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LEVERAGING THE LIGHT AMPHIBIOUS WARSHIP AS A MASS CASUALTY EVACUATION PLATFORM IN A CONTESTED ENVIRONMENT

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MONTEREY, CALIFORNIA

THESIS

LEVERAGING THE LIGHT AMPHIBIOUS WARSHIP AS A MASS CASUALTY EVACUATION PLATFORM IN A CONTESTED ENVIRONMENT

by

Codi A. Mullen

June 2022

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13. ABSTRACT (maximum 200 words)

The Marine Corps needs more accurate models and tools to examine the capabilities of evacuating mass casualties in a dispersed and disaggregated environment. Specifically, the Marine Corps needs to determine the types of platforms required to evacuate casualties for a distributed force as well as the accompanying concepts of operations. To assist in this, Massachusetts Institute of Technology Lincoln Laboratory is developing the Expeditionary Energy Multi-Domain Model (E2M2), which applies an agent-based simulation framework called Probabilistic Investigation of Resource Allocation in Networks of Hierarchical Agents (PIRANHA). The E2M2 evaluates the performance of the Light Amphibious Warship (LAW) used for casualty evacuations. This research utilizes high-dimensional experimental design to vary factors within an Expeditionary Advanced Based Operations scenario to explore varying hospital locations, number of LAWs, LAW configurations, and LAW transportation polices in evacuating mass casualties within the Indo-Pacific region. The E2M2 assists the Marine Corps in determining how LAW is best used as a viable casualty evacuation platform for a distributed force. This research identifies the best-fitting models, methods, and tools that can be used to support analysis in this area. It also includes a demonstration of the E2M2 in support of a scenario and documentation that identifies challenges and opportunities in using the E2M2 in support of concept development activities.

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The Marine Corps needs more accurate models and tools to examine the capabilities of evacuating mass casualties in a dispersed and disaggregated environment. Specifically, the Marine Corps needs to determine the types of platforms required to evacuate casualties for a distributed force as well as the accompanying concepts of operations. To assist in this, Massachusetts Institute of Technology Lincoln Laboratory is developing the Expeditionary Energy Multi-Domain Model (E2M2), which applies an agent-based simulation framework called Probabilistic Investigation of Resource Allocation in Networks of Hierarchical Agents (PIRANHA). The E2M2 evaluates the performance of the Light Amphibious Warship (LAW) used for casualty evacuations. This research utilizes high-dimensional experimental design to vary factors within an Expeditionary Advanced Based Operations scenario to explore varying hospital locations, number of LAWs, LAW configurations, and LAW transportation polices in evacuating mass casualties within the Indo-Pacific region. The E2M2 assists the Marine Corps in determining how LAW is best used as a viable casualty evacuation platform for a distributed force. This research identifies the best-fitting models, methods, and tools that can be used to support analysis in this area. It also includes a demonstration of the E2M2 in support of a scenario and documentation that identifies challenges and opportunities in using the E2M2 in support of concept development activities.

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LIST OF ACRONYMS AND ABBREVIATIONS

ARG	Amphibious Readiness Group
ASM	Anti-Ship Missiles
BAS	Battalion Aid Station
C4ISR	Command, Control, Communications, Computers, Intelligence, Surveillance, and Reconnaissance
CASEVAC	Casualty Evacuation
CD&I	Combat Development and Integration
CE	Command Element
CMC	Commandant of the Marine Corps
CPG	Commandant's Planning Guidance
CREsT	Casualty Rate Estimation Tool
DIS	Disease
DMO	Distributed Maritime Operations
DOD	Department of Defense
DON	Department of the Navy
DOW	Died of Wounds
E2M2	Expeditionary Energy Multi-Domain Model
E2O	Expeditionary Energy Officer
EAB	Expeditionary Advanced Base
EABO	Expeditionary Advanced Based Operations
EMEDS	Expeditionary MEDical Support
EMF	Expeditionary Medical Facilities
EMRE	Expeditionary Medical Requirements Estimator
EPF	Expeditionary Fast Transport
ERC	Enroute Care
FOB	Forward Operating Base
FRC	Forward Resuscitative Care
FRSS	Forward Resuscitative Surgical System
HNS	Host-Nation Support
HQ	Headquarters

HQMC	Headquarters Marine Corps
HSS	Health Service Support
INDOPACOM	Indo-Pacific Command
ISO	International Organization for Standardization
ISS	Injury Severity Score
JCS	Joint Chiefs of Staff
JMPT	Joint Medical Planning Tool
JP	Joint Publication
KIA	Killed In Action
LAAB	Littoral Anti-Air Battalion
LAW	Light Amphibious Warship
LCAC	Landing Crafty Utility Cushion
LCM	Landing Craft, Medium
LCT	Littoral Combat Team
LCU	Landing Craft Utility
LHA	Landing Helicopter Assault
LHD	Landing Helicopter Dock
LLB	Littoral Logistics Battalion
LOCE	Littoral Operations in a Contested Environment
LPD	Landing Platform Dock
LRUSV	Long Range Unmanned Surface Vessels
LSD	Dock Landing Ship
LST	Landing Ship Tank
LSV	Logistics Support Vessel
MAGTF	Marine Air Ground Task Force
MCWP	Marine Corps Warfighting Publication
MEB	Marine Expeditionary Brigade
MEDEVAC	Medical Evacuation
MEF	Marine Expeditionary Force
MEU	Marine Expeditionary Unit
MEU	Marine Expeditionary Unit
MITLL	Massachusetts Institute of Technology Lincoln Lab

MLR	Marine Littoral Regiment
MPTk	Medical Planners' Toolkit
MTF	Medical Treatment Facility
NBI	Non-Battle Injury
NSS	National Security Strategy
ONR	Office of Naval Research
OP	Operations Plan
OPNAV N4	Deputy Chief of Naval Operations for Fleet Readiness & Logistics
PFCOF	Patient Condition Occurrence Frequency
PIRANHA	Probabilistic Investigation of Resource Allocation in Networks of Hierarchical Agents
POI	Point of Injury
R/XR	Reconnaissance/Counter Reconnaissance
RTD	Return to Duty
SAM	Surface-to-Air Missile
SC	Surgical Companies
SIF	Stand-In Force
STP	Shock Trauma Platoon
TTP	Tactics, Techniques, and Procedures
UAS	Unmanned Aircraft Systems
WEZ	Weapon Engagement Zone
WIA	Wounded In Action
WWII	World War II

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EXECUTIVE SUMMARY

The United States has shifted its focus to the Indo-Pacific region, with China being designated as its pacing threat (Headquarters Marine Corps [HQMC] 2020). This shift in focus has led the Navy and Marine Corps to reevaluate how they operate in a distributed and complex fight against near peer threats as an integrated expeditionary naval force (HQMC 2020). Specifically, this distributed and disaggregated environment proposes unique challenges to how the Marine Corps evacuates mass casualties from austere locations. Air casualty evacuation, the primary means of casualty evacuations during the Iraq and Afghanistan Wars, made it possible for casualties to be evacuated to damage control resuscitation within one hour from the point of injury, known as the "golden hour." The "golden hour" became the standard of care for U.S. Service persons in Iraq and Afghanistan, however it may not be feasible in the shift to the Pacific. Enemy long range precision missiles pose significant threats to air assets when operating inside the weapon engagement zones. Additionally, having Marine forces dispersed in hard-to-reach locations, as well as the Marine Corps' lack of dedicated medical evacuation platforms, limits air's supportability to conduct a mass casualty evacuation (CASEVAC) in addition to supporting other demanding missions.

Surface CASEVAC, and in particular, the use of smaller, more lethal and more risk-worthy surface platforms, such as the Light Amphibious Warship (LAW), offers an alternative means than air CASEVAC (DON 2021a). Additionally, the placement of limited medical care facilitates and capabilities forward and during transit is vital to sustaining casualties past the "golden hour" requirement. This alternative method may provide the Marine Corps with the ability to evacuate mass casualties, while also sustaining the forces forward. Thus, this thesis is guided by two questions:

- How do maritime forces utilize the LAW to best address mass casualties during conflict in a contested environment?
- How does the CASEVAC mission affect the LAW's ability to conduct sustainment operations?

This thesis uses an agent-based simulation, developed by Massachusetts Institute of Technology, called the Expeditionary Energy Multi-Domain Model (E2M2). The E2M2 provides quantifiable data on the effects of factors (i.e., input variables) in the successful completion of the LAW conducting CASEVAC and ammunition resupply missions. The measures of effectiveness are (1) the total accumulated fatality risk, which is the average number of fatalities at the completion of the 60-day scenario, and (2) the delivery time to resupply six fire teams from a Marine Littoral Regiment with surface-to-air missile (SAM) pallets and anti-ship missile (ASM) pods. The factors explored include LAW transportation policies, number of LAWs, LAW capacity configurations, and hospital locations.

The scenario expands upon the E2M2's sustainment scenario as a baseline for the LAW CASEVAC portion. In the simulation, there are six fire teams located at Moon Island, a fictional island representing the characteristics of a potential expeditionary advanced base in the scenario explored (see Figure ES1). During the simulation, a mass casualty event injects 100 casualties (25% urgent, 25% priority, and 50% routine) at Moon Island. Casualty tracking starts at the forward resuscitative surgical system located in vicinity of a beach on Moon Island. A designated Loitering Point is the assigned supply point where the LAW picks up ammunition from surface connectors patrolling within that zone.

The E2M2 is a farmable model that provides flexibility to capture the key factors that influence the LAW's ability to conduct sustainment operations and CASEVAC missions. The E2M2 is capable of adding in additional technologies and casualty injects to simulate realistic scenarios that the Navy and Marine Corps may face in a distributed and contested environment. As a fast-running model, E2M2 explores the design space through thousands of simulated CASEVAC missions. Data farming enables the assessment of a large set of possible scenarios.

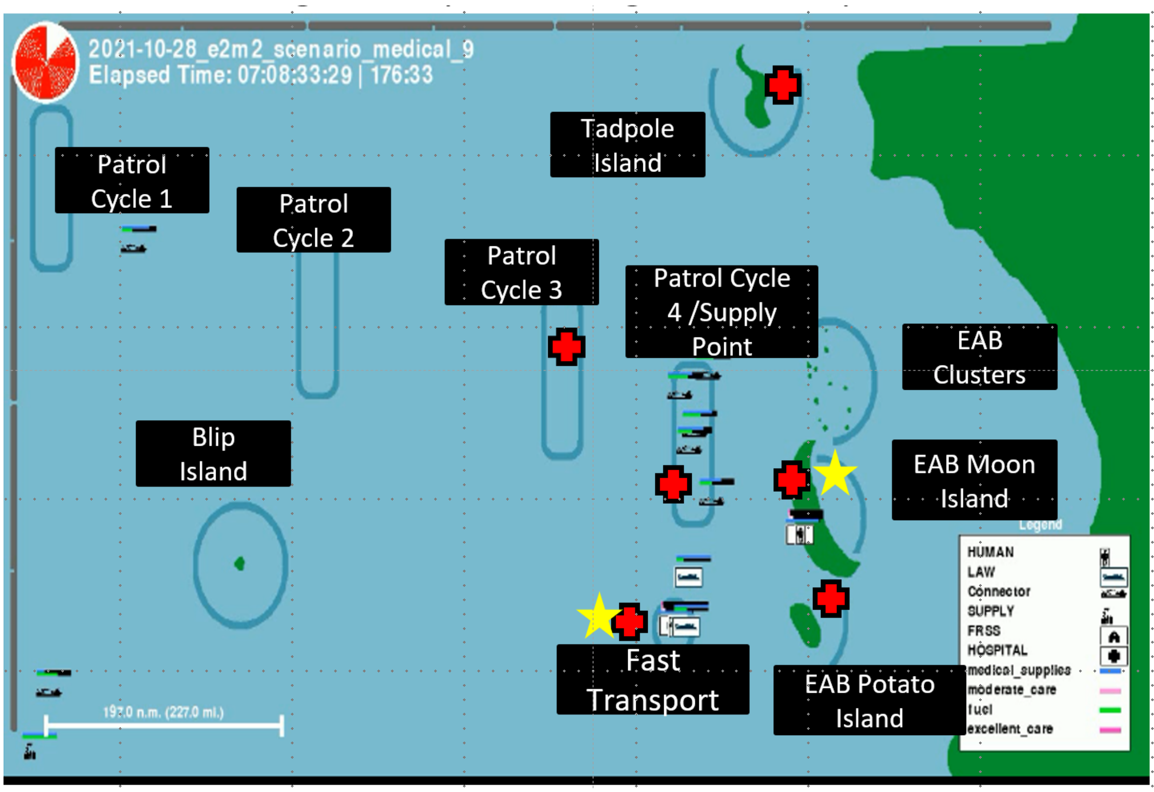

Figure ES1. Map of the scenario used in E2M2 explorations. The map is a fictional location with distances and geographic constraints similar to potential real-world deployments.

The conclusions are based on an exhaustive quantitative analysis of the E2M2 simulation results. The number of LAWs is the most influential factor. When the number of LAWs is small, the LAW configuration, LAW capacities, and the location of hospital facilities matter. Although having five LAWs is the best scenario, having at least three LAWs is recommended. The best policy for the three LAWs is to evacuate patients first, while opportunistically resupplying the six fire teams, with the LAWs' current supply of ammunition on-board at the start of the scenario. With three LAWs, each LAW should carry 20 patients, with first responder-level care, and 20 SAM pallets on the deck to evacuate casualties to the choice of three different hospital facility locations (Fast Transport, Potato Beach, or Loitering Point 4). With this allocation of assets, the LAW minimizes the number of fatalities and resupply delivery times during the conduct of both evacuation and sustainment missions.

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I. INTRODUCTION

Military operations are progressively transitioning to a more distributed and complex fight against near peer threats (Headquarters Marine Corps [HQMC] 2020). The United States has specifically shifted its focus to China in the Indo-Pacific region (Department of the Navy [DON] 2021). China's aggressive need for expansion economically, technologically, politically, and militarily proposes significant challenges to the United States and its allies, as China wants to force the United States outside of this region (DON 2021b). The U.S. Navy and Marine Corps have taken this emerging threat as an opportunity to create a lethal, integrated force able to operate discretely in a distributed and dispersed environment, such as the first island chain (DON 2021b). One problem when operating in and around the first island chain is the U.S. Navy and Marine Corps' ability to conduct logistics. Specifically, this dispersed and disaggregate environment for which U.S. forces must operate within, limits the availability of and access to dedicated medical evacuation (MEDEVAC) assets and forward Role II care to its forces throughout the area of operations (Moten, Teff, Pyle, Delk, and Clark 2019). Therefore, the U.S. Navy and Marine Corps must examine how casualties are evacuated through the medical network in a distributed maritime environment.

Over the past few decades, air transport has been the primary means of casualty evacuations (CASEVAC). The utilization of air transport provides quick and efficient transportation of casualties to the next role of care. As the military transitions to Distributed Maritime Operations (DMO), however, air transport may be restricted in its ability to operate within austere locations. Additionally, mass casualty scenarios, which may consist of hundreds of casualties, require additional means of evacuating these higher numbers of casualties out of a contested environment. One solution to looking at alternative means of evacuating casualties is the use of amphibious surface vessels, such as the Light Amphibious Warship (LAW), as CASEVAC platforms (O'Rourke 2022). Therefore, this analysis will simulate a surface CASEVAC scenario using the Expeditionary Energy Multi-Domain Model (E2M2). This simulation will aid in the analysis of the LAW and its ability to sustain forces forward, while also evacuating casualties out to the next role of care, ultimately informing the concept of operation and employment of the LAW.

A. MOTIVATION

During amphibious operations, the most difficult aspect of a logistic planner's job is sustaining a distributed force with the necessary supplies to maintain momentum of the forward operating units. There are six functions of logistics, and health service support represents one of these six functions (DON 2018). Logistics planners must work closely with medical planners to provide the necessary care and transportation, efficiently and effectively throughout the area of operations. This coordination is especially vital since the Marine Corps currently does not have a dedicated MEDEVAC platform.

The 2019 Marine Corps' Commandant's Planning Guidance (CPG) lays out significant changes to what the future fight looks like for the Marine Corps and how it will shape the structure of its forces to operate in a DMO environment (Berger 2019). Numerous problems arise in the Marine Corps' future fight. Because the Marine Corps has gotten away from its naval roots over the past 20-plus years, Navy's current surface platforms lack the ability to support and sustain smaller, dispersed, and more discrete Marine Corps forces operating in a contested environment, as laid out in the CPG (Berger 2019). Secondly, in a DMO environment, air transport will become very limited in its ability to support all Navy and Marine Corps forces within the area of operations, especially when air superiority has not been achieved. Lastly, with the lack of mobility and flexibility in current surface platforms, and the issue of having limited to no air transport available, the once requirement of evacuating casualties within one hour from point of injury (POI), otherwise known as the 'golden hour', becomes infeasible in this type of environment. Therefore, this study is motivated by necessary changes to the Marine Corps' future fight and force structure to address the following question: How does the Navy and Marine Corps effectively and efficiently evacuate casualties in an area like the first island chain when it lacks alternative evacuation platforms and medical capabilities to do so?

B. BACKGROUND

The Marine Corps has developed several new concepts based on the CPG to define its future fight against a near peer threat. These concepts consist of, but are not limited to, Littoral Operations in a Contested Environment (LOCE) (HQMC 2017), Force Design 2030 (HQMC 2020), Expeditionary Advanced Base Operations (EABO) (DON 2021b), Stand-In Forces (SIF) (DON 2021a), and Maritime Reconnaissance/Counter-reconnaissance Missions (R/XR) (Combat Development & Integration 2022). Thus, this study is based off these emerging concepts.

Navy and Marine Corps historical examples have shown, and are further explained in Chapter III, that the delivery of supplies, while being able to evacuate casualties off the battlefield, is vital during military operations. The LAW is a future investment for the Navy and Marine Corps to act as a multi-mission platform able to conduct the EABO concept and sustain Marine Littoral Regiments (MLRs) (O'Rourke R 2021). Thus, the LAW is the platform of choice to be the forward operating transportation asset. In this scenario, the LAW will be transporting supplies, as well as evacuating casualties within what is called the weapon engagement zone (WEZ). Additionally, the Navy is also investing in the expeditionary fast transport (EPF Flight II), which provides the fleet a platform with fast access to forward resuscitative care capabilities, and a limited Intensive Care Unit and medical wards (News 2022). The EPF Flight II can augment the LAW in the CASEVAC network.

In the previous wars in Iraq and Afghanistan, the placement of damage resuscitative care more forward increased the survivability of casualties (Moten et al. 2019). Therefore, in this study, each expeditionary advanced base (EAB) has a forward resuscitative surgical system (FRSS) capable of conducting Role I/limited Role II care at a casualty collection point on a designated beach on the EAB.

C. RESEARCH QUESTION

With the changes to the Navy and Marine Corps' future fight, the Navy and Marine Corps must evaluate the use of new technologies capable of sustaining the force, while also acting as a CASEVAC platform. Our analysis focuses on how a mass casualty scenario affects sustainment operations conducted by the LAW, as well as the affects delays may have on the casualties being evacuated. The following questions are addressed:

- How can maritime forces utilize the LAW to best address mass casualties during conflict in a contested environment?
- How does the CASEVAC mission affect the LAW's ability to conduct sustainment operations?

D. APPROACH

This research is the first study utilizing the Expeditionary Multi-domain Model, developed by the Massachusetts Institute of Technology Lincoln Lab (MITLL). Dr. Robert Seater and his team at MITLL are developing the E2M2 to improve upon current analysis tools for Marine Corps Logistics. MITLL has worked closely with the Marine Corps Expeditionary Energy Office (E2O), Marine Corps Systems Command, and the Office of Naval Research (ONR) to simulate active questions these organizations have regarding logistics (Seater 2021).

This study utilizes an existing sustainment scenario template created for the E2M2 as the basis of our modeling approach (Seater 2022). The sustainment template prescribes a set of roles, how they interact, and how broad map zones change their behavior (Seater 2022). Nodes within the map zones are referenced by policies to represent demand locations that require a certain amount of each commodity as well as evacuation drop off and pick up points (Seater 2022). In this study, all supply types are picked up from designated supply points by LAWs and pushed ashore. Casualties originate from an EAB.

This research includes simulation and data farming (Horne and Meyer 2010) to gain insight into the performance of surface assets acting as multi-mission platforms that can sustain the force and evacuate casualties. The model outputs curves that show the effectiveness in conducting prompt resupply of ammunition versus the ability to promptly evacuate casualties to the next role of care for varying number of LAWs, LAW configurations, LAW transportation policies, and medical facility locations (Seater 2022). This simulation allows us to model the effectiveness of the LAW's ability to deliver certain classes of supply when certain ones have a higher level of delivery urgency. Simplicity was included into the scenario to be able to provide a proof of concept of the E2M2 and the LAW. It is important that the E2M2 can eventually be used by planners planning future operations.

E. LITERATURE REVIEW

As previously discussed, this thesis is the first study using the Expeditionary Energy Multi-Domain Model, where it is analyzing both casualty evacuations and sustainment operations using surface connectors. This study is also a proof of concept for the LAW, which is currently a new investment for the Navy and Marine Corps. According to the March 2022 Congressional Report to Congress on the background and issues of the LAW, the Navy expects to procure its first LAW in fiscal year 2023, as well as acquiring potential alternatives with the Army Logistics Support Vessel (LSVs) (O'Rourke 2022).

Currently, the E2M2 has successfully simulated the sustainment of a MLR with the utilization of LAWs in an EABO environment. The model was able to test varying and inputted resupply policies to different resupply methods. The model outputted results on the maximum supportable demand given the distances of resupply points and the number of LAWs; effects of different paced missions; effects on the LAW when it is associated to an EAB verses a LAW loitering; and the effects of long deterrence missions, e.g., hybrid engines, command, control, communications, computers, intelligences, surveillance, and reconnaissance (C4ISR) and long-range unmanned surface vessels (LRUSV) (Seater 2021).

