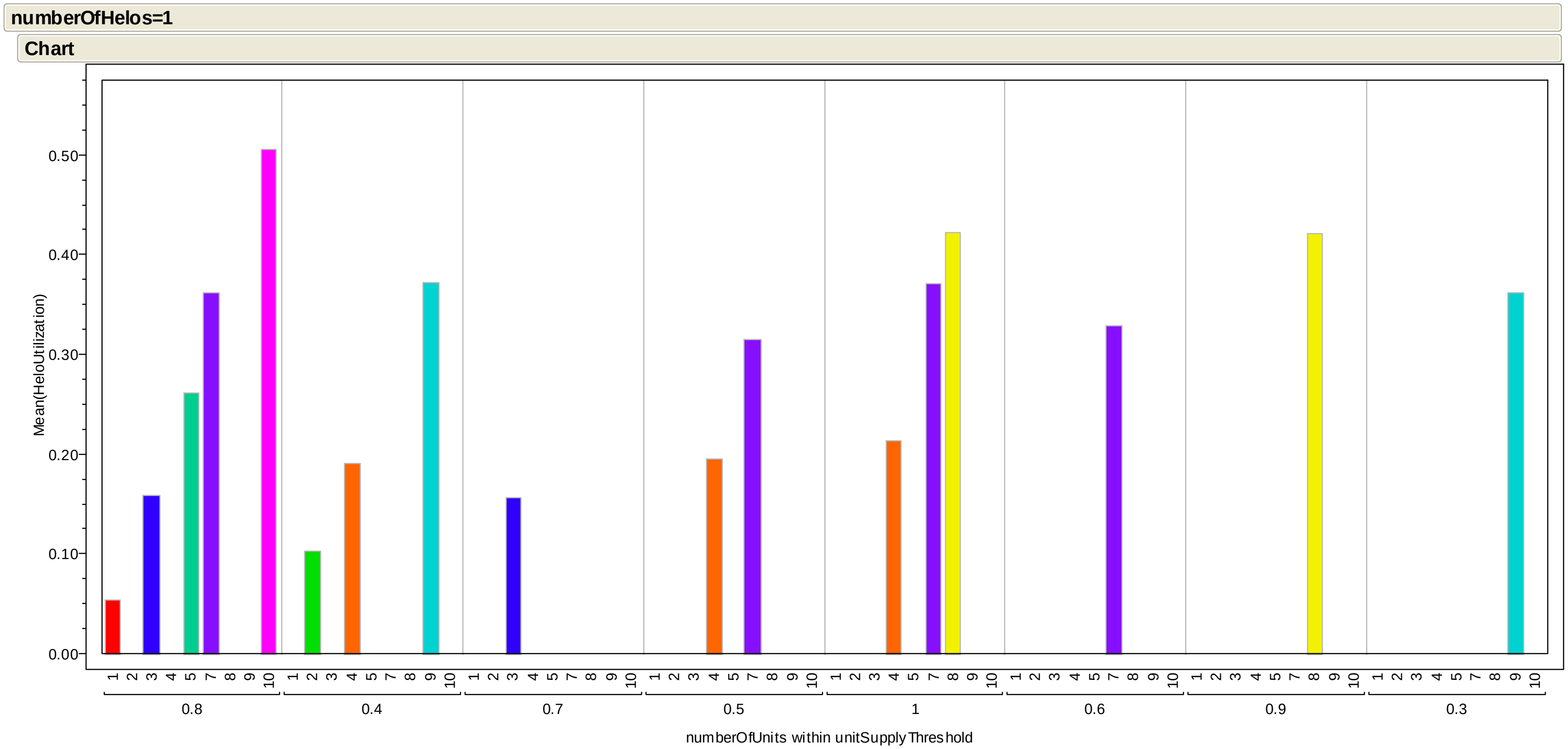

Figure 43. heloUtilization for numberOfHelicopter = 1 with numberOfUnits within unitSupplyThreshold

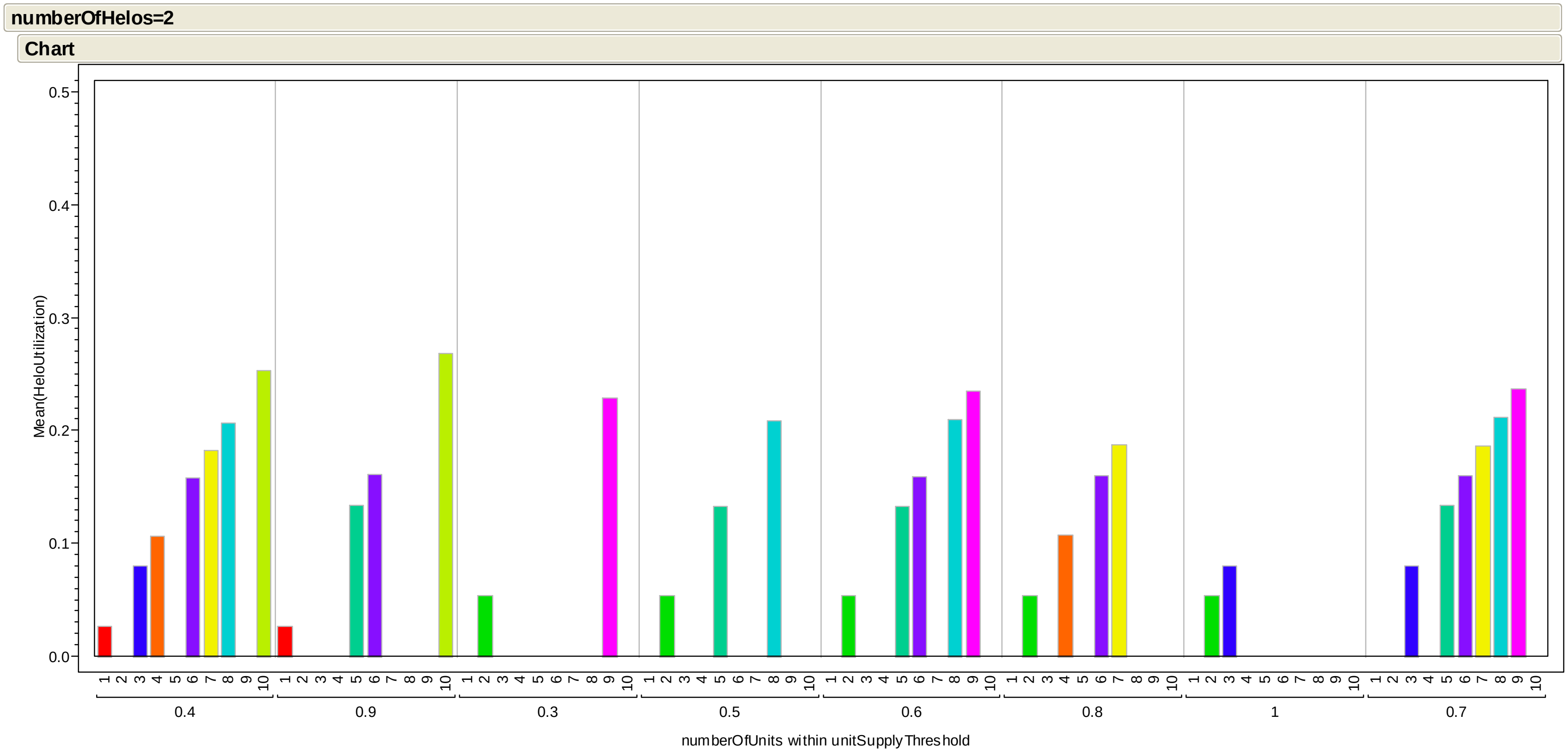

Figure 44. heloUtilization for numberOfHelicopter = 2 with numberOfUnits within unitSupplyThreshold