In the Fall of 2021, Naval Postgraduate School (NPS) students conducted a wargame for the Office of the Deputy Chief of Naval Operations for Fleet Readiness & Logistics (OPNAV N4). The wargame was intended to answer the following questions and the focus was based on the OPNAV N4's Naval logistics network and the Naval Expeditionary Naval HSS to DMO/EABO, seen in Figures 1 and 2 (Office of the Deputy Chief of Naval Operations for Fleet Readiness & Logistics [OPNAV N4] 2021):

- What are the best options, enabling concepts & technologies for posturing the theater to improve agility, speed, and reach?

- How do naval forces rapidly move from day to day (Phase 0) operations to lethal combat, assuming limited and/or ambiguous indications and warning?
- What is the most agile mix of expeditionary logistics sites? What locations?
- What capabilities/capacities? How mobile are they? How fast can they be moved? How often should they move?
- What force mix and capabilities best improves logistics agility and resilience?

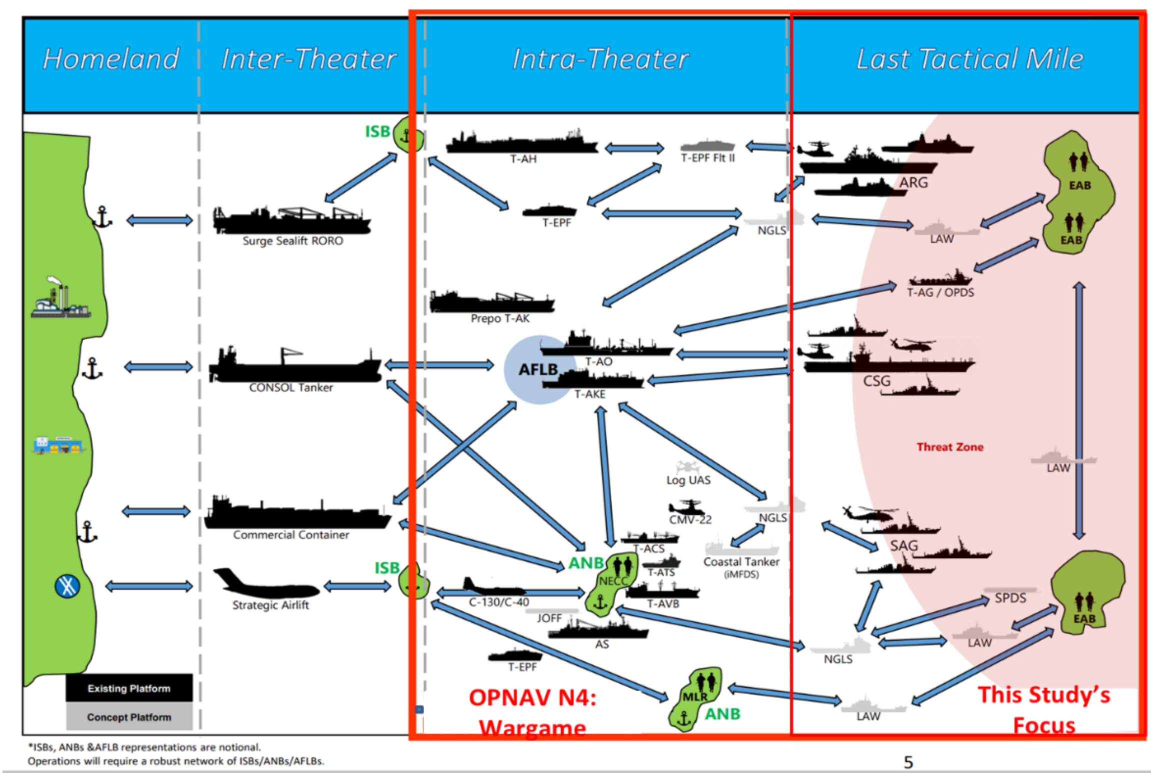

Figure 1. Naval logistics network. Source: Office of the Deputy Chief of Naval Operations for Fleet Readiness & Logistics (2021).

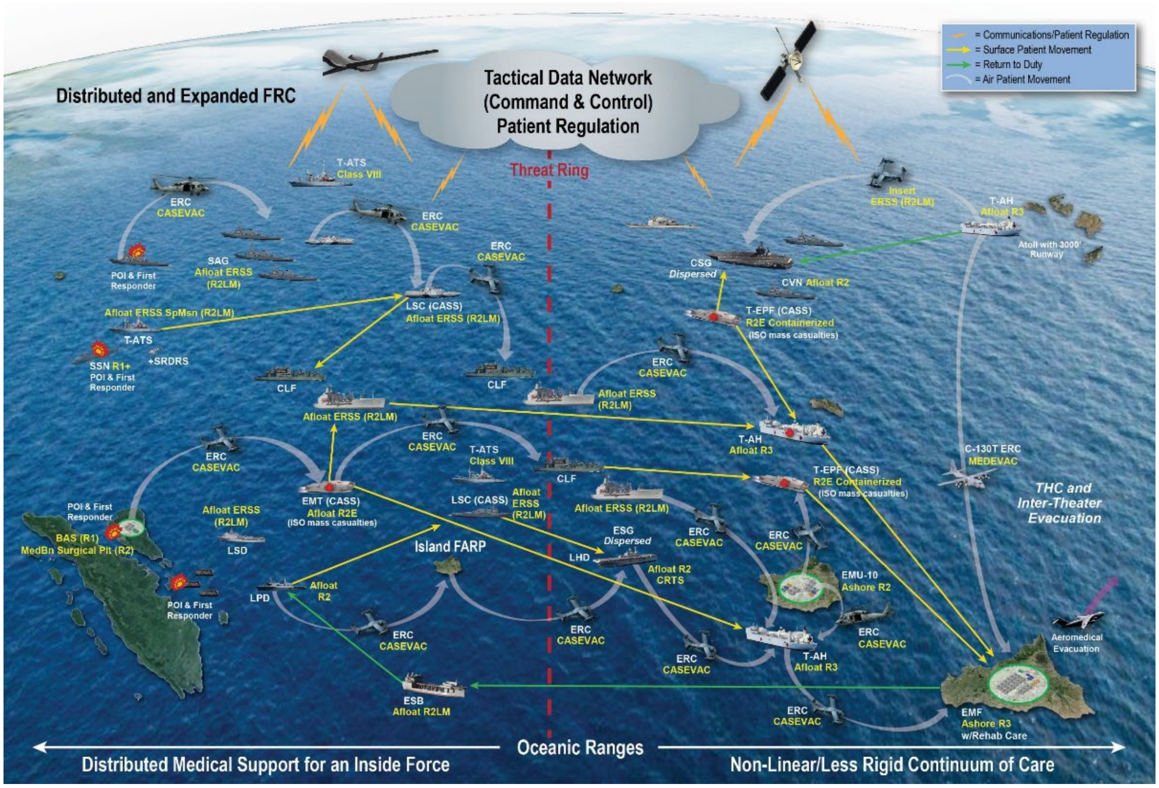

Figure 2. Naval Expeditionary HSS to DMO/EABO. Source: Office of the Deputy Chief of Naval Operations for Fleet Readiness & Logistics (2021).

In research closely related to this thesis, Captain Ralph Featherstone (USMC) used the Joint Test and Evaluation Model, which is an agent-based simulation, for his analysis on unmanned CASEVACs in a distributed environment. Captain Featherstone conducted a further analysis on unmanned CASEVACs using Nearly Orthogonal Latin Hypercubes (MacCalman, Vieira, and Lucas 2016), and data farming to determine critical factors (Featherstone 2009). Featherstone's measure of effectiveness was the number of CASEVACs completed by the unmanned aircraft systems (UAS) within one hour from the time of injury, otherwise known as the 'golden hour' (Featherstone 2009). The factors that were examined consisted of:

- The number of UASs.
- Maximum airspeed of the UAS.
- The Number of litter patients on each UAS.

- The flight altitude of the UAS.

Featherstone's scenario consisted of three platoon locations, separated by over 50 miles. Casualties took place between five to 45 miles away from surgical care (Featherstone 2009). Featherstone's approach is like the one taken for this analysis. Captain Featherstone's thesis shows the UAS as being a viable asset to transport casualties within an hour.

The UAS scenario is based off the creation of a forward operating base (FOB) and lacks the maritime aspect of what is trying to be captured in this analysis, which could mean the 'golden hour' requirement is infeasible. While the E2M2 sustainment scenario gives the Marine Corps a baseline for the requirements needed to sustain a MLR during EABO, amphibious sustainment operations are rarely dedicated to exclusively sustainment operations only. Similarly, the wargaming scenario had the transportation assets, such as the Expeditionary Fast Transport Flight II and the Japanese Maritime Self-defense Force US-2 Seaplane as dedicated MEDEVACs picking up casualties from EABs and/or the Surface Action Groups. This study did not consider the vulnerability of having these assets too far forward inside the WEZ. The Navy and Marine Corps must consider available transportation assets as multi-mission platforms that can operate inside the WEZ and their ability to sustain the force as well as conduct CASEVAC missions.

F. THESIS ORGANIZATION

Chapter I covers the introduction and overview of this analysis. In Chapter II, this thesis discusses future threats and the Commandant's vision for the Marine Corps. Chapter III is an overview of amphibious CASEVACs. Chapter IV provides detailed descriptions of the Joint Medical Planning Tool (JMPT) and the E2M2 model. Chapter V shows a demonstration analysis using E2M2's outputs. Lastly, Chapter VI provides conclusions and recommendations for follow-on research. There are several appendices that provide supplemental information and analysis.

II. FUTURE THREATS AND COMMANDANT'S VISION FOR THE MARINE CORPS

Chapter II discusses the background on why the United States is refocusing its efforts to the Indo-Pacific region. This chapter explains the actions that China has recently taken that have influenced the Marine Corps to reevaluate its current force structure and its ability to fight against a near peer threat in a dispersed and disaggregated environment. This background is important to understanding how future sustainment operations and casualty evacuations will change based on the Commandant's vision and future Marine Corps investments.

A. CHINA

After fighting 20+ years in land-based conflicts against non-peer opposition, the United States shifts their focus to the Indo-Pacific region against a near-peer threat. The Indo-Pacific region, currently designated by the United States as Indo-Pacific Command (INDOPACOM), stretches from the west coast of India to the western shores of the United States (National Security Strategy [NSS] 2017). Within this vast region, shown in Figure 3, are many remote and dispersed islands.

Figure 3. U.S. Indo-Pacific Command Area of Operations. Source: U.S. INDOPACOM (2022).

The United States has consistently maintained interests in having the Indo-Pacific region free and open (NSS 2017). This means that United States is committed to ensuring all nations are "secure in their sovereignty and able to pursue economic growth consistent with international rules, norms and principles of fair competition" within the Indo-Pacific region (Department of Defense [DOD] 2019). China seeks to remove the United States from the Indo-Pacific region by "expanding the reaches of its state-driven economic models and reordering the region in its favor" (NSS 2017 p. 25, 45–47). In a Frontline article, "What is the China Model? Understanding the Country's State-Led Economic Model," the authors Abby Johnston and Catherine Trauwein (2019) describe China's current model as "a blend between national control and ownership of resources and economic activities dominated by private entrepreneurs." For China to carry out its state-driven economic model, it seeks to obtain key infrastructure to leverage control of resources and economic activities in the Indo-Pacific region (Johnston and Trauwein 2019). China's motives to control key infrastructures have recently been concentrated in occupying small islands in the South China Sea. Dating back to 1974, during the Battle of the Parcels, China has maintained interest in these islands, when China defeated South Vietnam and took control over several outposts in the Paracel Islands (DOD 2017). Similarly in 1988, China seized control from Vietnam outposts in the Spratley Islands during the Johnson South Reef Skirmish (Collin and Tri 2018). Today, China has expanded its outposts to seven in the Spratly Islands and 20 in the Paracel's, as seen in Figures 4 and 5 (Grossman 2020, p. 3).

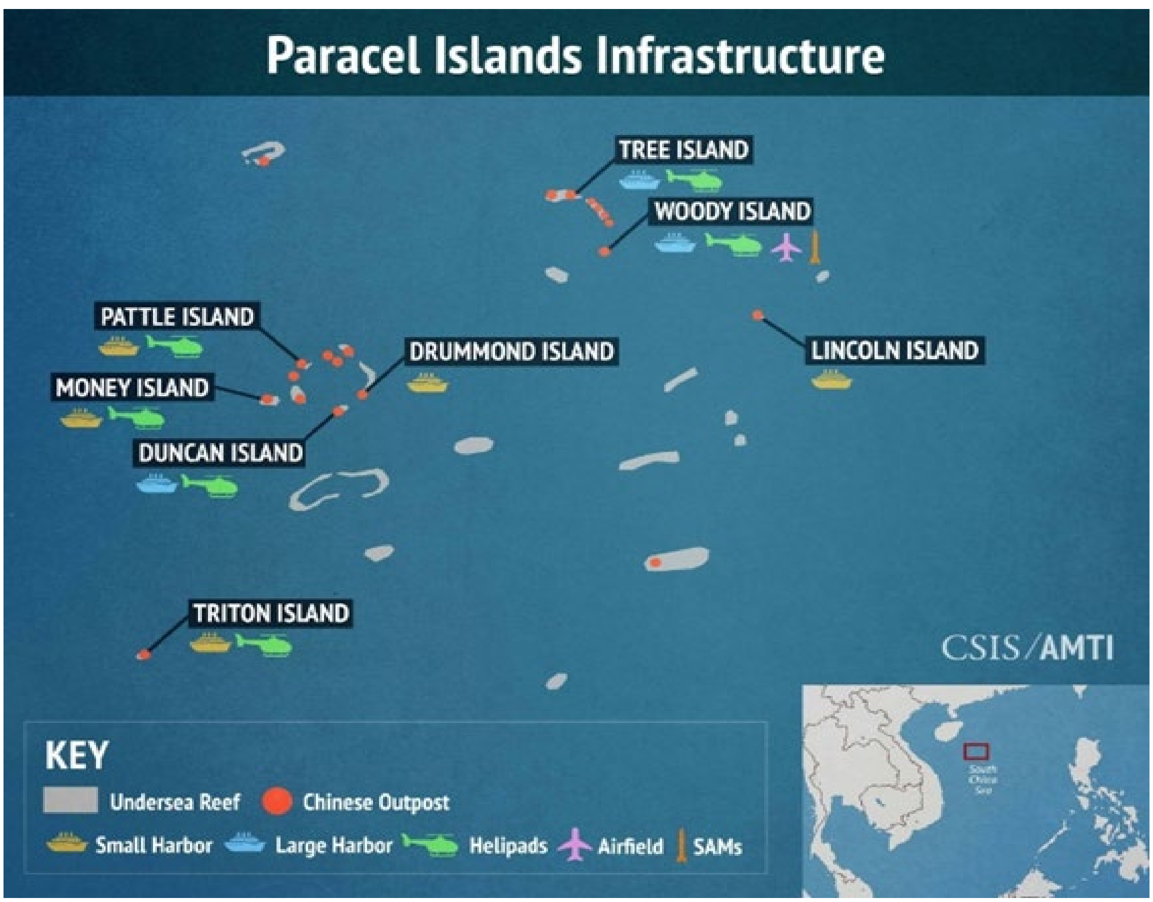

Figure 4. Chinese occupancy in the Paracel Islands. Source: CSIS (2017).

Figure 5. Images of Chinese occupancy in the Spratly Islands. Source: CSIS (2017).

According to the Center for Strategic and International Studies' Asia Maritime Transparency Initiative (2018) and as seen in satellite images in Figure 5, China has been building up these outposts to act as air and naval bases. China's initiative to control the region with these outposts pose significant threats to the United States and nearby nations in the region, especially with China's developments in advanced technologies and long-range precision weapon systems. The United States military's current assumptions of sea control, air superiority, and assured communications in the operating environment are now being challenged by these capabilities. Additionally, China's capabilities give her the ability to operate at far distances within all domains of warfare, whether land, sea, air, space, cyberspace, and the electromagnetic spectrum. China's recent activities and its ability to conduct stand-off engagements could keep United States forces away from these key areas of operations while minimizing their own personal risks (DON 2021b). It is vital for the United States to reevaluate its current forces and technologies to confront these challenges, as currently, United States' forces in INDOPACOM are concentrated in increasingly vulnerable operating areas within range of China's missile capabilities, surface and subsurface naval combatants, and manned and unmanned aerial attack platforms (Wilson 2016). The United States must reevaluate how the Marine Corps will be able to operate and sustain its forces within China's threat ring to deter China's aggression. Furthermore, the last conflict against a near-peer threat was WWII, which inflicted large amounts of casualties. Thus it is vital for the United States to reevaluate its current forces and technologies to confront how the Marine Corps will treat and evacuate mass casualties in a dispersed, disaggregated, and contested environment against a formidable foe.

B. COMMANDANT'S VISION

U.S. Navy and Marine Corps are refocusing their efforts to progressively transition and evolve their forces and technologies to be capable in fighting the future fight against a near pear threat in an austere environment. This leads to the question of how the Navy and Marine Corps will be manned, trained, and equipped to conduct CASEVAC in the future? Commandant of the Marine Corps (CMC), General David H. Berger states in his 2019 CPG that the Marine Corps is currently not manned, trained, and equipped to support the naval force operating in "contested maritime spaces, facilitating sea control, or executing DMO" (Berger 2019, p. 2). General Berger stresses the need for the Marine Corps to "build a force capable of persisting and operating forward as a critical component of a naval campaign" (DON 2021b, p. 1-2). The Navy and Marine Corps address these challenges with the EABO concept.

The EABO concept derives from Operations Plan (OP) 712-H: Advanced Base Operations in Micronesia, developed in 1921 by Major Earl H. Ellis (DON 1992). This OP was developed to address the actions of Japan after WWI, when Japan captured islands in the Pacific. These islands acted as bases suitable for launching attacks on the Philippines and United States assets (DON 1992). Because of Japan's actions, the United States determined that a war against Japan would require capturing strategic island bases in the Pacific for follow-on support to the fleet (DON 1992). Ellis knew that for the Marines to execute an amphibious assault in the Pacific and conduct follow-on sustainment operations, the U.S. needed to occupy closer bases than Hawaii and Guam (DON 1992).

Today, the Marine Corps is evolving advanced base operations to prepare for possible future conflicts by adopting the EABO concept. The EABO concept requires integrated naval forces (Navy and Marine Corps), otherwise known as the littoral force, able to project naval power by executing assigned tasks within and from expeditionary advance bases (EABs). According to the Technical Manual (TM) for EABO, a EAB is

> a locality within a potential adversary's weapon engagement zone (WEZ) that provides sufficient maneuver room to accomplish assigned missions seaward while also enabling sustainment and defense of friendly forces therein. Its expeditionary nature means it is not permanent and must be able

to change locations quickly enough to maintain relative advantage. (DON 2021b, p. 1-5)

Given this definition, littoral forces must be mobile and low in signature to complicate adversary efforts to find and target them (DON 2021b). To build a force capable of conducting EABO, the Marine Corps concluded that its current force structure is inadequate in carrying out these operations.

1. Current Force Structure

To understand how the Marine Corps needs to change, it is important to first look at its current force structure. The Marine Corps is known for operating as a Marine Air-Ground Task Force (MAGTF) (United States Marine Corps [USMC], n.d.b). The MAGTF is organized to conduct missions across the range of military operations. There are four types of MAGTFs, from largest to smallest: Marine Expeditionary Force, Marine Expeditionary Brigade, Marine Expeditionary Unit, and a Special Purpose MAGTF (USMC, n.d.b). A Marine Expeditionary Force (MEF) is the foremost Marine Corps warfighting organization (USMC, n.d.b). A Marine Expeditionary Brigade (MEB) is a non-standing task organized force, formed only in times of need (USMC, n.d.b). The Marine Expeditionary Unit is typically the forward deployed Marine expeditionary organization designed to be "first on the scene," and a Special Purpose MAGTF is a non-standing MAGTF formed for a specific mission (TECOM) (USMC, n.d.b). Each MAGTF has some form of an air, ground, logistics, and command element.

a. Amphibious Readiness Group (ARG)

A part of the Commandant's vision is reevaluating how the Navy and Marine Corps integrate. Currently, the Navy has the Amphibious Readiness Group (ARG), which consists of a three-ship construct consisting of an Amphibious Assault Ship (landing helicopter dock (LHD) or a landing helicopter assault (LHA)); an Amphibious Transport Dock (landing platform dock (LPD)); and a Dock Landing Ship (LSD) (USMC, n.d.b). The ARG has a Marine Expeditionary Unit (MEU) embarked on it, as seen in Figure 6.

Figure 6. Amphibious Readiness Group (ARG) / Marine Expeditionary Unit (MEU) force layout. Source: Lagrone (2016).

MEUs embarked on ARGs operate in areas of responsibilities of the Geographic Combatant Commanders and are organized and conduct operations based on the Geographic Combatant Commanders' requirements, which is important to recognize in understanding the Commandant's vision and further explained in the next section (USMC, n.d.b).

2. Force Design 2030

The Commandant's vision is to have a "Navy-Marine Corps Team [that] will enable the joint force to partner, persist and operate forward despite adversary employment of long-range precision fires" (Berger 2019, p.2). To do this, General Berger emphasizes force design as his top priority. General Berger (2019) explains that the ARG/MEU's three-ship model needs to be reconsidered as well as the employment of the different sized MAGTFs. The Commandant states the Marine Expeditionary Force will "remain as the principal warfighting organization; however, our MEFs will need not to be identical" (Berger 2019). Each MEF will be designed based on the needs of the Fleet and Combatant Commanders (Berger 2019). CPG also states that the Marine Corps will no longer use a "2.0 MEB requirement" of a 38-ship construct (Berger 2019). Lastly, Commandant seeks to reevaluate the MEU to bring more relevance to the Fleet. One significant change to the Marine Corps force structure to meet the demands of the EABO concept is the introduction of the MLR and the LAW.

3. Marine Littoral Regiment

According to the TM EABO, the 2030 MLR is a force capable of maneuvering and persisting inside a contested maritime environment (DON 2021b). The Marine Corps states that an MLR will be a "self-deployable, multi-domain force optimized for the contact and blunt layers, and will leverage the amphibious platforms, connectors and boats" that are a part of the naval expeditionary force (HQMC 2021). Figure 7 shows the force structure of an MLR, which consists of a headquarters (HQ) Command Element (CE), Littoral Combat Team (LCT), Littoral Logistics Battalion (LLB), and a Littoral Anti-Air Battalion (LAAB) (DON 2021b).

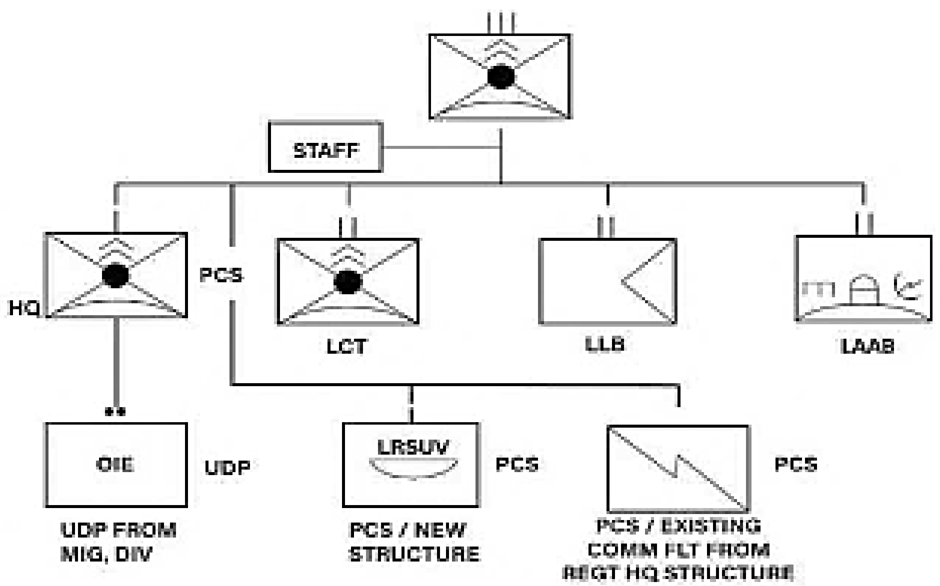

Figure 7. MLR task organization. Source: DON 2021b.

An important take-away in understanding the differences of the MEU and MLR is in how the littoral force will change in its ability to sustain and provide the necessary logistical functions to its forces conducting EABO. The MLR force structure will be the primary force for this analysis. A MLR will act as a stand-in force (SIF) operating in and around EABs. A SIF is defined as:

> Small but lethal, low signature, mobile, relatively simple to maintain and sustain forces designed to operate across the competition continuum within a contested area as the leading edge of a maritime defense-in-depth in order to intentionally disrupt the plans of a potential or actual adversary. Depending on the situation, stand-in forces are composed of elements from the Marine Corps, Navy, Coast Guard, special operations forces, interagency, and allies and partners. (DON 2021a)

According to *A Functional Concept for Maritime Reconnaissance and Counter-Reconnaissance*, Combat Development and Integration (CD&I) states that the SIF "will be employed in an enduring mission to help the fleet and joint force win the reconnaissance and counter-reconnaissance battle" (Combat Development and Integration [CD&I] 2022, p. 3). The central idea is that the SIF will conduct reconnaissance to help locate the adversary to "deliver decisive effects," while conducting counter-reconnaissance to prevent the adversary from locating our fleet and forward forces (CD&I 2022, p. 7).

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III. SURFACE CASUALTY EVACUATIONS IN DISTRIBUTED MARITIME OPERATIONS ENVIRONMENT

With an understanding of how the Marine Corps is changing, it is now vital to look at how its new force structure will conduct sustainment operations and mass casualty evacuations. This chapter lays out the history of how the Navy and Marine Corps have conducted these two missions in the past and how both have evolved over the years. This chapter also discusses how the Marine Corps' current capacities may not be feasible in an EABO environment. And lastly, this chapter highlights new capabilities to inform the reader on possible strategies in conducting casualty evacuations in a dispersed contested environment.

A. HISTORY ON CASUALTY EVACUATIONS

Casualty evacuations in dispersed and disaggregated environments are challenging. Dating back to World War II (WWII), the Marine Corps experienced high casualty rates fighting against the Japanese. Furthermore, the geographical region in which the Marine Corps was fighting in posed even more significant challenges in its ability to evacuate casualties throughout the battlespace. During this time frame, the Marine Corps used surface platforms to transport large numbers of personnel and supplies to the beachheads. These platforms were also used to evacuate casualties out of the enemy threat area to nearby afloat or land-based facilities with more robust medical capabilities (Sanger 1966). In an article written by Mr. Quintin M. Sangar, the head of the Medical History and Reporting Branch, Bureau of Medicine and Surgery Department of the Navy (DON), he named several of these surface platforms. One platform is the landing ship, tank (LST (H)) which is seen in Figure 8. Several LSTs were converted to dedicated CASEVAC platforms after there were long delays in having to do both CASEVAC and resupply missions (Sangar 1996). Other platforms that Mr. Sangar (1996) discussed are the landing craft, medium (LCM) and the landing ship, vehicle.

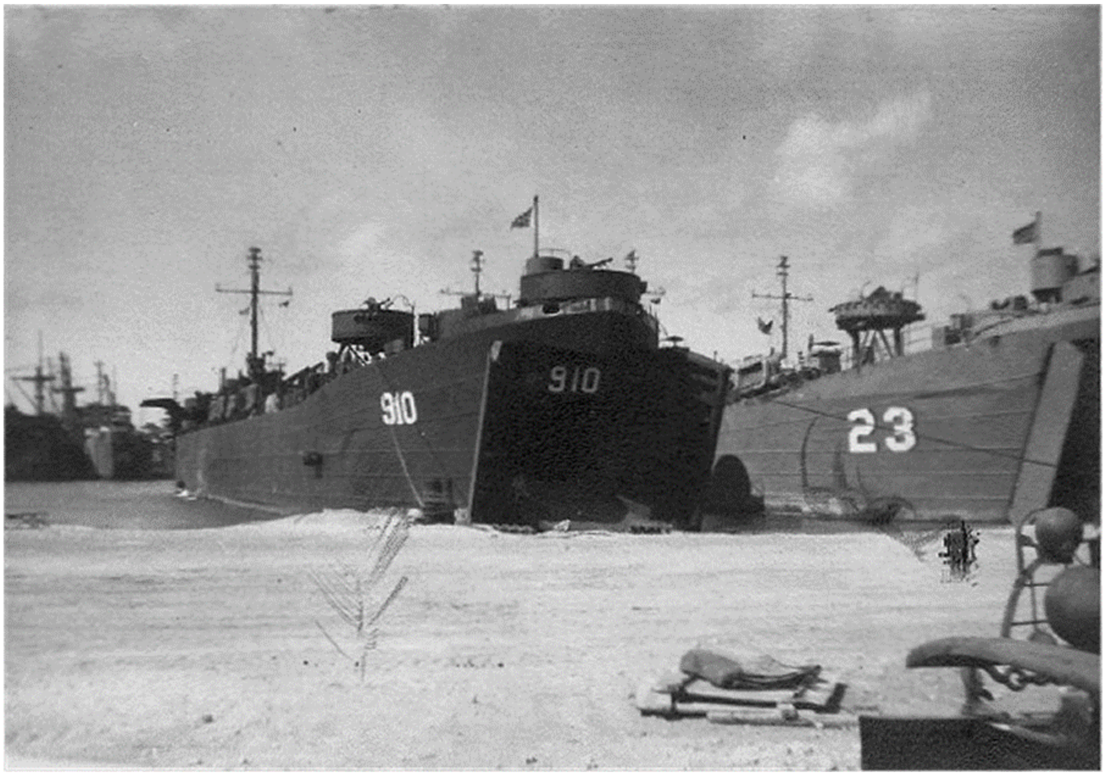

Figure 8. USS LST-910 and USS LST-23, beached in the Philippines, circa 1944. Source: Almond and Priolo (2021).

In order for these surface craft to provide definitive care to combat injuries during transit, medical staffs were placed on these smaller transport vessels, see Appendix B for the specific medical care on board (Sangar 1996, p. 36). An example of what the evacuations looked like in WWII is provided to explain how the "chain of evacuations" using surface vessels were conducted. During the Battle of Iwo Jima,

> the chain of evacuation of casualties included 4 LST(H)'s or evacuation control LST's, especially equipped with medical personnel and supplies and designated to make preliminary "screening" examinations of casualties and distribute them equally among the transports and hospital ships. One LST(H) was available for each of the invasion beaches, making two for each Marine division. All ships, [landing vehicle tracked] LVT or [large amphibious landing vehicles] DUKW, that evacuated wounded from beaches were to proceed to their respective evacuation control LST(H). Those casualties unable to endure the trip to a transport or hospital ship were to be transferred immediately to an LST(H) for treatment, while less seriously wounded patients were unloaded onto a barge alongside the LST(H) and then transferred to [landing craft, vehicle and personnels] for

> further transfer to transport or hospital ship. Aboard each LST(H) were 4 surgeons and 27 corpsmen, increased on arrival at the objective by the transfer of one beach party medical section (1 medical officer and 8 corpsmen) from a [transport] APA, giving each LST(H) 5 surgeons and 35 corpsmen. At all times these beach party medical sections were on call by the Transport Squadron Commander. Two hospital ships and one [hospital transport] APH were designated to evacuate patients to Saipan, where 1,500 beds were available, and to Guam, where there were 3,500 beds. Air evacuation of casualties to the Marianas was to begin as soon as field facilities would permit. Experience gained in the Marianas campaign had emphasized the necessity of having the casualties screened by a qualified flight surgeon to insure proper selection of patients for evacuation by air. Medical personnel and adequate medical supplies and equipment were to be aboard each plane. (Schwartz n.d., p. 89)

Having surface platforms available to pick-up casualties after dropping off supplies from the beachheads was vital in getting thousands of casualties evacuated. On D-Day alone, approximately 2,000 casualties were evacuated onto LST(H)s; in three days approximately 5,000 were evacuated to Attack Transports, which were ships with more robust medical capabilities; and by the end of the month about 5,000 were then evacuated to hospital ships (Schwartz n.d.). Although these vessels were significant in evacuating large numbers of casualties, advances in air assets after the Korean War, created a shift to being the primary means of evacuating casualties.

B. HOW CASUALTY EVACUATIONS IN AMPHIBIOUS OPERATIONS EVOLVED

1. Marine Corps: The Build-Up and Moving Away from Its Naval Roots

In the most recent wars in Iraq and Afghanistan, the Marine Corps shifted away from its naval roots to conduct counterinsurgency operations ashore. At well-established FOBs, large footprints of Marine forces and their supplies were built up to operate out of and conduct sustainment operations in support of forward forces. The thesis of Naval Postgraduate School Student, Major Gregory Lynch, titled, *Networked Logistics: Turning The Iron Mountain Into An Iron Network*, explained how the Marine Corps built-up and distributed supplies from a central location known as the "Iron Mountain" (Lynch 2019). During this time, it was also assumed that the United States had dominant air presence. This made it possible for large military transport aircraft, such as the C-17 and KC-130, to fly into captured nearby airports and constructed airfields for continuous sustainment operations and robust medical evacuation networks. Furthermore, in 2009, Defense Secretary Robert M. Gates directed the requirement for wounded Servicemembers to receive resuscitative and surgical care within the 'golden hour' to improve patient survivability rates (Moten, Teff, Pyle, Delk, and Clark 2019). To meet this requirement, damage control resuscitation and surgical capabilities were placed forward to increase their responsiveness (Moten, Teff, Pyle, Delk, and Clark 2019). This allowed for rapid removal of casualties and early surgical intervention, ultimately increasing survival rates. However, an increased footprint to move capabilities forward, ultimately created a lack in mobility to rapidly move forces around the battle space and provided "substantial targets for adversaries with precision-guided weapons or large-scale attack capabilities" to target Marine units (Lynch 2019). This is especially important when operations shift to a distributed maritime environment against a near peer threat, which is why the Commandant of the Marine Corps has emphasized change and his interest in a smaller, mobile, and more lethal force. This section discusses the background of how the Navy and Marine Corps currently conducts amphibious operations and the health service support (HSS) mission within amphibious operations, as well as the introduction of new capabilities.

2. Defining Amphibious Operations

According to the Joint Publication (JP) 3–02, *Amphibious Operations,* amphibious operations seek to exploit "the element of surprise and capitalize on enemy weakness by projecting and applying combat power precisely at the most advantageous location and time" (JCS 2009, p. I-3). Amphibious operations are combined arms operations between the Navy and Marine Corps. The Navy element is the Amphibious Force, whose primary purpose is bringing the Marine element or the Landing Force ashore (JCS 2009). This combined arm is called the amphibious task force, which operate under the umbrella of the Joint Force Commander, see JP 3-02 for additional information.

3. Health Service Support Mission

Extensive coordination must be done between the Amphibious Force, the Landing Force, the Joint Task Force, and their respective medical subject matter experts to create a robust HSS plan, see Figure 9 for HSS planning considerations.

Figure 9. HSS planning considerations. See JP 3-02, Chapter V Section 19 for more HSS planning, patient movement, and hospital regulating requirements. Source: JCS (2009).

HSS planning considerations become more vital when operations move to a multidomain, multifunctional environment in the Western Pacific (Moten et al. 2019). In the article, *Joint Integrative Solutions for Combat Casualty Care in a Pacific War at Sea*, the authors emphasize the repercussions due to the lack of medical planning during amphibious operations, when the article states, “lack of preparedness and shortfalls with our current combat casualty treatment plans and capabilities for a potential [war at sea] WAS expose us to the loss of hundreds, if not thousands, of Servicemembers in the event a ship is critically damaged” (Moten et al. p. 55). Thus, it is vital to understand combat casualty treatment plans for operating in and out of EABs, as well as the respective roles of medical available that can be placed at these austere locations.

4. Roles of Care

During amphibious operations, where the Amphibious Task Force is conducting operations in a DMO environment, the ‘golden hour’ requirement becomes less feasible to obtain due to distributed medical capabilities and finite resources. Planners should focus on capabilities available throughout the area of operations to best treat patients, with time being a “tuning” factor for the medical network, not a limitation due to finite resources (Cone S et al. 2022). In order to understand the required capabilities, the reader must first understand the levels of care available. There are four roles of medical care used, as seen in Figure 10.

Roles of medical care. The characterization of health support for the distribution of medical resources and capabilities.	
R1	Role 1. Provides medical treatment, initial trauma care, and forward resuscitation, not including surgical care. Also known as unit-level medical care.
R2	Role 2. Provides medical treatment, advanced trauma management, emergency surgery, and resuscitative care. Role 2 can be subdivided into Role 2 light maneuver (LM) and Role 2 enhanced (E).
R2LM	Role 2, light maneuver. Light and highly mobile medical unit able to conduct advanced resuscitation procedures up to damage control surgery.
R2E	Role 2, enhanced. Provides basic secondary health care built around primary surgery; intensive care unit (ICU); ward beds; and augmented by some ancillary support and is able to stabilize postsurgical cases for evacuation.
R3	Role 3. Provides emergency and specialty surgery, intensive care, medical specialty care, and extended holding capacity and capability augmented by robust ancillary support.
R4	Role 4. Provides the full range of preventive, acute, restorative, curative, rehabilitative, and convalescent care found in United States base hospitals and robust overseas facilities.

Figure 10. Roles of medical care. Source: OPNAV N4 (2021).

Below is a further explanation of what personnel and/or facilities are provided at each Role:

- Role 1 is the first medical care received. It consists of the first responder (self-aid/buddy aid), unit hospital corpsman, combat lifesaver and/or the battalion aid station (BAS) (DON 2018).

- Role 2 consists of forward resuscitative care (FRC), the forward resuscitative surgery system (FRSS), shock trauma platoons (STP), surgical companies (SC), and/or casualty receiving and treatment ships (DON 2018).

- Role 3 care facilities include theater hospitalization/surgical-clinical specialties, hospital ships, USN expeditionary medical facilities (EMFs) overseas hospitals, MTFs of other Services, and/or host-nation support (HNS) agreements providing theater level HSS (DON 2018).

- Lastly, Role 4 care is back in U.S. base hospitals or more robust overseas facilities (DON 2018).

5. Casualty Types

Once the levels of care have been defined, it's important to understand the different casualty types during operations. The list below defines the different casualties defined in the Joint Medical Planning Tool:

- Killed In Action (KIA) are casualties who die before they enter a MTF with a physician present (Naval Health Research Center [NHRC] 2021).

- Wounded In Action (WIA) are troops who receive a battle injury. These injuries are either life or non-life threating (NHRC 2021).

- Died of Wounds (DOW) are casualties who die after being seen by a physician (NHRC 2021).

- Returned to Duty (RTD) are casualties who were considered WIA, disease or non-battlefield injury (NBI) that can return to their unit (NHRC 2021).

- Non-battlefield Injury (NBI) are injuries that occurred outside the battlefield (NHRC 2021).

- Disease (DIS) are casualties such that a person presented an illness at a MTF (NHRC 2021).

For this study, the focus is on casualties categorized as WIA and DOW. The category DOW will be interchanged with the term fatalities in this study.

6. Casualty Evacuation Categories

Lastly, once casualties have been stabilized for evacuation, each casualty is categorized based on his/her severity of injuries. The category levels are:

- Urgent/Urgent Surgical casualties are when the patient has life threatening "injuries such as temporarily corrected hemorrhage, temporarily controlled airway injuries, or temporarily controlled breathing issues" (HQMC n.d.a). These casualties need to be evacuated to a higher level of care to save the casualties life or limb. Urgent Surgical needs to be "taken to a facility with surgical capabilities" (HQMC n.d.a).

- Priority casualties are patients with "potentially life-threatening injuries such as compensated shock, fractures causing circulatory compromise, and uncomplicated but major burns" (HQMC n.d.a). These casualties need to be evacuated to the next role of care, or else their condition will worsen, thus being redesignated as an Urgent casualty (HQMC n.d.a).

- Routine casualties are the least severe. These patients sustained "injuries so insignificant or extreme that chances of survival are not based on evacuation time" (HQMC n.d.a). These casualties need to be evacuated to complete full treatment (HQMC n.d.a).

For this study, the focus is on these three categories and the accumulated risk each of these categories receive at each level of care. The Naval Health Research Center defines in the Joint Medical Planning Tool the severity of injuries based on injury severity scores (ISS). The ISS' are categorized into the following six mortality risk categories: None, Low, Medium, High, Minimal, Head Injury (NHRC 2021). For more information see the Modeling Mortality section in the JMPT Methodology Manual (NHRC 2021). For this study, the Low, Medium, and High categories correlate to Routine, Priority, and Urgent casualties. Further explanation is provided in the Modeling Chapter.

7. Current Amphibious Ships' and Connectors: Casualty Evacuations and Medical Capabilities

a. 'Big-deck'/'Small-deck' Ships

Each of the three ships that make up the ARG (LPD, LHD/LHA, and LSD) have Role II medical capability onboard. The LHD/LHA, considered as the 'big-deck' ships, are an essential asset to the amphibious strike group (ASG) and is the primary landing ship for the MEF. Upon landing its forces, the LHD/LHA is designated as the casualty receiving treatment ships, which means the ship is augmented with additional HSS personnel for more casualty treatment capabilities, see MCRP 4–11.1E Table 3–1 for the LHD/LHA medical capabilities and staffing. The LPD/LSD are the 'small-deck' ships. The LPD utilizes surface and air connectors to transport Marines, equipment, and supplies to shore. The LPD's enhanced C2 capabilities are vital in supporting the LF when its ashore. Lastly, the LSD utilizes the landing craft utility cushion (LCAC) and augmented helicopters to transport Marines, equipment, and supplies to shore, see MCRP 4–11.1E Table 3–2 and 3–3 for the LPD and LSD medical capabilities and staffing.

b. Surface Connectors

Currently, the main surface connectors used by a MEU are Landing Craft Air Cushions (LCACs) and Landing Craft Utility's (LCUs). LCACs and LCUs can both be stored in any of the ARG's three ships. The two platforms differ significantly. The LCAC provides "fast, over-the-horizon movement from ship-to-shore of combat troops and equipment through the surf zone and across the beach" (United States 2nd Fleet Commander n.d.). The LCAC is known for its fast speeds of up 40+ knots. The LCU is a highly versatile, self-sustaining craft known for its heavy payloads, see MCRP 3–31B for more information and characteristics on the LCAC and LCU. The LCAC and LCU can be used for CASEVACs with some form of Role I care, but are limited in their range (DON 2018).

c. Military Sealift Command

The Military Sealift Command provides the amphibious force with augmented hospital ships for mobile, flexible, and responsive Role III medical care during amphibious operations. Currently, there are two hospital ships, the U.S. Naval Ship Mercy (T-AH 19) and the U.S. Naval Ship Comfort (T-AH 20) (DON 2018). These hospital ships function underneath the Geneva Convention, see MCRP 4–11.1E Table 3–4 for the Hospital Ships medical capabilities and staffing.