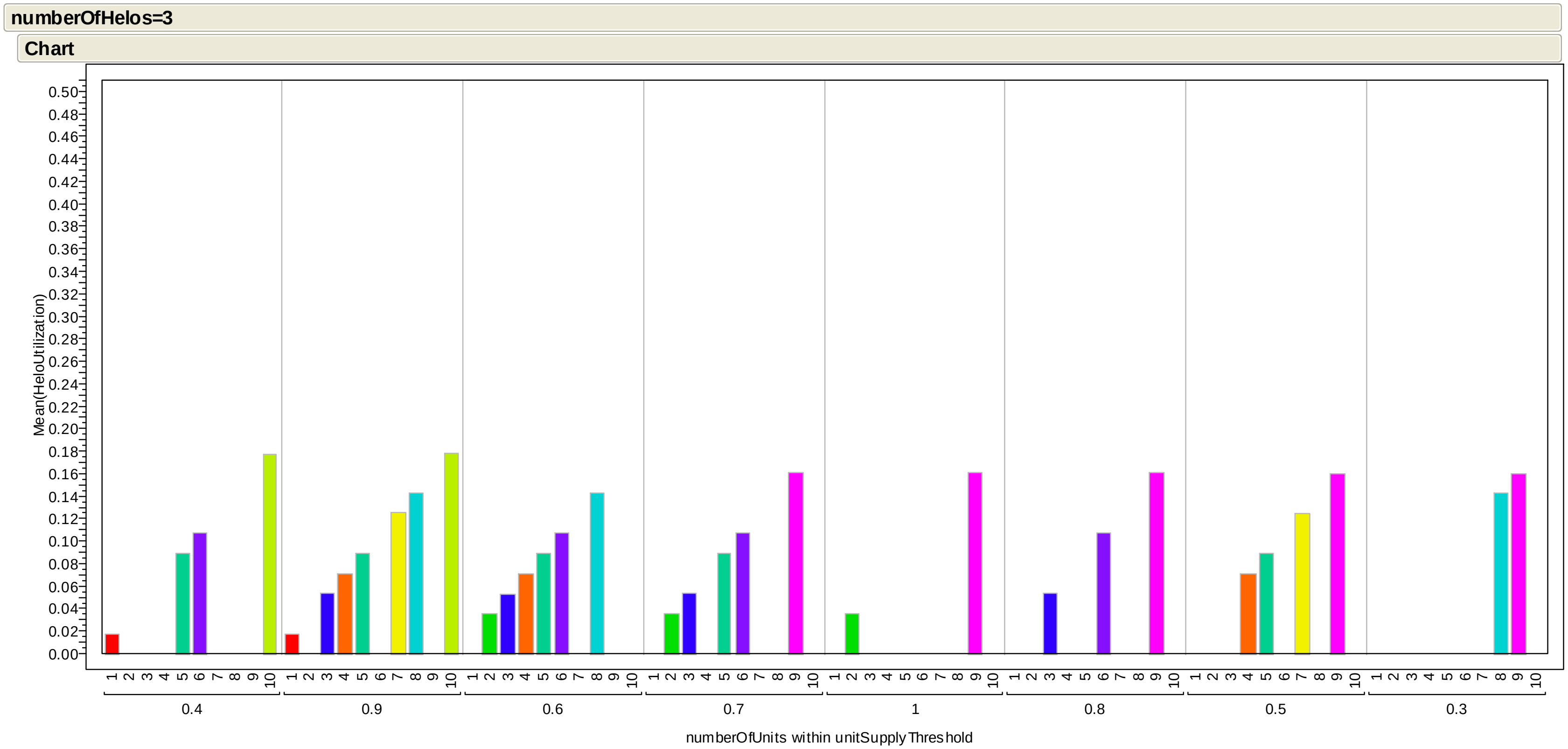

Figure 45. heloUtilization for numberOfHelicopter = 3 with numberOfUnits within unitSupplyThreshold