8. Future Amphibious Connectors

General Berger, Commandant of the Marine Corps, emphasized in his CPG that Force Design is his top priority (Berger 2019). Included in the Marine Corps' force design effort is naval integration. General Berger states, "the future naval force development and employment will include new capabilities that will ensure the Navy-Marine Corps team cannot be excluded from any region in advancing or protecting our national interests or those of our allies" (Berger 2019, p. 2).

a. Light Amphibious Warship

New capabilities and technologies must tie into the EABO concept, in which they enable "a framework of integrated naval logistics supporting the movement and sustainment of decentralized forces throughout the littorals" (TM EABO p. 99). As part of the Marine Corps' effort to fulfill General Berger's' guidance, the Marine Corps is looking at divesting legacy platforms in order to increase the number of a new mix of amphibious warships (O'Rourke 2021). One solution to support this new requirement is to invest in the LAW program, as seen in Figure 11 and 12.

Figure 11. Light Amphibious Warship (LAW). Source: South (2022).

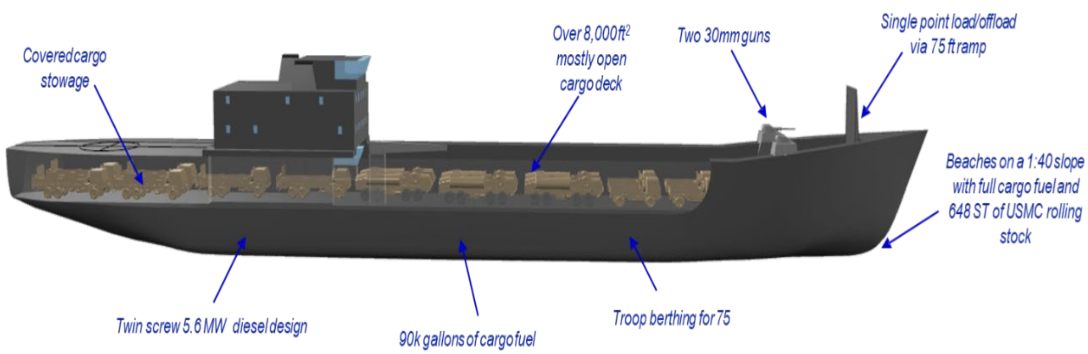

Figure 12. Beachable landing vessel — 200–400’, 2000 Tons, 14–22 kts, 8–12 ksqft cargo space, lead ship ~$160M, minimum organic self-defense of FAC/FIAC threat. Source: Campbell (2022).

The LAW will mimic certain capabilities that the landing ship, tank (LST) had during WWII and will be a supplement to the LCACs and LCUs. The LAW is designed to support the day-to-day maneuver of SIFs operating in the littoral operations area (O’Rourke 2021). The 2022 Congressional Report states,

> Under the [EABO] concept, the Marine Corps envisions, among other things, having reinforced-platoon-sized Marine Corps units maneuver around the [Western Pacific] theater, moving from island to island, to fire anti-ship cruise missiles (ASCMs) and perform other missions to contribute, alongside Navy and other U.S. military forces, to U.S. operations to counter and deny sea control to Chinese forces. The LAW ships would be

> instrumental to these operations, with LAWs embarking, transporting, landing, and subsequently reembarking these small Marine Corps units" (O'Rourke 2022, p. 4).

The LAW will be smaller and less expensive to procure than the current amphibious ships (O'Rourke 2022). As seen above, in WWII the use of large numbers of smaller surface vessels were significant in transporting supplies and personnel, as well as conducting CASEVAC missions. Because the Marine Corps does not have a dedicated MEDEVAC platform, it must look at the LAW as a multi-mission platform able to sustain the MLR as well as evacuate its casualties. Further details regarding the LAW can be referenced in the March 2, 2022, Congressional Report, *Navy Light Amphibious Warship (LAW) Program: Background and Issues for Congress*.

b. Expeditionary Fast Transport Flight II

During WWII, hospital ships proved to be proficient Role III capabilities afloat (Moten et al. 2019). They provided "maneuverability, proficiency with advanced surgical and medical care, and capacity to treat large volumes of combat casualties" (Moten et al. 2019, p.63). Currently, with only two hospital ships in the Navy's inventory and an increase threat to these platforms due to near peer threats, the Navy invested in the Expeditionary Fast Transport (EPF) Flight II, as seen in Figure 13. The goal for EPF Flight II is to provide faster and closer forward Role II capabilities afloat in multiple areas around the area of operations (Ong 2021). Appendix B shows the capabilities and characteristics of the EPF Flight II.

Figure 13. Expeditionary Fast Transport Flight II. Source: News (2022).

c. *Army Surface Connectors*

The Army utilizes the Logistics Support Vessel (LSV) to transport up to 2,000 tons of cargo from ship to shore during operations (Pikes 2016). The LSV's current missions include "intratheater line-haul in support of unit deployment or relocation; tactical and sustained resupply to remote, undeveloped areas along coastlines" (Pikes 2016). The LSV, shown in Figure 14, is included to be considered as a possible option for the Navy and Marine Corps' future fight, as its characteristics are somewhat like the LAW.

Figure 14. Logistics Support Vessel. Source: United States Army Acquisition Support Center [USAASC] (n.d.).

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IV. MODELS

This chapter reviews the two models studied in this research, the Joint Medical Planning Tool (JMPT) and the Expeditionary Energy Multi-domain Model (E2M2).

A. JOINT MEDICAL PLANNING TOOL

JPMT is a simulation tool, developed by the Naval Health Research Center, to help medical planners model the flow of patients from point of injury (POI) through definitive care (Naval Health Research Center [NHRC] 2021). JMPT is the Department of Defense's current accredited medical planning and programming tool. Models are developed using the Medical Planners' Toolkit (MPTk) and JMPT, as seen in Figure 15.

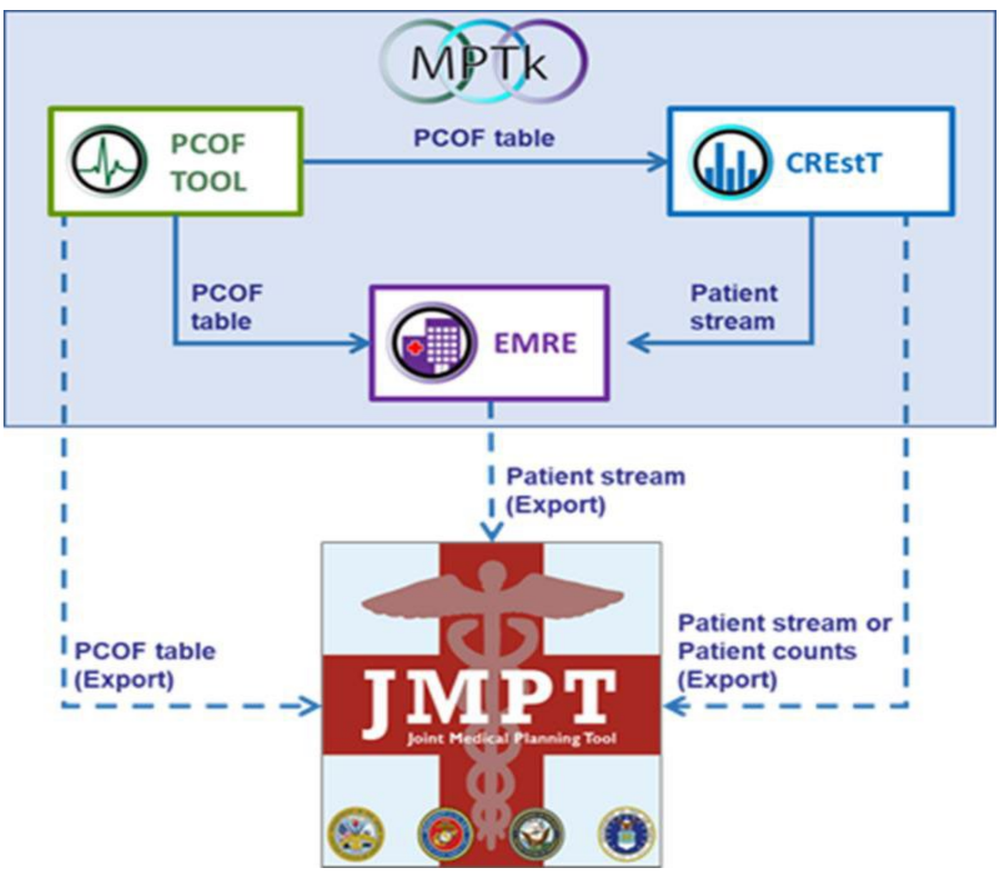

Figure 15. Medical Planners' Toolkit (MPTk) and Joint Medical Planning Tool. Source: Unpublished Training Brief (Aldich, 2021).

MPTk is a “suite of tools [that] provides planners with an end-to-end solution for medical support planning across the range of military operations from combat operations to humanitarian assistance and disaster relief missions” (NHRC 2021, p. 3). MPTk is used to create and analyze casualty streams based on generated scenarios. Within MPTk is the Patient Condition Occurrence Frequency (PFCOF), Expeditionary Medical Requirements Estimator (EMRE), and the Casualty Rate Estimation Tool (CREsT). PCOF provides the baseline probability distributions for illnesses and injuries across a range of military operations (NHRC 2021). The Joint Medial Planning Tool Methodology Manual (2021) describes the EMRE, which provides time-phased estimates for the operating room tables, intensive care unit beds, ward beds, evacuee numbers, and blood supplies necessary to Level 3 requirements. Lastly, the CREsT is a patient stream generator which yields the average casualty rates over a specified period (NHRC 2021). CREsT plus EMRE results are exported in a format to import into JMPT. Figure 16 depicts a screenshot of the JMPT interface.

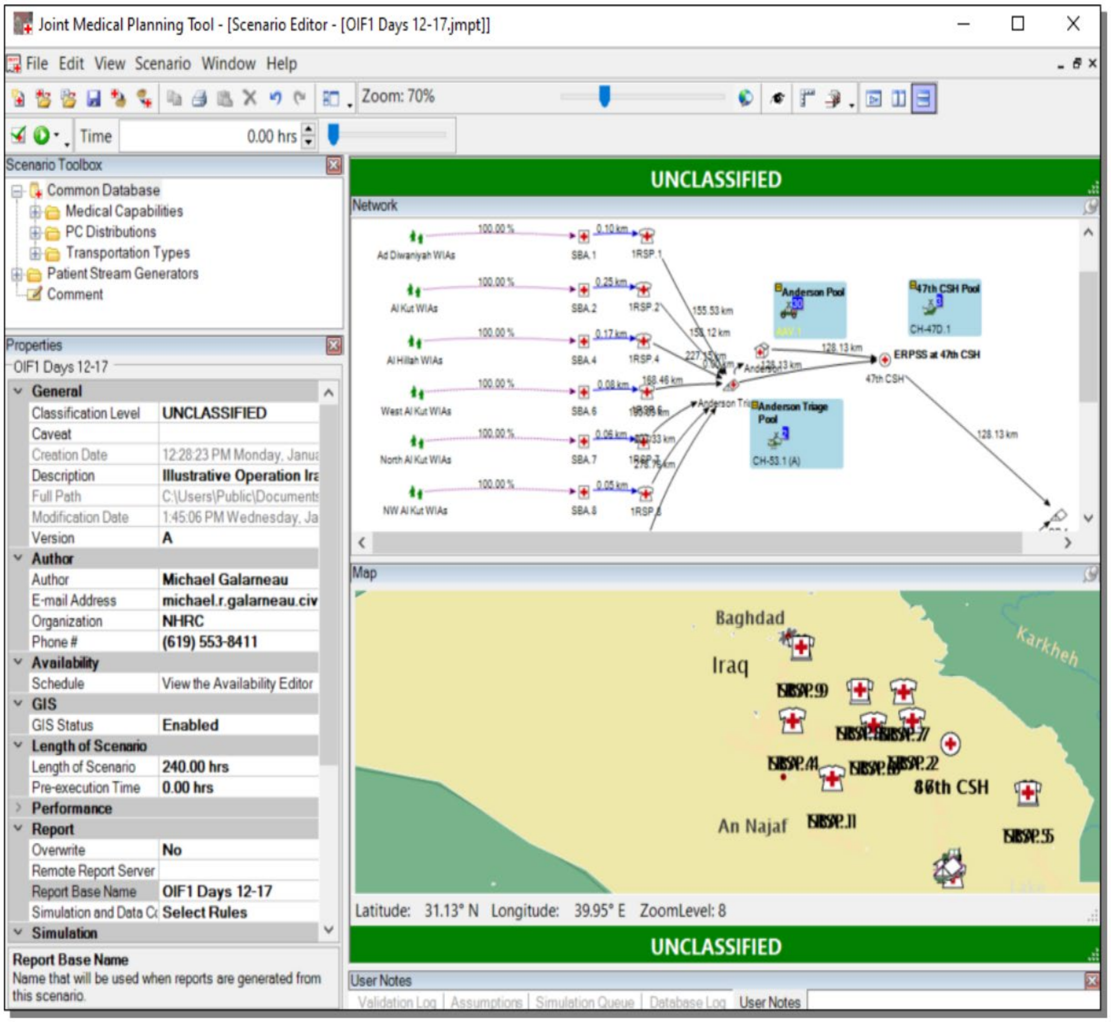

Figure 16. Joint Medical Planning Tool interface. Source: NHRC (2021).

1. Modeling

a. Survivability

The JMPT defines mortality risks in six categories based on injury severity scores (ISS). These categories are none, low, medium, high, minimal, and head injury. For this study, the focus is on the low, medium, and high categories, which correlate to the evacuation priorities, routine, priority and urgent. Furthermore, JMPT breaks down the level of care by code. In the code column of Figure 18, the code number 1 is self-aid/buddy-aid; 1A is a First Responder, 1B is a Battalion Aid Station (BAS), and 1C is a Shock Trauma Platoon. The other codes of emphasis are 2, which is Forward Resuscitative Care and is used to model the EPF Flight II care, and Role II Light Maneuver, which is the FRSS. In order to show enroute care on the LAW, the mortality risk for standard care is assumed to be equivalent to a First Responder. Having improved care or an enroute care team on the LAW is assumed to be equivalent to a BAS level of care for the E2M2 model scenario. JMPT uses DOW coefficients that are "probability distribution parameters that describe the survival time distributions for casualties with a given mortality risk at a given level of differentiated care" (NHRC 2021, p.108). These parameters are seen in Figure 17.

Table 11. JMPT DOW Coefficients

Weibull Parameters			
Mortality Risk	**Code**	**a**	**b**
Low	1	323.03	0.81
Medium	1	2.75	0.59
High	1	0.5199	0.475
Minimal	1	240.16	2.64
Head Injury	1	147.58	0.53
Low	1A	427.6	0.75
Medium	1A	7.93	0.56
High	1A	1.8074	0.5229
Minimal	1A	240.16	2.64
Head Injury	1A	186.76	0.51
Low	1B	624.78	0.68
Medium	1B	32.78	0.5
High	1B	6.19	0.5
Minimal	1B	329.8	2.42
Head Injury	1B	259.78	0.51
Low	1C	763.78	0.68
Medium	1C	584.28	0.38
High	1C	6.73	0.49
Minimal	1C	419.17	2.1
Head Injury	1C	466.01	0.45
Low	1X	624.78	0.68
Medium	1X	375.075	0.46
High	1X	5.65	0.51
Minimal	1X	329.8	2.42
Head Injury	1X	346.24	0.49

Lognormal Parameters			
Mortality Risk	**Code**	**b_0**	**b_1**
Low	2	11.5759	2.9785
Medium	2	11.3088	3.8228
High	2	5.679	2.0704
Minimal	2	10.088	0.7118
Head Injury	2	9.8543	3.0651
Low	2E	12.2765	1.6453
Medium	2E	11.904	4.024
High	2E	6.5103	3.2127
Minimal	2E	9.8858	0.4988
Head Injury	2E	10.8335	3.3393
Low	2LM	11.32	2.99
Medium	2LM	10.378	3.427
High	2LM	5.3998	1.9877
Minimal	2LM	10.3466	0.9491
Head Injury	2LM	9.6745	3.1388
Medium	3	15.402	5.7223
High	3	8.4459	3.7008
Head Injury	3	14.2023	4.7854
Medium	3S	14.9116	5.3958
High	3S	7.3127	4.1804
Head Injury	3S	12.7271	3.9395

Figure 17. JMPT DOW coefficients. Source: NHRC (2018).

Based on the level of care and the mortality risk of a casualty, these parameters are plugged into either the Weibull or the Lognormal probability density function to then determine its cumulative distribution function used to determine the survivability of a casualty at that specific level of care based on a given amount of time. See Figure 18's probability density function equations with note that the Weibull equation is expressed in hours and the Lognormal equation in minutes.

The Weibull probability density function is defined below where 'a' is the scale parameter and 'b' is the shape parameter. The variable 't' represents time in hours.

$$f(t) = \frac{b}{a}\left(\frac{t}{a}\right)^{b-1} e^{-\left(\frac{t}{a}\right)^{b}}, t > 0$$

The Lognormal probability density function is defined below where 'b0' and 'b1' are the mean and standard deviation of the distribution on the log scale, respectively. The variable 't' represents time in minutes.

$$f(t) = \frac{1}{\sqrt{2\pi}(b_1 t)} e^{-\left(\frac{(\ln(t)-b_0)^2}{2{b_1}^2}\right)}, t > 0$$

Figure 18. JMPT Manual Weibull and Lognormal probability density functions. Source: NHRC (2018).

b. Modeling Example

To illustrate the use of the JMPT, a small study is included in this section. This analysis helped gain insight into how to model casualty evacuations in the E2M2.

An analysis was done based on a 2045 notional scenario given in a Joint Campaign Analysis course at the Naval Postgraduate School (NPS), conducted by four NPS students that formed "Team AIRMID." For this analysis, the JMPT was used to understand how casualties are moved through an established medical network in a DMO environment. The notional scenario comprises of China having the world's leading economy and is consistently trying to control trading routes in the southern seas (Kline 2021). The scenario was built in JMPT by one of the team members, LT Ken Marler, Operations Research student at NPS. The United States' response to China's actions was to conduct EABO with a stand-in force (SIF) operating within the South China Sea. A Marine Littoral Regiment (MLR) is operating out of expeditionary advance bases (EAB) in Brunei, Luzon, and Palawan, while the U.S. Navy is exercising DMO in the Philippine Sea (Kline 2021). The MLR is the leading edge of a maritime defense-in-depth to disrupt China's plans to take over more territory and trading routes (Cone S et al. 2022). Due to China being a near-peer threat, a robust medical concept of operations was developed with distributed medical capabilities and evacuation assets throughout the region to prepare for high casualty rates, as seen in Figure 19 (Cone S et al. 2022).

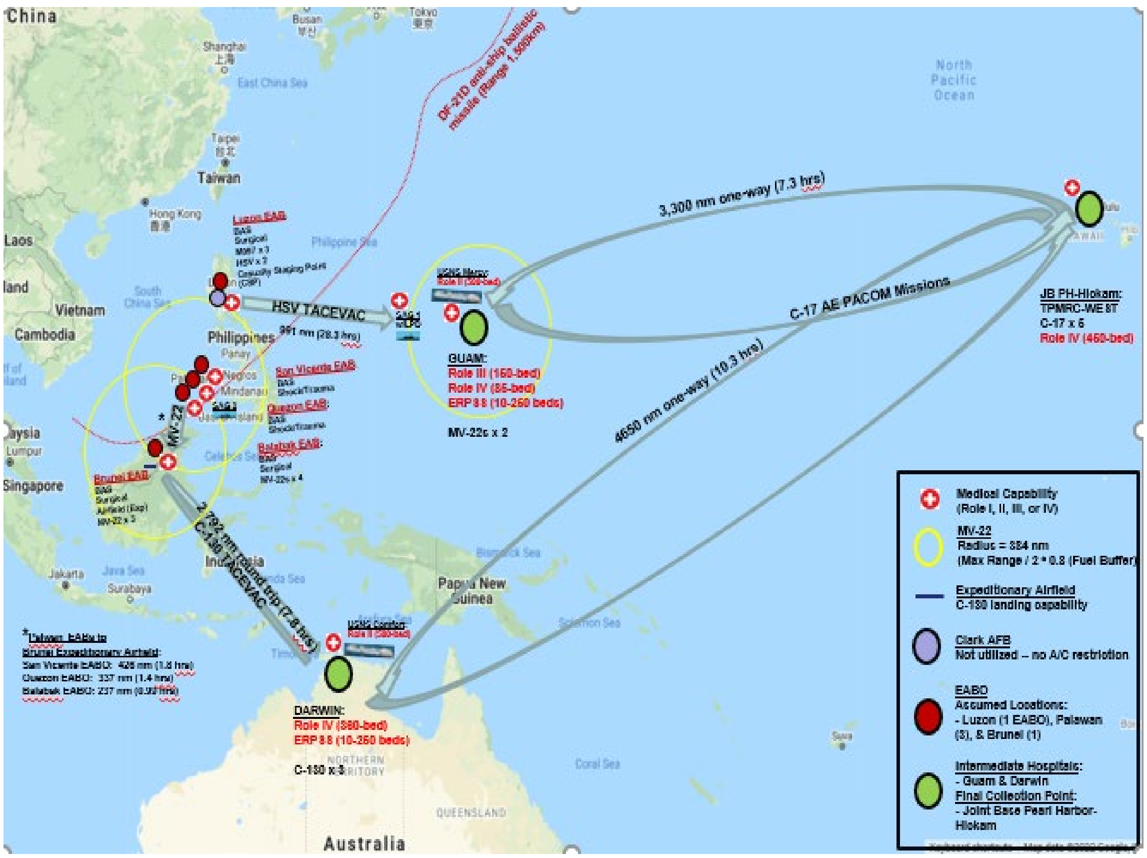

Figure 19. Medical concept of operations. Source: Cone et al. (2022).