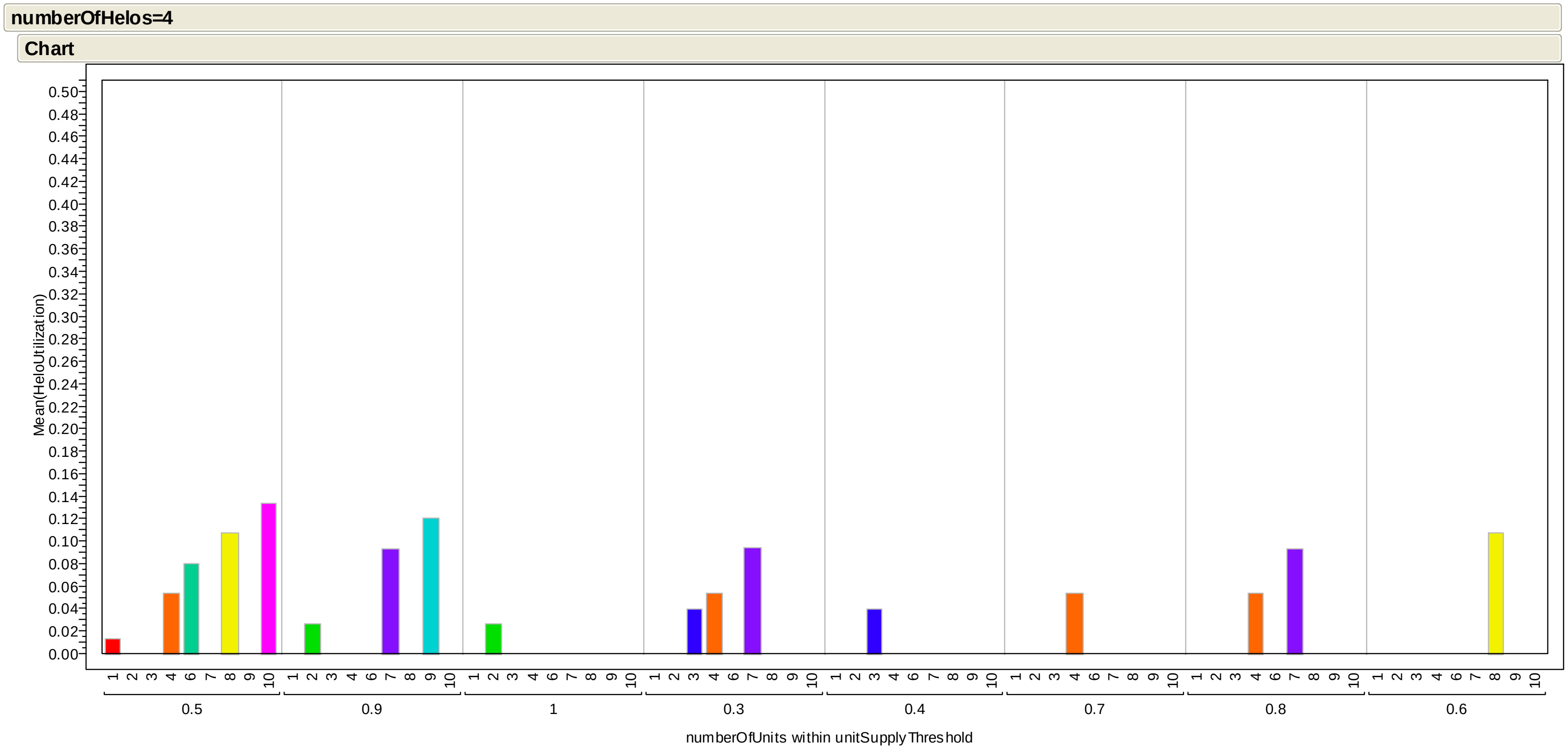

Figure 46. heloUtilization for numberOfHelicopter = with numberOfUnits within unitSupplyThreshold

APPENDIX D – SOF UNIT SUPPLIES AND WEIGHTS

Supply Type	Item	Quantity	Weight (lbs)
Ammunition	Full Magazines for M4A1 and M249 SAW	8 per person	8.4
	Frag and Smoke Grenades	8 per person	8
Equipment	AN/PRC 117F(C)	1 per unit	15.9(Harris Corp.)
	AN/PRC - 126	1 per person	3.125(Brooke Clark)
	Batteries	Equipment dependent per person	~ 3
	Computers(e.g., Navigational, ISR gear)	Mission dictates per person	~10
	M4A1 SOPMOD	1 per person (unless issued M249)	~ 7
	M249 SAW	1 per unit	15.16
	Protective Gear (e.g. Clothing, Helmet, Goggles)	1 per person	14.19 (Note: not included in carried weight)
	Body Armor	1 per person (mission dependent)	33
Medical	Personal Medkit	1 per person	1
	Field Medical Bag	1 per unit	~ 30
Subsistence	Meals Ready to Eat	8 per person	10.4
Water	Containered Water	8 quarts per person	16.66

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