The study used a 30-day scenario that included five missile strike injects on EAB's Palawan and Luzon, and on Surface Action Group (SAG) 1. The JMPT results from this scenario yielded patient survivability, operational supportability, surgical capacity, and bed capacity (Cone S et al. 2022).

Team AIRMID (2022) analyzed the utilization of the dedicated medevac platforms. The utilization percentages showed the EPF Flight II or HSV in this scenario as having the highest percentage of 66% and an average of four casualties per trip (one ambulatory, three litter) (Cone S et al. 2022). Team AIRMID (2022) concluded that this was mainly due to the HSV being the only transport from EAB Luzon to SAG 1, and the HSV having to transport a high number of disease and non-battle injuries, which would drop the utilization of the HSV to 29% if they were excluded.

(i) Surface vs. Air Scenario

Within the overall scenario above, a sub-scenario was looked at to compare surface evacuations to air evacuations. The updated scenario included an increased threat of China's long range weapon systems; thus, air superiority has not been achieved near the Palawan EAB. The study evaluated a mass casualty scenario where a helicopter is unable to reach Palawan, so smaller surface connectors, such as the landing craft, mechanized (LCM) and the expeditionary fast transport (T-EPF) were used to evacuate casualties operating out of EAB San Vincente to an additional EAB added, EAB Negros. From the western coast of EAB San Vincente to the eastern coast of EAB Negros, it is approximately 330 km (Mullen and Marler 2022).

The study team entered a scenario into CREsT based on an unclassified near-peer ground combat scenario. The scenario lasted eight days, with combat on days one through five simulating an opposed landing against a defended location. On day zero, the population at risk is 500 close, 100 support (forward), and 200 support (rear). During the landing, the advantage was set to neutral, per the JMPT designated inputs. The environment modeled represents rolling terrain and hot climate in the Indo-Pacific region. In addition to WIA, Disease and Non-Battle Injury (DNBI) were considered in the scenario (Mullen and Marler 2022). LT Marler ran 200 replications of the model. The CREsT output was then imported into JMPT where it was fed into the structured medical network.

The medical network, shown in Figure 20, consisted of (1) a first responder (RSP.1), (2) battalion aid station (BAS.1), (3) FRSS that was co-located with a STP (FRSS/STP.1), and (4) a Role II collection location, that was an Air Force Expeditionary MEDical Support with 25 additional personnel (EMEDS+25.1). The scenario was replicated looking at two different transports between locations the FRSS and the EMEDS. Fixed transportation was used between the other locations in the model. The first scenario simulated an aviation-based evacuation using the MV-22. Figure 20 shows the aviation-based evacuation network.

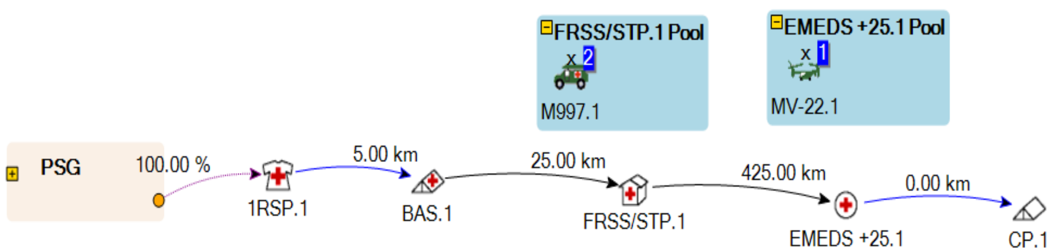

Figure 20. Joint Medical Planning Tool (JMPT) medical network for the aviation-based evacuation scenario.

The second scenario simulated a surface-based evacuation, consisting of both a landing craft LCM-8 and an expeditionary fast transport (T-EPF). The LCM-8 was included to add realism since the T-EPF would likely not be able to approach shore to retrieve the casualties (Mullen and Marler 2022). This scenario is shown in Figure 21.

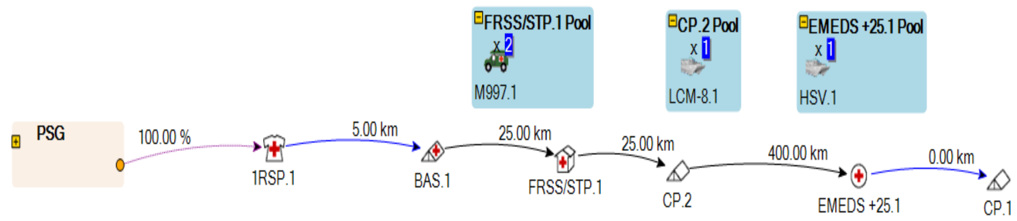

Figure 21. Joint Medical Planning Tool (JMPT) medical network for the surface-based evacuation scenario.

(ii) Results

After the scenarios were run in JMPT, an analysis that compared the air and surface scenario results was conducted. Casualty statistics were split into three categories — WIA, NBI, and DIS. For WIA casualties, the surface scenario had approximately 12 DOWs (12 WIA and 1 NBI). The air scenario had approximately 11 DOWs (10 WIA and 1 NBI). Both scenarios had very high numbers of non-life threating injuries (130 for surface and 131 for air), on average, which is reflected in the casualty statistics under the RTD casualties. Each yielded approximately 45 RTD casualties on average. At the conclusion of the air and surface scenarios, each had approximately eight casualties at the Role II collection point (CP.1) waiting for follow-on care, and approximately 67 casualties left in the system waiting to be determined RTD or evacuated to the next role of care. In eight days, the BAS was able to treat 138 patients, the FRSS was able to treat 112, and the EMEDS+25 treated about 110. Thus, each scenario was able to throughput about the same number of casualties to the casualty collection point one (CP.1). Because of this, it is important to now understand the efficiency of the transportation modes in the model.

The last analysis was based on the transportation statistics of the surface and air scenarios. The utilization percentage was higher for the EPF Flight II (85%) and the LCM-8 (68%) than the MV-22, which had a utilization of 60%. The EPF flight II made only seven trips compared to the LCM-8 and MV-22, which averaged around 47 trips. Lastly, the EPF was able to handle an average 15 casualties per trip, where the LCM and MV-22 averaged about two casualties per trip. What is interesting is that the percentage of requests with no delays for each of the three transportation assets are approximately the same (about 30%). Some factors that may increase these delays are load/unload times, configuration times, communication delays, and maintenance. Additionally, coordination had to be made between the two surface connectors to decrease the amount of delay at casualty collection point two (CP.2). LT Marler added a one-hour wait time on the LCM-8 at the FRSS to allow the EPF Flight II to travel to the EMEDS and drop off patients. This study found that it was better for the patients to wait at the FRSS then to wait at CP.2 for transfer.

This analysis was useful, but what the JMPT lacks is the ability to also capture the resupply mission, for not only medical supplies, but other classes of supplies to the EABs, affects the CASEVAC mission and vice versa. The E2M2 fills this gap.

B. EXPEDITIONARY ENERGY MULTI-DOMAIN MODEL

The E2M2 employs an agent-based simulation framework called the Probabilistic Investigation of Resource Allocation in Networks of Hierarchical Agents (PIRANHA) to different logistics domains (Seater et al. 2021). The E2M2, along with the JMPT, provides insights into using the LAW for sustainment operations and casualty evacuations (CASEVAC) in an EABO environment. The E2M2 currently allows the user to select a pre-configured scenario template to serve as a baseline. A pre-established EABO sustainment scenario was used as the baseline in the model, with edits made to meet the needs of simulating CASEVACs (Seater et al. 2021).

1. Template Parameters

The EABO CASEVAC scenario template prescribes a set of roles, how they interact, and how broad map zones change their behavior. Formally, the template is characterized by the roles, policies, resources, zones, labels, events, terrain, and positional units (Seater et al. 2021).

a. Agents

(i) Roles

A role is the largest group of agents that all can be assigned the same set of policies. Policies must be well defined. Different members of a role can have different policies activated, but it is required that all the policies make sense for all the members (Seater et al. 2021). The set of roles is hierarchical, and every agent must belong to exactly one leaf role at any given time. Lastly, roles might be specifically referenced by a name in policies, so the set of roles cannot be altered or renamed. Table 1 contains the defined roles for this scenario. The sustainment scenario has three roles with sub-roles within each: EAB teams, Surface Transport, and Supply Points. This scenario focuses only on the six fire teams, designated as FIRES, within MLR 2 of the EAB teams' role, as seen in Table 1.

Table 1. Defined roles for the CASEVAC scenario. The red font are the units used in the scenario of MLR_2. Source: Seater et al. (2021).

EAB Team	Surface Transport	Supply Points	Patients	Hospital Facitilties
MLR_2 **FIRES_ii_1_A** **FIRES_ii_1_B** FARP_ii_1 LRUSV_ii_1 C4ISR_ii_1 LAAB_ii_1 **FIRES_ii_2_A** **FIRES_ii_2_B** FARP_ii_2 LRUSV_ii_2 C4ISR_ii_2 LAAB_ii_2 **FIRES_ii_3_A** **FIRES_ii_3_B** FARP_ii_3 LRUSV_ii_3 C4ISR_ii_3 LAAB_ii_3 HQMLR_ii HQAIR_ii HQCLC_ii **MEDICAL TEAM**	allLaws: LAW_1 LAW_2 LAW_3 LAW_4 LAW_5 LAW_6 LAW_7 LAW_8 LAW_9 NavyNear CONNECTOR_1 CONNECTOR_2 CONNECTOR_3 NavyMid CONNECTOR_4 CONNECTOR_5 CONNECTOR_6 NavyFar CONNECTOR_7 CONNECTOR_8 CONNECTOR_9 EFP	USMC_BASE_T in TADPOLE_BASE FAST TRANSPORT Navy_CLF in MSC	100 Patients -Urgent (25%) -Priority(25%) -Routine(50%)	LOITER POINT 3 LOITER POINT 4 TADPOLE BASE POTATO BEACH 1 FAST TRANSPORT

(ii) Casualties.

Casualties are modeled as individual agents, and each casualty is given a value based on their evacuation priority: urgent (2), priority (1), or routine (0). These values are only included so the LAW agents can pick up the more severe casualties first, and to determine the risk accumulated for each scenario at the end of the simulation. These values have no other effect on the simulation (Seater 2022).

(iii) Scheduler/Dispatcher.

In an email conversation with Dr. Robert Seater (2022), he defined the Scheduler/ Dispatcher as,

> a disembodied agent that helps coordinate actions between agents. When it sees that a patient has a request to be extracted to the hospital, it decides which (if any) LAW can serve that request. Similarly, when it sees that a FIRES team wants to receive SAM and [Anti-Ship Missiles] ASM ammo, it decides which (if any) LAW can serve that request. In both cases, it has to ask the LAW, and the LAW might refuse.

(iv) Care Providers.

Care providers are a part of the medical team. Care providers are agents that have "no storage capacity for care" (Seater 2022). Dr. Seater (2022) describes that, "the sim engine knows that agents with no ability to store a resource should not produce it until the moment they are about to give it away." As a result, the care providers will hold onto their stores of medical supplies until a casualty asks the care provider for care. At that point, medical supplies are converted to medical care to meet that casualties' request.

b. Map

The background image with the node structure overlaid on the map image is shown in Figure 22.

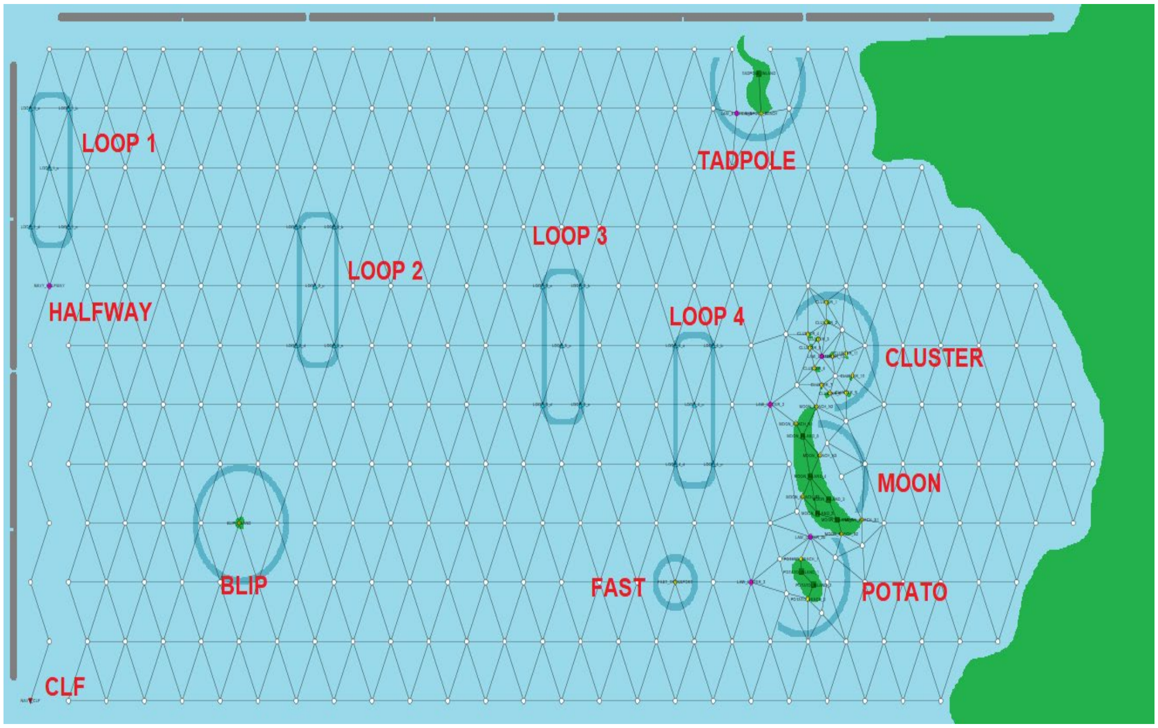

Figure 22. EABO sustainment scenario map image. Source: Seater (2021).

Map Zones cover spatial regions of the map, and every node in that region is a part of that zone. Zones can be specifically referenced by name in policies and can be parameterized (such as level of risk) (Seater et al. 2021). Within Figure 22 are several defined Map Zones that are the focus for this study. These zones are Island Cluster Zone, Moon Island Zone, and Potato Island Zone, which are depicted in Figure 23.

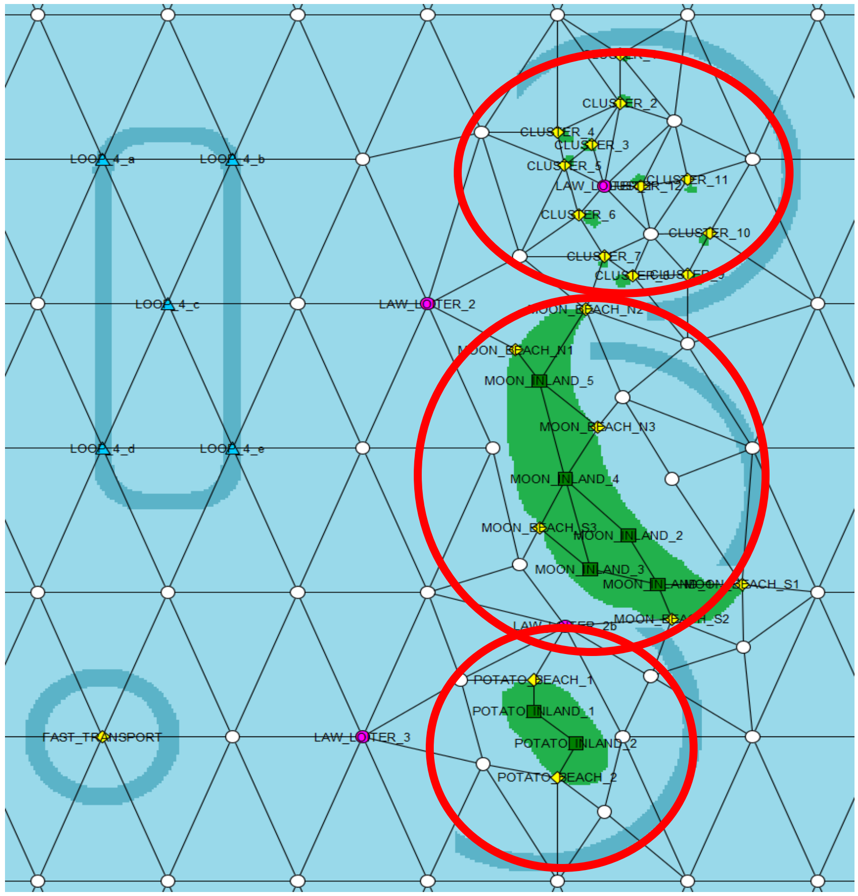

Figure 23. E2M2 EABO sustainment template map zones. The red circles are examples of three map zones. Source: Seater (2021).

c. Location Labels

Node labels must be applied to nodes within the map. Even if the map is changed, those labels must still exist, as they could be referenced by policies and missions (Seater et al. 2021). Figure 24 shows an example of the location labels. The location label MOON_BEACH_S3 is circled in red.

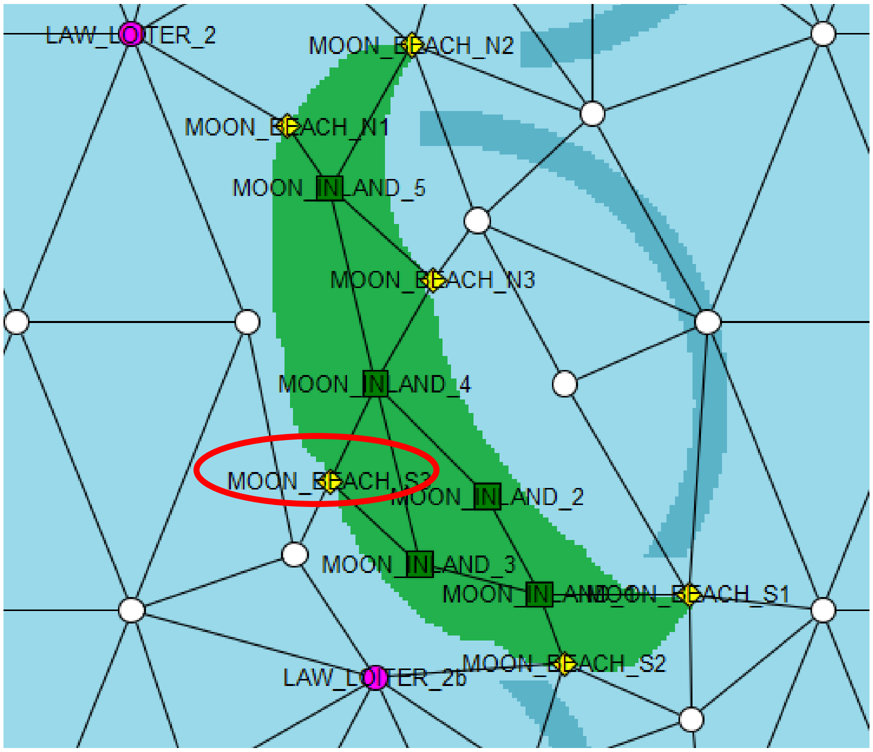

Figure 24. Location labels. Source: Seater (2021).

d. Policies

Every agent is assigned zero or more policies at any one time. Different agents within the same role might have different sets of policies, and agents might change policies over time (Seater et al. 2021). At the start of this scenario, the six FIRES teams located at Moon Island start with no SAMs or ASMs, and immediately want to be resupplied (Seater 2022). Depending on the defined LAW policies below, that determine when the LAW will accept a request to carry patients or provide ammo, eventually all the FIRES teams will be resupplied and the casualties evacuated.

(i) Transport Policies.

There are four transport policies.

- Patients first means that the LAW strictly evacuates patients first from the EAB to the next role of care, then resupplies the FIRES team.

- Patients first with opportunistic resupply policy is the same as patients first, except that if the LAW has ammunition on board at the time it must pick up patients, then the LAW can go ahead and resupply the FIRES team while it is there. The LAW will not divert to pick-up more ammunition from the supply point until all the patients are evacuated. If the LAW is already at the connector to receive fuel for its organic fuel tanks, it will resupply its ammunition reserves at the same time.

- Resupply first means that the LAW will strictly resupply FIRES first and then evacuate the patients.

- Triangle means that the LAW will pick up casualties, drop them off at the next role of care, pick up ammunition at the supply point, and then head back to the EAB to resupply FIRES and pick-up more casualties. This pattern continues until all casualties are evacuated and the FIRES team is resupplied.

(ii) Supply Policies

There are several policies that capture supplies carried. These policies include capacities of medical supplies versus patients. In the model, LAWs can carry either 10 or 20 SAM pallets and 10 or 20 patients on board.

- The “20 SAM pallets and 20 patients” policy maximizes the patients and pallets on board in exchange for having less room for medical care and supplies.

- The “20 SAM pallets and 10 patients” policy again maximizes SAM pallets, but now the LAW takes fewer patients in exchange for having enroute care teams on board.

- The “10 SAM pallets and 20 patients” policy reduces the SAM pallets to place the enroute care team and their equipment on the deck in

International Organization for Standardization (ISO) containers, maximizing patients inside the berthing area.

There is also a policy that governs when LAWs refuel. Dr. Robert Seater (2022) describes the baseline policy for when the LAWs refuel, as follows,

> LAWs…have the right to decide to refuel themselves whenever they get low. They want to avoid hitting zero and will seek resupply from a Navy OSV Connector if they need to. Similarly, the Navy OSV connectors will provide supply to any LAW who asks, unless they are busy with another LAW or fetching their own supplies from the CLF node. The CLF node is an abstracted representation of the rest of the Navy logistics chain and is just a fixed source of supply about 1000nm away.
>
> When a LAW resupplies itself with fuel, it will also grab ASM and SAM if it has space. In this manner, sometimes a 'patient first but lazy resupply' policy looks a lot like a 'triangle balance' policy, when the LAW goes to refill itself, it picks up ammo. When it visits the beach, it drops that ammo off opportunistically (Seater 2022).

(iii) Casualty Policies.

Each casualty has a policy that opportunistically takes any type of care available from the care providers at the casualty's current location. This means that casualties don't have any initiative to find a care provider, but they will accept care from any care provider that they end up sharing a location with (Seater 2022). Initially, the casualties all start at a node designated as the FRSS, so that each casualty can start receiving care from the FRSS. The FRSS then starts converting medical supplies into 'FRSS care' to meet the casualties' demands.

An agent can only accept resources from one source at a time. So, when a LAW arrives at the beach on Moon Island, the casualties continue receiving care from the FRSS until the moment the LAW picks up the casualties and moves off the beach, at which point, the casualties stop receiving resources from the FRSS (Seater 2022). As the simulation runs, the user will see the casualties at the beachhead, which acts as a check if recipients of a resource transfer are at the same location as the care provider. Figure 25 shows the casualty at the same location as the care providers, which are located at the FRSS.

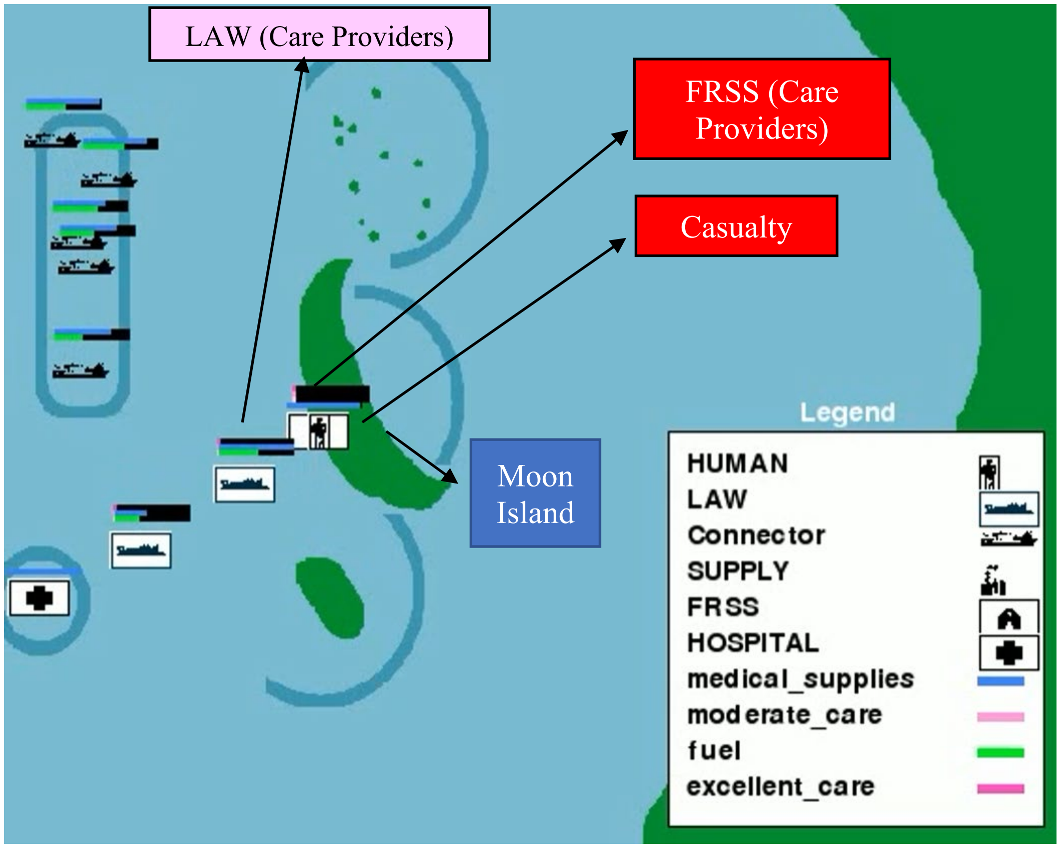

Figure 25. Casualty/FRSS simulation visual. Source: Seater (2022).

Transfers end once the recipients are separated from the care providers. So, when the LAW carries away a casualty, the user sees a pink bar pop-up over the LAW. This means that casualties are on board and are receiving Standard or Improved Care (moderate or excellent per the simulation). This implies that the casualties on board have stopped getting care from the FRSS and are now receiving care from the LAW, as shown in Figure 25. A casualty wants all types of care all the time, so it will look around to see who else at its location can provide it care. While on the LAW, the only caregiver a casualty sees is the LAW, so it starts taking 'LAW standard care' or 'LAW improved care' from the LAW, depending on how the LAW is configured. The LAW obliges by converting medical supplies into care to meet that demand (Seater 2022).

The same process repeats when the LAW arrives at the hospital. The LAW arrives, and the patients are still taking care from it. They cannot take care from two sources at once, so for now they keep taking from the LAW. The moment the LAW drops them off and leaves, they find that their connection to the LAW is gone. They cannot get care from the LAW anymore, so they look for care from another source. All they see is the Hospital, so they start taking care from the hospital, who obliges by converting medical supplies into 'hospital care'.

In that manner, patients accumulate care as a resource to track how much care they received. If that was all the information provided, then the model can show how much total care each patient received, but not the order in which the patient received care or when the patient received care. That would be acceptable for a linear model of fatality risk, but not for the non-linear models we borrowed from JMPT.

e. Resources

Dr. Robert Seater, Emmanuel Mallea and Yan Glina (2021) designed the resources based on a fixed set of supply types that can be carried and consumed by agents, and an agent can carry several supply types and have multiple separate transport capacities for the same supply type, such as organic fuel and cargo fuel (Seater et al. 2021). Dr. Seater (2021) designed supply types to be referenced by policies (such as a refuel policy), so the set of supply types cannot be extended or renamed. In this scenario, one of the supply types are SAMs and ASM to resupply the six FIRES teams. Each LAW can carry 14 ASM pods or 28 SAM pallets.

Another supply type is the amount of care a casualty receives. There are four levels of care resources used in the model, which are the FRSS, Hospital, Standard Care on the LAW, and Improved Care on the LAW. The FRSS is at the EABs, and the Hospital is the next level of care that the casualty needs to be transported to. In this scenario, the Hospital can be a robust Role II or a Role III facility, because the casualty's accumulated risk is only tracked to the Hospital care, and not at the Hospital. If the risk was tracked at the Hospital, the model would further define the Hospital into the specific facility, such as Hospital Ship, EPF Flight II, Air Force Expeditionary Medical Support, etc. The difference between the LAW Standard and Improved Care is that the Standard Care has the level of a First Responder on board and the Improved Care means there are enroute care teams, which is correlated to having battalion aid station level of care onboard. Casualties have unlimited storage capacity for each type of care, and the amount of each type of care they have stored represents the amount of that type of care they received. For example, a patient with 10 units of 'LAW-standard care' received care from the LAW for 60 minutes (Seater 2022).

(i) Randomness

The CASEVAC model has two stochastic components: the starting resource levels of each LAW and of each Offshore Support Vessel (OSV). Each of these surface craft start between 30% and 100% full and are computed separately for each type of cargo and its organic fuel tank (Seater 2022). These factors affect how much ammunition the LAWs can deliver on their first trip to EAB Moon Island. Furthermore, the random resource levels affect how far the LAW can travel to find an OSV.

Connectors are modeled as running constant loops waiting for resupply requests from LAWs, except when they return to the combat logistics force (CLF) point for their own refueling. LAWs prefer to resupply from a connector who has enough supplies on board, to avoid making multiple stops. LAWs will get paired with the closest connector, but that could be at the near end of the loop or the far end of the loop, which can vary as much as 100 nm. So, as an emergent effect of starting fuel levels, LAWs might spend more or less time traveling to meet a connector.

Every time the sim runs, all random values are drawn using a random seed. So, each sim run receives a random sequence of values to use for its decisions, and repeatability is ensured given that the seed used for each run is stored. Thirty replications were performed for each combination of inputs (known as design points) varied via our design of experiment.

f. Events

At a scheduled time, a global event flag can toggle on, and these flags are good for modeling a phase shift in the scenario that requires different parts of the scenario to change in sync (Seater et al. 2021). Dr. Seater, Emmanuel Mallea, and Yan Glina (2021) define unit-specific events as flags that trigger when a specified condition occurs to a unit, which are good for modeling when an individual unit has changed modes or phases separate from the larger scenario. Event flags have no inherent meaning, and are something that can be referenced by policies, disruptions, scheduled unit availability, and missions to allow synchronization (Seater et al. 2021).

2. Design of Experiments

Design of experiments provides a powerful methodology for exercising a model over numerous inputs simultaneously to increase understanding of model behavior, key drivers of performance, and influential change or threshold points. These are insights that would be difficult or impossible to obtain if we limit ourselves to just a small number of ad hoc runs. The Simulation Experiments and Experimental Design (SEED) Center for Data Farming at the NPS (https://harvest.nps.edu) specializes in providing a variety of efficient and flexible experimental designs to meet a variety of analytic goals for high-dimensional computational models.

The SEED Center uses the metaphor of "data farming" to describe iterative design and analysis of computer experiments (Lucas et al. 2015). Just like a farmer cultivates a plot of land to maximize yield, a data farmer intentionally and effectively manipulates simulation inputs using sound DOE techniques, to maximize information gained from experimentation. The data farmer thereby "grows" data needed for their analysis, according to their carefully designed experimental plan (Kleijnen et al. 2005). Kleijen et al. provides an overview of the benefits that can be gained by data farming any model that takes inputs and produces outputs. Though the particular approach used to design the experiment depends on analysis goals, the nature of the model, and computational budget, data farming greatly improves the information and insights possible from running any computational model.

With that in mind, and with confidence in the baseline model, we chose four factors to vary in our design of experiment. These factors, shown in Table 2, are as follows:

Table 2. Factors.

Hospital Locations	LAW Configurations	LAW Transportation Policies	Number of LAWs
-Loiter Point 3 -Loiter Point 4 -Tadpole Island (Marine Corps Base) -Potato Island -Fast Transport	-20 patients and 20 SAM pallets -20 patients and 10 SAM pallets -10 patients and 20 SAM pallets	-Patients first -Patients first with opportunistic resupply -Triangle -Resupply first	1 to 5 LAWs

Note: This table shows four factors. The first three factors represent policies that govern LAW behavior.

Although flexible and efficient designs are available, for this experiment we choose a full factorial design, which tests every possible combination of the inputs. This design yields the maximum amount of information and was deemed computationally feasible. Each combination of inputs constitutes a single design point, or equivalently, a row in the run matrix. For our factor set, the total number of runs is calculated as: (5 medical facilities × 3 LAW configurations × 4 LAW Transportation policies × 5 LAW Numbers) = 300 design points. For each design point, 30 replications were made, for a total of 9,000 CASEVAC simulation runs. In order to simplify assumptions, LAW configurations correlate to the number of patients with level of care on board.

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V. ANALYSIS

The E2M2 simulation runs were made by MITLL on their computers. The raw output generated by the simulation was post-processed by the MITLL team and shaped into a data frame that contains a record of simulation inputs, output metrics, and random seeds. To these data, we applied a variety of statistical and visual analyses to gain insights on the LAW's ability to perform mass casualty evacuations. The statistical analysis was conducted using JMP 7.0 Statistical Discovery Software (www.jmp.com). The analysis performed was focused on the following research questions from Chapter I:

- How can maritime forces utilize the LAW to best address mass casualties during conflict in a contested environment?
- How does the CASEVAC mission affect the LAW's ability to conduct sustainment operations?

A. DATA PROCESSING

The data from the 9,000 simulation runs includes two key measures of effectiveness (MOEs), the average total accumulated fatality risk (FatalityRisk) and delivery time (DeliveryTime) of ammunition to all six FIRES teams. As mentioned previously, our data also includes the values of the four experiment factors used for each run. We first summarize each design point by its mean, though certainly other statistics may be of interest. With the data table consisting of the means, we produce histograms and summary statistics for Mean(FatalityRisk) and Mean(DeliveryTime), with n = 300 for each, and these are displayed in Figure 26.

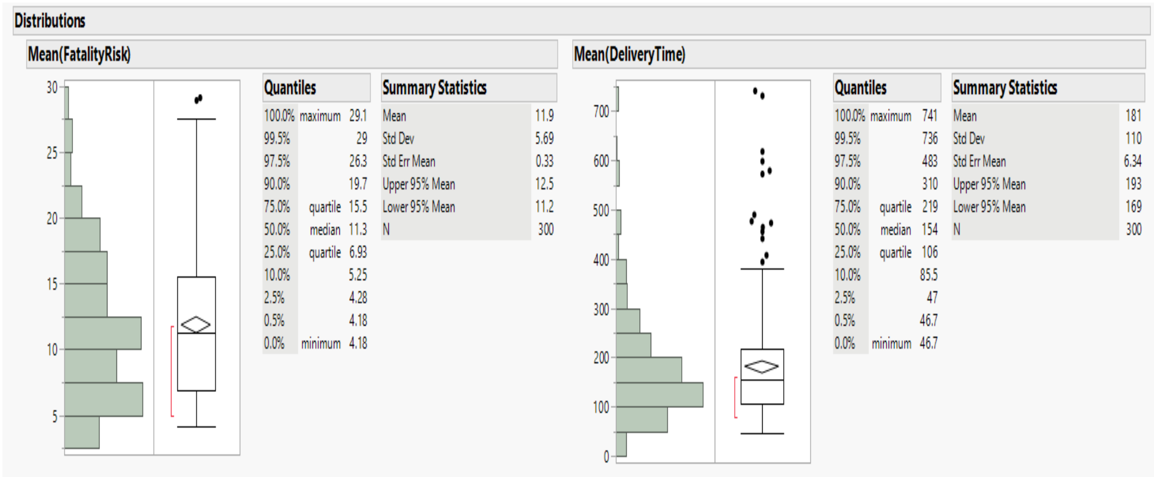


Figure 26. FatalityRisk and DeliveryTime Histograms and Summary Statistics

Based on this summary, the average FatalityRisk over the 300 design points is approximately 12 casualties, which approximates losing a Marine Infantry Squad. The average DeliveryTime is approximately 181 hours or 7.5 days. Both MOEs are accumulated over a 60-day scenario. Also observed in the analysis is that the experiment was successful in inducing interesting and meaningful variation, so the analysis next turns to understanding the significant drivers of this variability.

B. FACTOR INFLUENCE

The study seeks to conduct exploratory analysis, and in the process, come to understand how the experiment's factors influence FatalityRisk and DeliveryTimes, either individually or in combination. Their influence was analyzed using the techniques of stepwise regression and partition trees. Each of these techniques has strengths and limitations, and are particularly effective when used together, since their respective insights complement each other.

1. Interactive Linked Visualization

The first look at the data, through interactive linked visualization, reveals factor settings that correspond to the highest fatality risk. Figure 27 shows highlights of the fatality risk values (darkened color) that were greater than or equal to ten. The darkened areas on the four input factor distributions to the left indicate where the preponderance of these values are located.

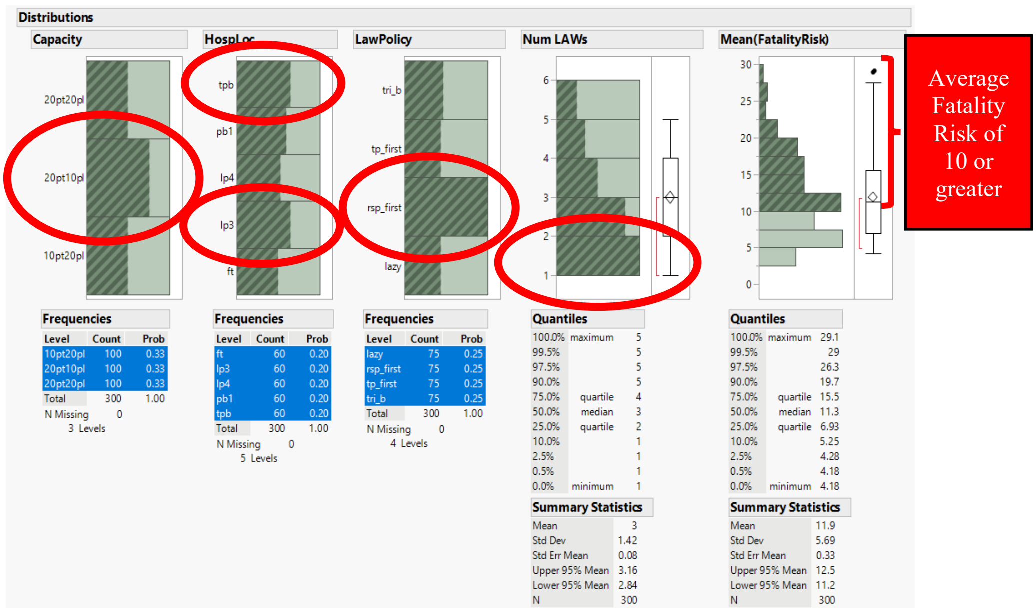


Figure 27. Linked histograms showing the factor settings that correspond to an average of 10 or more fatalities.

Figure 27 shows, circled in red, the factor settings (policies) that are associated with the highest fatalities. These policies are:

- 20 patients and 10 ammunition pallets capacity.
- Hospital locations at Tadpole Island and Loitering Point 3. These locations are greater than 3,000 nm away.
- Resupply First policy, which prioritizes resupplying all six FIRES teams before evacuating any casualties to the next role of care.
- Use of only one LAW.

We repeat this analysis for the DeliveryTimes metric and display the result in Figure 28. The darkened points highlight the policies that are associated with average DeliveryTime (to resupply all six FIRES teams) of eight days or greater.

Figure 28. Linked histograms showing the policies that correspond to an eight day or greater average DeliveryTime.

Similar to Figure 27, Figure 28 also reveals, circled in red, several policies that had the greatest influence on long DeliveryTimes. The main difference between this result and the previous is the LAW policy of patients first (vice the resupply first policy). The LAW Capacity policy of 20 patients and 10 pallets is most associated with the longest DeliveryTimes. Similarly, the triangle method follows closely behind the patients first for having long DeliveryTimes.

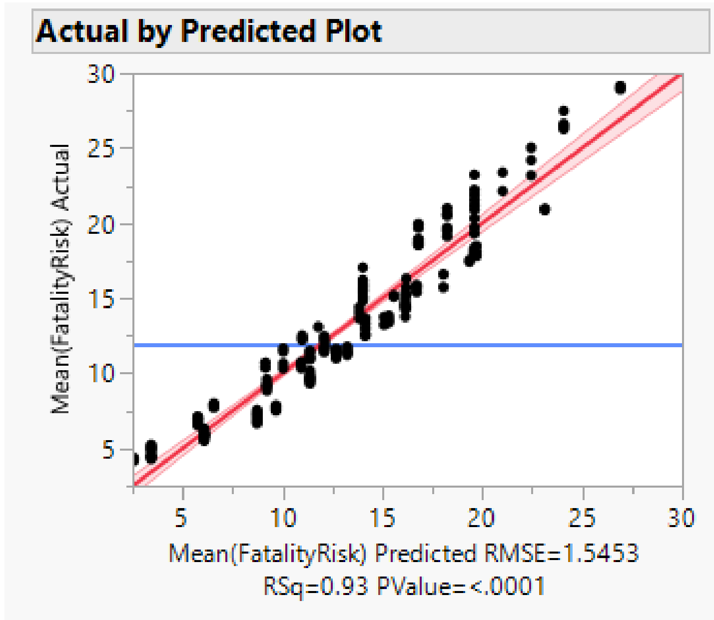
According to these views, the resupply first policy is the best policy for achieving fast DeliveryTimes, and the patients first policy is the best policy for achieving low fatalities. This makes intuitive sense and adds confidence to the modeling. Examining the worst outcomes for both metrics, the scenario with the highest fatalities (average of 30) corresponds to the use of only one LAW, using the 20 patients and 10 pallets capacity policy, and conducting resupply first missions to Tadpole Island. Similarly, the longest delays are associated with these same parameters, except that the LAW utilizes a policy of patients first. With this basic understanding of the output, we turn now to stepwise regression to further reveal information about the most significant factors and interactions.

2. Stepwise Regression

Stepwise regression uses an algorithm to iterate through adding or removing possible regressors until a specified stopping criterion is reached to arrive at the final model (Montgomery, Peck, and Vinning, 2006). For relative simplicity and ease of understanding, the stepwise regression model we fit to each of our two metrics considers all main effects and two-way interactions of the four experiment factors.

a. FatalityRisk

We next fit a stepwise regression model to Mean(FatalityRisk). The final model has an R-Squared of 0.93, which means that 93% of the variability of the mean FatalityRisk is explained by the model. Figure 29 shows the actual by predicted plot and summary of fit of the regression model. The actual versus predicted graph provides a visual of how well the model fits the data. Points that are further from the fitted model (red line) are not as well explained by the model as those that are closer to or lie on the red line. The solid blue line indicates the overall average FatalityRisk.



Summary of Fit

RSquare	0.929
RSquare Adj	0.926
Root Mean Square Error	1.545
Mean of Response	11.89
Observations (or Sum Wgts)	300

Figure 29. Actual by Predicted Plot and Summary of Fit for the regression on Mean(FatalityRisk).

A low p-value for the F ratio in the Analysis of Variance table, shown in Figure 30, indicates that the model as a whole is statistically significant and has more explanatory power than simply the overall mean.

Analysis of Variance				
Source	DF	Sum of Squares	Mean Square	F Ratio
Model	9	8997.1	999.68	418.6251
Error	290	692.52	2.39	Prob > F
C. Total	299	9689.6		<.0001*

p-value

Figure 30. Analysis of Variance Table for the regression on Mean(FatalityRisk).

The relative influence of each factor is determined by the t-Ratio and its corresponding p-value. The higher the absolute value of the t-ratio, the greater the relative influence on the MOE. Figure 31 lists the parameter estimates in order of significance (t-Ratio).

Parameter Estimates				
Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	23.4	0.22	107.10	<.0001*
Num LAWs	-3.1	0.06	-49.74	<.0001*
LawPolicy{lazy&tp_first&tri_b-rsp_first}	-2.5	0.1	-24.04	<.0001*
Capacity{20pt20pl&10pt20pl-20pt10pl}	-2.1	0.09	-22.66	<.0001*
HospLoc{ft&lp4&pb1-tpb&lp3}	-0.8	0.09	-8.30	<.0001*
(HospLoc{ft&lp4&pb1-tpb&lp3}-0.2)*(Num LAWs-3)	0.46	0.06	7.12	<.0001*
(Capacity{20pt20pl&10pt20pl-20pt10pl}-0.33333)*(Num LAWs-3)	0.41	0.07	6.07	<.0001*
(Capacity{20pt20pl&10pt20pl-20pt10pl}-0.33333)*(HospLoc{ft&lp4&pb1-tpb&lp3}-0.2)	0.42	0.1	4.38	<.0001*
(LawPolicy{lazy&tp_first&tri_b-rsp_first}-0.5)*(Num LAWs-3)	-0.3	0.07	-4.10	<.0001*
(Capacity{20pt20pl&10pt20pl-20pt10pl}-0.33333)*(LawPolicy{lazy&tp_first&tri_b-rsp_first}-0.5)	-0.3	0.11	-3.15	0.0018*

Figure 31. Parameter estimates for the regression on Mean(FatalityRisk).

We observe that the t-Ratio for the number of LAWs (Num LAWs) is -49.74. This is the highest of any factor, which means that Num LAWs is the most significant factor in the determination of FatalityRisk. The negative value indicates that as the number of LAWs increases, the FatalityRisk decreases. Figure 32 shows the prediction profiler for FatalityRisk and DeliveryTime side-by-side.

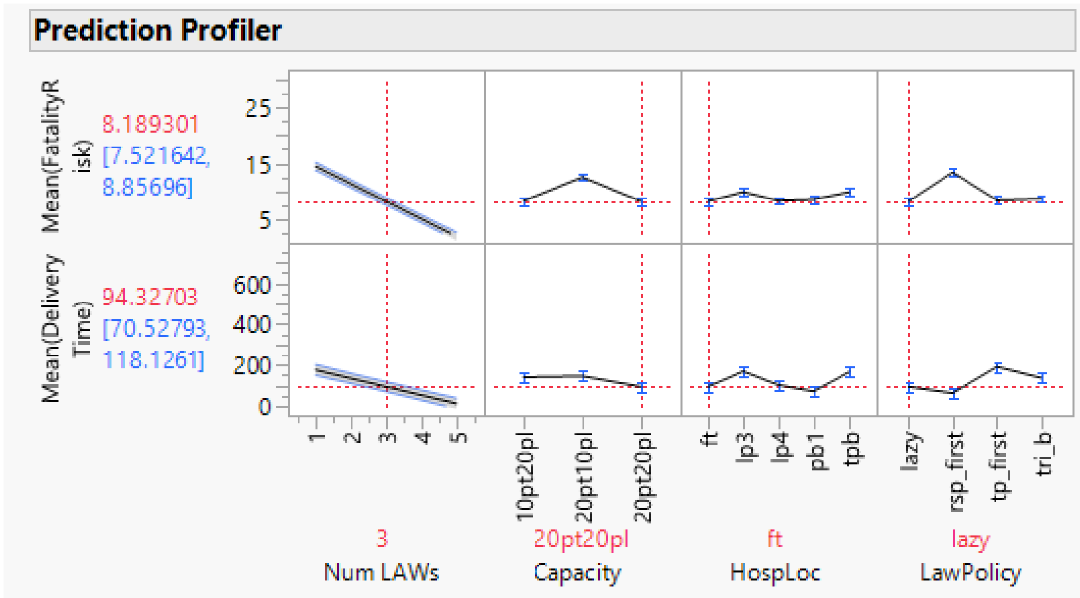
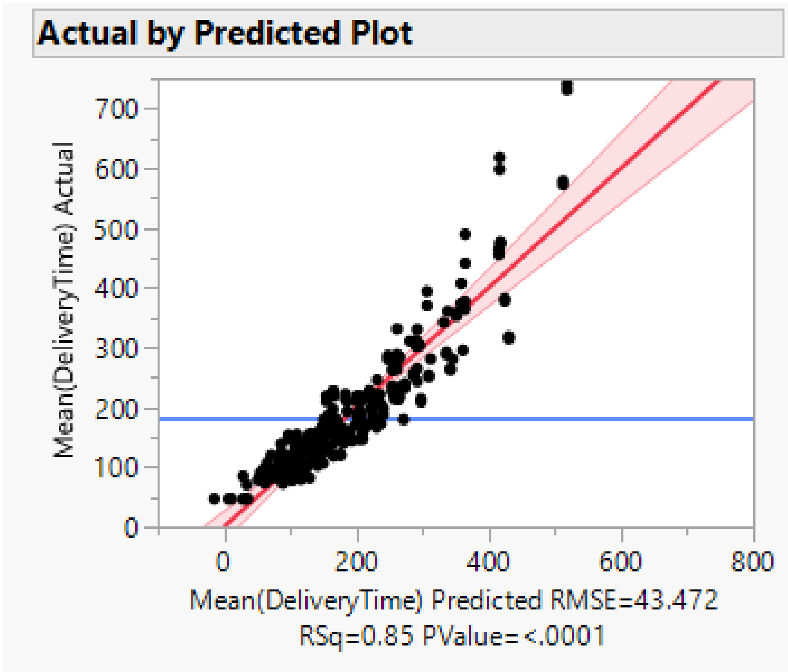


Figure 32. Prediction Profiler for the regression of Mean(FatalityRisk) and Mean(DeliveryTime).

The Prediction Profiler in JMP gives insight into how the FatalityRisk and DeliveryTime change as a function of the factors and allows for interactive one-at-a-time changes. For example, Figure 32 shows the number of LAWs having been set to three. Looking at the remaining factors, the policies chosen, yield the lowest fatalities and fastest delivery times. The policies selected are the LAW capacity of 20 patients and 20 pallets, transport policy of patients first, and opportunistic resupply to the hospital location at the Fast Transport. With these settings, the predicted values for the responses are approximately eight fatalities and four days to resupply six FIRES teams, on average.

b. DeliveryTime

We next fit a stepwise regression to Mean(DeliveryTime). The model attained an R-Squared of 0.85, which means that 85% of the variability of the mean DeliveryTime is explained by the model. This model fit is not as good as the one achieved for Mean(FatalityRisk), but is deemed sufficient for our purpose. We choose to leave the outliers in and note that they are explained by the use of only one LAW. Figure 33 displays the actual by predicted plot and summary of fit for the regression model.



Summary of Fit

RSquare	0.853556
RSquare Adj	0.843058
Root Mean Square Error	43.47159
Mean of Response	181.0306
Observations (or Sum Wgts)	300

Figure 33. Actual by predicted plot and summary of fit for the regression on Mean(DeliveryTime).

A low p-value for the F ratio in the Analysis of Variance table, shown in Figure 34, indicates that the model fit as a whole is significant and has higher explanatory power than the overall mean.

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	20	3073084.5	153654	81.3080
Error	279	527248.3	1890	Prob > F
C. Total	299	3600332.8		<.0001*

p-value

Figure 34. Analysis of variance table for the regression on Mean(DeliveryTime).

c. Number of LAWs

We next examine the influence of the number of LAWs through a scatter plot. Figure 35 shows a scatter plot of Mean(FatalityRisk) versus Mean(DeliveryTime), where the points are colored by the number of LAWs.

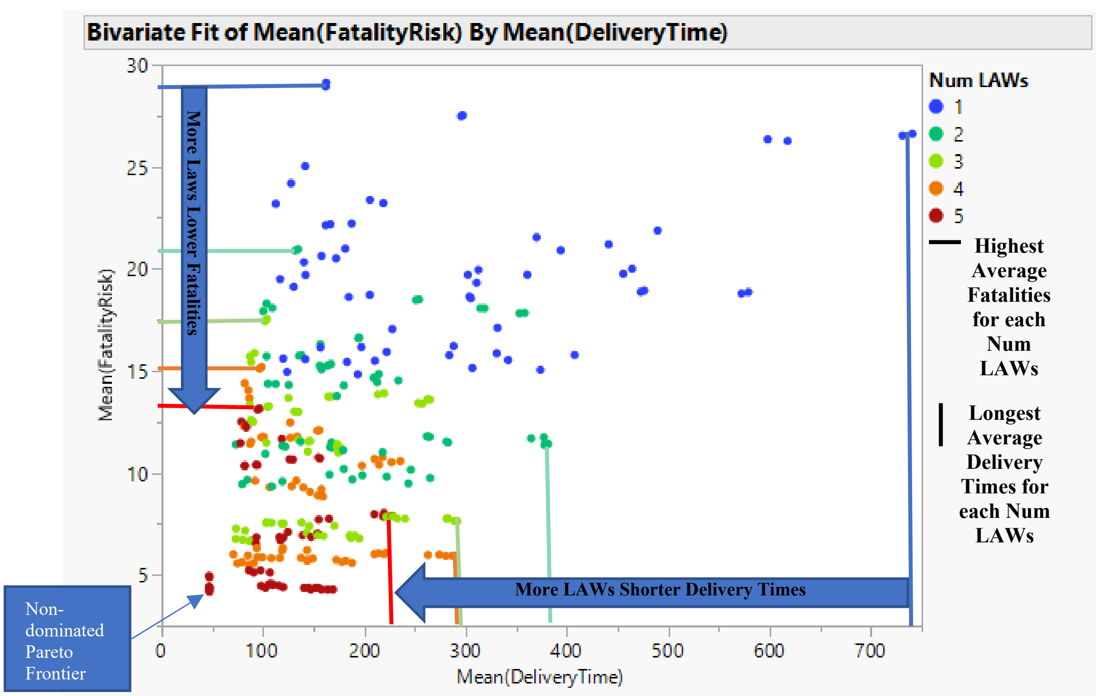


Figure 35. Mean(FatalityRisk) versus Mean(DeliveryTime) colored by Number of LAWs. Four points shown near the origin are in the non-dominated Pareto frontier.

Figure 35 generally conveys that, scenarios with only one LAW result in very long delivery times as well as high fatalities. Even the worst scenario with an additional LAW (i.e., two LAWs) reduces the average fatalities by about eight, compared to the highest FatalityRisk for one LAW, as shown by the colored horizontal lines on the graph. Each line is drawn at the worst FatalityRisk for each Num LAW. In other words, the highest blue line indicates the highest value when only one LAW is used, the next is the highest with two LAWs, and so on. Similarly, having even just one additional LAW, for a total of two, decreases the DeliveryTime to an average of about 12.5 days. Out of all the 300 scenarios, Figure 36 shows the only four scenarios in the nondominated Pareto frontier. Each point in the Pareto frontier represents a unique CASEVAC scenario. All of the four scenarios that are very close in terms of performance of the FatalityRisk and DeliveryTime and are shown closest to the origin in Figure 36.

Num LAWs	Capacity	Capacity_Patients	Capacity_Pallets	HospLoc	LawPolicy	N Rows	Mean(FatalityRisk)	Mean(DeliveryTime)
5	10pt20pl	10	20	lp3	lazy	30	4.1833903381	46.996666667
5	10pt20pl	10	20	tpb	lazy	30	4.1833903381	46.996666667
5	20pt20pl	20	20	lp3	lazy	30	4.2262690863	46.7
5	20pt20pl	20	20	tpb	lazy	30	4.2262690863	46.7

Figure 36. Nondominated Pareto frontier data points that show the optimal values of minimizing Mean(FatalityRisk) and Mean(DeliveryTime).

For further insight, Figures 37 and 38 depict box plots for FatalityRisk and DeliveryTimes, respectively, versus the number of LAWs.

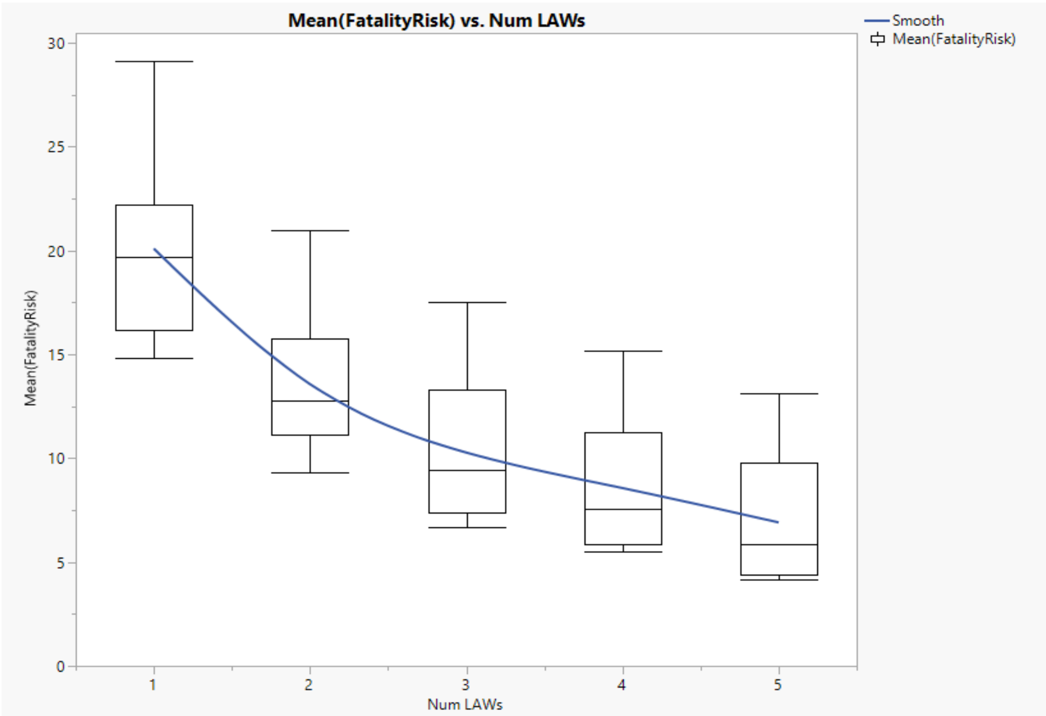


Figure 37. Box plot of Mean(FatalityRisk) versus number of LAWs.

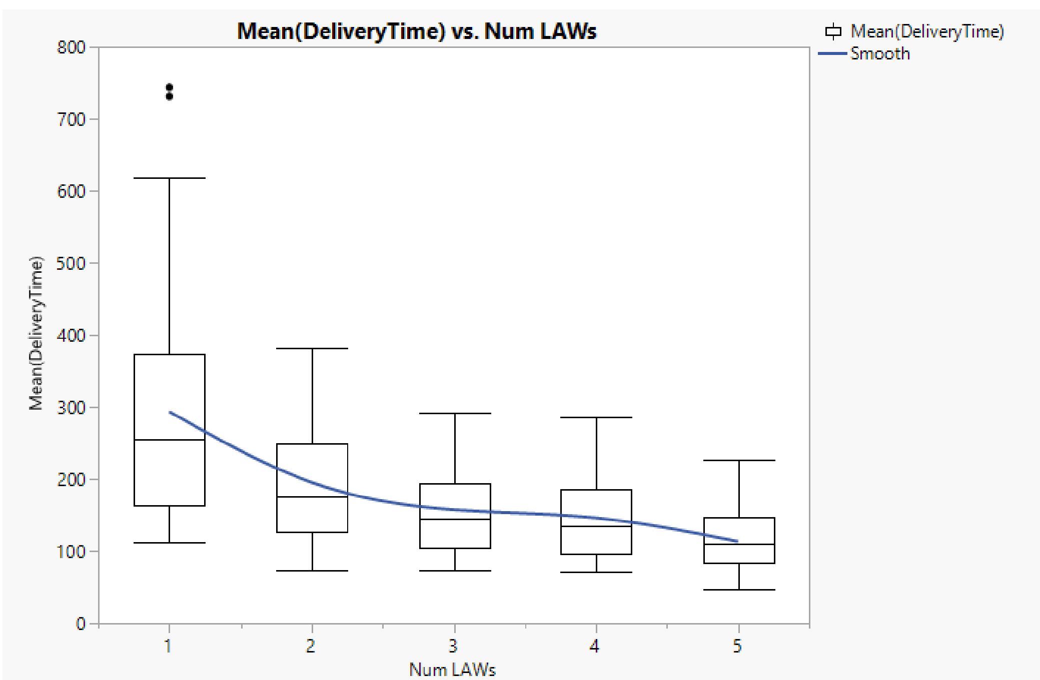


Figure 38. Box plot of Mean(DeliveryTime) versus number of LAWs.

In Figures 37 and 38, we observe appreciable improvement for both FatalityRisk and DeliveryTime as the number of LAWs increases. Based on the differences between the medians (middle line) in each box, the largest decreases occur from one LAW to two, with each MOE starting to level-out with three or more LAWs.

3. Partition Trees

This section introduces the use of partition tress to capture the influence of the factors on a given response. A partition tree, a nonparametric technique, recursively partitions the data into two groups, each time choosing the factor and split value that most increases the RSquared value of the tree model. The result might be loosely interpreted as a tree of decision rules that best separate "good" from "bad" outcomes. A partition tree created for Mean(FatalityRisk) is shown in Figure 39. This partition tree achieves an RSquared of 0.87.

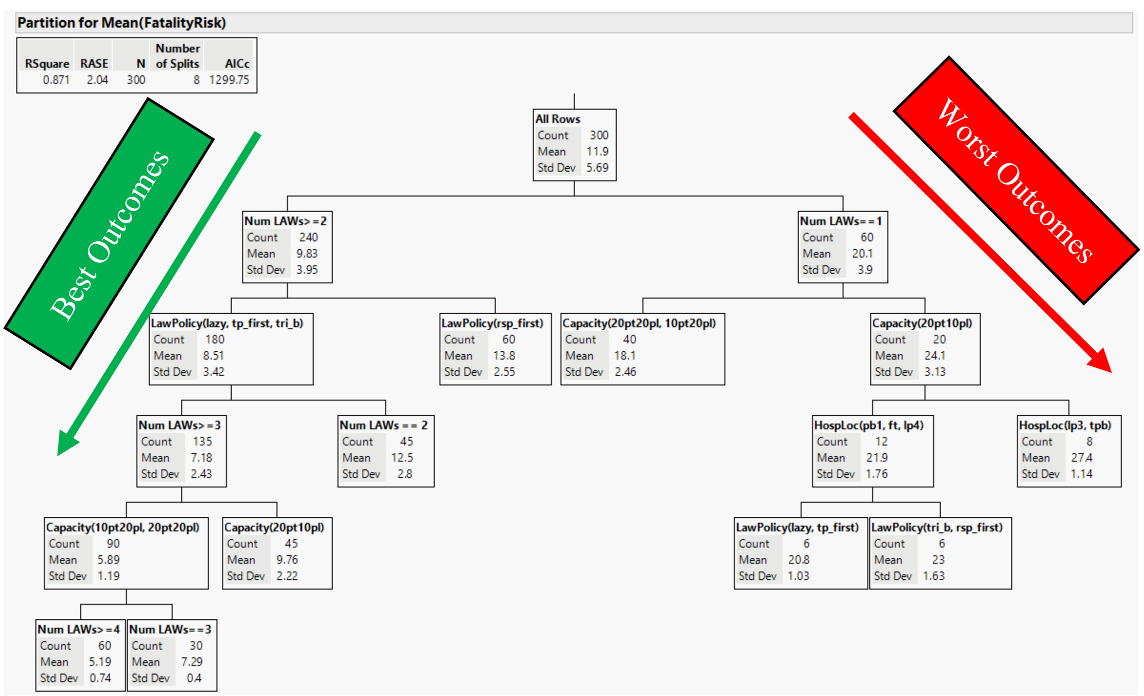


Figure 39. Partition tree for Mean(FatalityRisk).

The first split occurs on Num LAWs, which was also the most influential factor identified by the stepwise regression analysis. The split value occurs at two LAWs. The average fatality with greater than or equal to two LAWs is on average about 10 fatalities less than if there is only one LAW (9.83 versus 20.1). The second split is on the LAW's policies (LAWPolicy). When the LAW conducts the patients first, patients first with opportunistic resupply, or the triangle policy, the fatalities are five fatalities less than if the LAW conducted the resupply first policy (8.5 versus 13.8). Further increasing the number of LAWs to three or greater decreases the average fatalities to approximately seven.

If only one LAW is available to support the MLR, we conclude that it better to use the 20 patients, 20 pallets or the 10 patients, 20 pallets capacity policies, which achieve a lower average fatality of 18, on average, across the other scenarios, but of course this is still too high since every life saved matters.

Another partition tree is created for Mean(DeliveryTime), shown in Figure 40. This partition tree achieves an RSquared of 0.63, explaining about 63% of the observed variability.

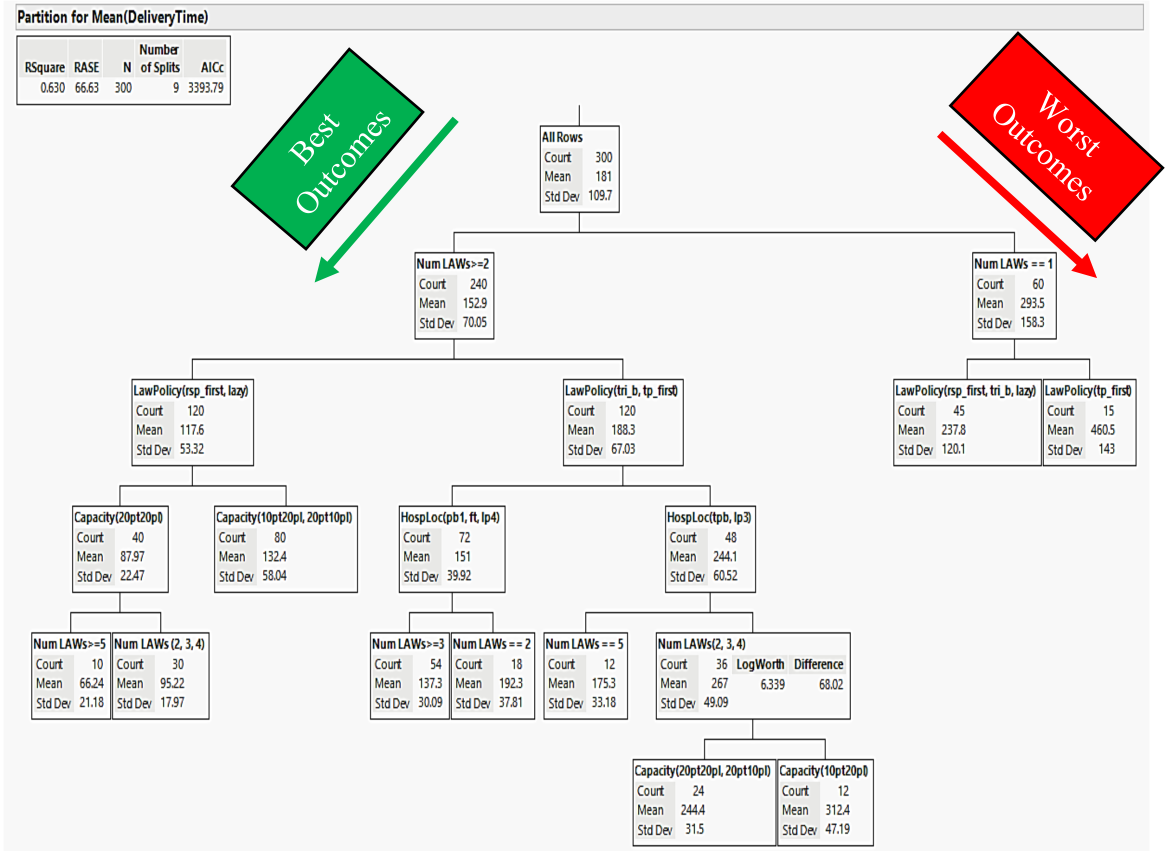


Figure 40. Partition tree for Mean(DeliveryTime).

The first split also occurs on Num LAWs, with the split value again occurring at two LAWs. The average delivery time with greater than or equal to two LAWs is on average about 141 hours or close to six days less than if there is only one LAW (153 versus 294). The second split is on the LAWPolicy. When the LAW conducts the resupply first or patients first with opportunistic resupply, the DeliveryTime is 10 hours less than if the LAW conducted the other LAWPolicy's (118 versus 181). Improvements are seen from the DeliveryTime of 118 hours when the LAWs Capacity is 20 patients and 20 pallets (88 hours). Further increasing the number of LAWs to five decreases the average delivery time by 20 hours.

If only one LAW is available to support the MLR, we conclude that it better to use any of the LAW transport policies except for patients first. Choosing any of the other policies with one LAW decreases the average delivery time of about 200 hours! This would of course require that other assets are available to evacuate casualties. Appendices D, E and F show more robust tables that support this.

VI. CONCLUSION

The purpose of this thesis is to advance the development of the E2M2 in a prototype study to determine if the LAW might be a viable CASEVAC platform and begin to understand how CASEVAC missions could affect the LAW's ability to conduct sustainment operations in a EABO environment. Insights into the development of future tactics, techniques, and procedures (TTPs) for the LAW are provided and discussed in the context of comparable surface platforms conducting CASEVAC in the distributed environment. In addition, the E2M2 simulation was explored via design and analysis of experiments. We deem E2M2 to be a viable and capable tool for conducting further studies of logistical support to combat operations.

A. EXPLORATORY ANALYSIS OF LAW REQUIREMENTS

E2M2 was run over many combinations of inputs to yield insight into questions regarding the LAW's ability to support both CASEVAC and resupply missions in a notional scenario. Summary statistics, plots, regression analysis, and partition trees are used to determine how the experiment factors affect the total accumulated fatality risk and the delivery time to resupply six fire teams. Of the inputs varied via the design of experiment, the factors with the greatest effect on fatality risks and delivery times are the number of LAWs and the LAW's transport policies. The configuration of each LAW was determined by analyzing the number of patients, the number of ammunition pallets, and the level of care on-board. The impact of various hospital locations was analyzed to illustrate the trade-off between a Commander's choice to move medical facilities farther forward to decrease fatalities or move medical care farther away to decrease risk from enemy threats to the medical facilities.

1. Number of LAWs

The number of LAWs was varied between one and five. The average fatality risk and average delivery time were used to determine the number of LAWs necessary to achieve low fatalities and short delivery times. When one LAW is used, the average fatality risk) is 20 fatalities, and the average delivery time is approximately 256 hours (10.5 days).

The average fatality risk decreases to 13 fatalities and the average delivery time to about 176 hours (~7.5 days) when a second LAW is added.

The average fatality risk drops when three LAWs are available, to an average of nine fatalities, eight fatalities for four LAWs, and six fatalities for five LAWs. Similarly, the average delivery time drops to an average of 145 hours (6 days) with three LAWs, 136 hours (5.5 days) with four LAWs, and 109 hours (4.5 days) with five LAWs.

Although a significant drop in fatalities and delivery times occur from one LAW to two LAWs, the results suggest that three LAWs may be adequate to support both the MLRs sustainability and CASEVAC missions, for this notional scenario, keeping in mind that significantly variability still exists over the other factor settings and random chance.

2. LAW Transport Policy

Four LAW transport policies were tested. The LAW transport policy necessary to achieve low fatalities and fast delivery times varies as the number of LAWs change. This is an example of an interaction effect that may have been missed if both weren't varied simultaneously, vice one at a time changes. When one LAW is available, the "patients first" or "patients first with opportunistic resupply" policies yielded the lowest fatalities. To achieve low delivery times, the "resupply first" policy is the best, followed by "patients first with opportunistic resupply." Because "resupply first" with one LAW produces the highest fatalities, and "patients first" produces the longest delivery times, the best policy with one LAW is the patients first with opportunistic resupply, assuming a balance is desired and other assets are available to handle a portion of the CASEVAC missions. These findings also generally held with two LAWs. When three LAWs are available, the triangle policy can be added as an option to achieve the lowest fatality risk, but the "triangle" and "patients first" policies produce the worst delivery times, with an increase of about 80 hours. Therefore, "patients first with opportunistic resupply" remains the best policy for three LAWs. If the LAW starts with no ammunition on board, the next best policy would be the "triangle" policy. This is because the "resupply first" and "patients first" favors one MOE at the expense of the other.

3. LAW Capacity

Three configurations for LAW capacity were tested. The capacity required to achieve an acceptable fatality risk and delivery time varies with the number of LAWs. As the number of LAWs is increased, though, the difference in outcomes between the capacity options is less pronounced

Capacity configurations of "10 patients with an ERC team and 20 SAM pallets" or "20 patients with no ERC team and 20 SAM pallets" yielded the best results in terms of low fatalities if only one LAW is available to minimize the number of fatalities. These two configurations performed consistently as the number of LAWs increase. Conversely, the fastest delivery times with only one LAW was achieved with the "20 patients and 20 pallets" configuration. This configuration also consistently performed better than the other two configurations, with respect to delivery time, as the number of LAWs increase. Thus, the "20 patients and 20 pallets" yielded the best results when taking into account both fatality risk and delivery time.

4. Hospital Locations Dependent on Number of LAWs

Five hospital locations were tested. As expected, with only one LAW, fatality risk was lowest when transporting to the closest locations: Potato Island, Fast Transport, and Loitering Point 4. Delivery times were generally lower when transporting casualties to Potato Island. As the number of LAWs increased to two or more, the hospital locations became insignificant with respect to fatality risk. Hospital locations had a greater influence on delivery times. With the increase of LAWs, the farther hospital locations such as Loitering Point 3 and Tadpole Island had the longest delivery times. The remaining three locations yielded similar performance as the number of LAWs increased. Given the previous insights on the effect of increasing the number of LAWs from one to five, we conclude that having three LAWs that transport to any of the three closest hospitals are better at achieving lower fatality risk and resupply times in this scenario.

5. Recommendations

The analysis of the E2M2 experiment reveal potential requirements for the number of LAWs, the LAW capacity, and transportation policy, given hospital location, to adequately respond to the 100 simulated casualties and resupply missions at Moon Island. Based on initial results, three LAWs conducting the "patients first opportunistic resupply" transport policy with 20 patients, no ERC team and 20 pallets on board to Potato Island, Loitering Point 4, or Fast Transport yielded the best result in this test scenario. Though this analysis was based on a notional scenario, the recommendation illustrates that the goal is to present a Commander with options for placing Role II/Role III medical facilities throughout the area of operations, in order to both adequately evacuate and treat casualties and conduct resupply operations in support of EABO.

B. FOLLOW-ON RESEARCH

The insights from this thesis are based on a single notional scenario. This study focuses on how the LAW can best be utilized to handle both resupply and CASEVAC missions. Future analysis of LAW employment should incorporate adversary actions given that forces and transportation assets will reside inside the adversary's weapon engagement zone. Further analysis should also include updated information on the LAW's design, new technologies and surface platforms, as well as the integration of air assets. Although assumed in this scenario that the facilities on the LAW can accommodate medical personnel, equipment, and casualties (both litter and ambulatory), it is important to note that the design of the LAW must accommodate the mobility of casualties throughout the LAW, as well as the means to transfer casualties on and off the LAW. Specific medical equipment, supplies, and care require additional requirements, for example, refrigeration, power, potable water, and grey water drainage.

Weather injects could be included to capture realistic delays, especially within the Pacific Region. Furthermore, having multiple mass casualty events on separate EABs or on surface platforms will allow for capturing the complexities of these events occurring in a dispersed and disaggregated environment. Additionally, ammunition represents only one type of supply demand, so additional supply types might be considered. Different refueling policies for the LAW, such as having to go off-station versus refueling at sea, and different fuel types are considerations for further evaluation.

The focus of this study was to solely evaluate the LAWs performance. For future analysis, it is vital to consider the demands on medical personnel and resources. Adding demands for rotating medical staffs and medical resupplies for medical facilities such as the FRSS and on-board the LAW must be investigated further in this scenario. The medical concepts outlined in the current Navy and Marine Corps doctrines may be too robust and unrealistic for an EABO environment (Lyon 2021). The Navy and Marine Corps should evaluate new medical concepts, specifically looking at the research done by Lieutenant Colonel Regan Lyon, United States Air Force, and a graduate from the Naval Postgraduate School on guerilla warfare/unconventional warfare medical systems (Lyon 2021). With regards to the medical footprint on an EAB, the Navy and Marine Corps should also consider capabilities and TTPs of discrete Joint units that have "jumpable" operating rooms with small footprints to learn from or to utilize in this type of environment (Muench 2022). Lastly, exploring emerging medical technologies can be added to this study for further analysis in reducing the medical footprint forward.

Lastly, in an EABO environment, communications may be degraded or denied, thus command and control delays should be considered as well. Lastly, this thesis research is the first to use the E2M2, and its further use is recommended. E2M2 represents a valuable addition to the suite of models that could be used to explore energy and logistical implications of Navy and Marine Corps concepts and technologies.

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APPENDIX A. CASUALTY EVACUATION SURFACE PLATFORMS

Platform	Notes	Medical Personnel
Attack Transports (APA)* (Inactive)	Litter 12 Ambulatory 325	-3 Medical Officers -1 Dental Officer -1 Hospital Corps Officer -20 Corpsman
Amphibious Force Flagship (AGC)* (Inactive)	[redacted]	-2 Medical Officers -1 Dental Officer -10 Corpsman
Hospital Ship (AH)*	Litter 350 Ambulatory 200	[redacted]
Attack Cargo Ships (AKA)* (Inactive)	Litter 15 Ambulatory 50	-1 Medical Officers -5 Corpsman
Transports (AP)*	Litter 70 Ambulatory 150	-2 Medical Officers -1 Dental Officer -1 Hospital Corps Officer -7 Corpsman
Hospital Transport (APH)*	Litter 200 Ambulatory 400	-10 Medical Officers -1 Dental Officer -4 Hospital Corps Officer -51 Corpsman
Amphibious Cargo Ship (LKA-113)** (Inactive)	Speed 20 knots Range at 16 knots 9,600 nautical miles Officer accommodations 15 Enlisted accommodations 211 Vehicle square (square feet) 47,000 Cargo cube (cubic feet) 88,100 Helicopter landing spot 1 Operating room 1 bed Isolation ward 4 beds Primary care ward 9 beds	-Doctor
Landing Ship, Vehicle (LSV)* (Inactive)	Litter 50 Ambulatory 144–200	-2 Medical Officers -1 Dental Officer -1 Hospital Corps Officer -7 Corpsman
Logistics Support Vessel (LSV)***	US Army; “Direct transport and discharge of liquid and dry cargo to shallow terminal areas, remote under-developed coastlines and on inland waterways” (Naval Technology (2000) Cargo 2000 tons Deck area 10,500 square feet Range 8,200 nautical miles at 12.5 knots (light); 6,500 nautical miles at 11.5 knots (loaded)	[redacted]
Landing Craft, Vehicle and Personnel (LCVP)* (Inactive)	CASEVAC from Beach head to APA Litter 17 Ambulatory 36	
Landing Vehicle, Tracked (LVT)* (Inactive)	Used when reefs were an issue* CASEVAC from beach head to LVCP to APA Needs a float or pontoon barge to transform platforms* Litter 4	
Landing Craft, Infantry (LCI)* (Inactive)	Best for internship transfer of small number of casualties* Difficult to get stretcher into troop compartment * Litter 15 Ambulatory 400	-1 Medical Officers -1 Corpsman
Landing Ship, Medium (LSM)* (Inactive)	Not routinely used for CASEVAC due to size Difficulty of handling at sides of ships	[redacted]
Landing Craft Tank (LCT)* (Inactive)	During WWII, not routinely used for CASEVAC due to size.* Difficulty of handling at sides of ships.*	-1 Medical Officers -2 Corpsman

Tank Landing Ship (LST-1179)** (Inactive)	Speed 22 knots Range 14,250 nautical miles Officer accommodations 20 Enlisted accommodations 294 Surge accommodations (E-6 and below) 72 Vehicle square 16,500 square feet Cargo cube 4,500 cubic feet Helicopter landing spot 1 No Medical Capabilities	[redacted]
Landing Ship, Tank (H) (LST (H))* (Inactive)	May be used as CASEVAC to transports or hospital facilities on adjoining islands LSTs used for casualty evacuation Ambulatory 300	-1 Medical Officers -3 Corpsman
Landing Craft, Utility (LCU)**	Cargo deck 1,850 square feet Displacement (loaded) 437 tons Troop capacity (on deck) 400 Cargo capacity 143 tons Speed 12 knots Range 1,200 nautical miles	[redacted]
Landing Craft, Air Cushion (LCAC)**	Cargo deck 1,809 square feet Troop capacity 24 Cargo capacity (design) 60 tons Cargo capacity (overload) 75 tons Displacement (full load) 166.6 tons Displacement (capacity load) 181.6 tons Speed 40+ knots Range 200 nautical miles	[redacted]
Landing Craft, Mechanized (LCM)**	Steel: Cargo deck 588 square feet Troop capacity 200 Cargo capacity 60 tons Speed 12 knots Aluminum: Cargo deck 714 square feet Troop capacity 200 Cargo capacity 60 tons During WWII, not routinely used for casualty evacuation due to their size and difficulty of handling at the side of the ships*	[redacted]
Expeditionary Fast Transport (EPF Flight II)****	Airline seating for more than 312 personnel; fixed berthing for an additional 104; Seating is on a roller (Conversation with LT Ken Marler) Role II Speed 33 knots with payload, 43 knots without payload Range 1200nm at 33 knots (Maximum transit), 4700 at 21 knots (Self-deployment), 2000nm at 21 knots (Medical mission) Medical Ward Beds 23 Intensive Care Unit Beds 10 Isolation Berths 8 Medical Personnel Berths 147 OR-1 Surgical Suite Containing 2 operating tables OR-2 Minor Procedures Room 1 operating table ICU/Ward area with nurse's station Patient Triage, Patient Administration, Medical Library Ancillary Services (Medical Laboratory, pharmacy, Blood bank) Patient Elevator between 02LVL Ward Area & Mission Bay Heli Spot 1	-4 Medical Officers -4 Nurses
Light Amphibious Warship (LAW)*****	Embark 75 Marines 4,000 to 8,000 square feet of cargo area for the Marines' weapons, equipment, and supplies Speed at least 14 knots	

	Range 3500nm at 14 knots	
Amphibious Assault Ship (LHA-1)**	4 LCU or 1 LCAC 9 Heli Spots Operating rooms 4 Post-operative recovery/Intensive care 17 beds Isolation ward 4 beds Primary care ward 48 beds Officer accommodations 172 Enlisted accommodations 1,731 Vehicle square 28,700 square feet Cargo cube 156,000 cubic feet Speed 24 knots Range at 20 knots 10,000 nautical miles	-Doctor -Dentist
Amphibious Assault Ship (Multipurpose) (LHD-1)**	LCACs 3 or LCUs 2 Helicopter landing spots 9 Speed 22 knots Officer accommodations 173 Enlisted accommodations 1,720 Surge accommodations 201 Vehicle square 24,012 square feet Cargo cube 145,000 cubic feet Operating rooms 6 Post-operative recovery/Intensive care 18 beds Isolation ward 6 beds Primary care ward 36 beds 6 Cargo elevators Pallet conveyors (½-ton/300 pallets per hour) 2	-Doctor -Dentist
Amphibious Transport Dock (LPD-4)**	Speed 21 knots Range at 20 knots 7,700 nautical miles Officer accommodations 68 Enlisted accommodations 641 Surge accommodations 176 Vehicle square 14,000 square feet Cargo cube 51,000 cubic feet Helicopter landing spots 2 Operating room 1 Isolation ward 4 beds Primary care ward 8 beds LCAC 1 or LCU 1 1 Cargo and weapons elevator 3 Pallet conveyors(1½-ton) Boat and aircraft crane (30-ton) 1	-Doctor -Dentist
Amphibious Transport Dock (LPD-17)**	Officer accommodations 66 Enlisted accommodations 638 Surge accommodations 99 Vehicle square 25,000 square feet Cargo cube 35,000 cubic feet Helicopter landing spots 2 Operating room 2 Isolation ward 4 beds Primary care ward 24 beds LCAC 1 or LCU 1 or 4 LCM-8 1 Cargo and weapons elevator 3 Pallet conveyors(1½-ton) Boat and aircraft crane (30-ton) 1	-Doctor -Dentist
Dock Landing Ship (LSD-36)**	Officer accommodations 27 Enlisted accommodations (E-7) 375 Surge accommodations 101 Vehicle square 11,831 square feet Cargo cube 8,970 cubic feet	-Doctor -Dentist

	Helicopter landing spots 2 4 LCACS or 3 LCU Speed 20 knots 1 OR 1 post-operative recovery/intensive care bed 2 isolation ward beds 5 primary care ward beds 6 forklifts Cargo elevator (4-ton) 1 Bridge crane (15-ton [two 7½-ton hoists]) 1 Boat and aircraft crane (60-ton) 2 Boat and aircraft crane (20-ton) 1	
Dock Landing Ship (LSD-49)**	Officer accommodations 27 Enlisted accommodations (E-7) 380 Surge accommodations 101 Vehicle square 20,200 square feet Cargo cube 67,600 cubic feet Helicopter landing spots 2 Operating Room 1 Post-operative recovery/Intensive care 1 bed Isolation ward 2 beds Primary care ward 5 beds Cargo lift platforms 3 / Cargo elevators (4-ton) 2 Boat and aircraft crane (30-ton) 1 Cargo weapons elevator (12,000 pounds) 1 LCACs 2 or LCU 1	-Doctor -Dentist
T-AH******	Speed 17.5 knots Intensive care wards: 80 beds Recovery wards: 20 beds Intermediate care wards: 280 beds Light care wards: 120 beds Limited care wards: 500 beds Total patient capacity: 1000 beds Operating rooms: 12 Additional capabilities: Casualty reception, Radiological services including CT, Main laboratory plus satellite lab, Central sterile processing medical supply/pharmacy, Physical therapy and burn care Intensive care unit, Dental services, Optometry/lens lab, Morgue Laundry, burn treatment, Angiography, Blood bank, Oxygen producing plants (two)	-up to 1,200 medical personnel

* Source: DON (1944).

** Source: HQMC (2001).

***Source: Pike J (2016).

****Source: Appendix B.

***** Source: O'Rourke R (2021).

****** Source: Ong P (2021).

Note: Several of the surface platforms Medical Personnel boxes are not broken down to their full extent, due to limited information found on it.

APPENDIX B. EXPEDITIONARY FAST TRANSPORT FLIGHT II

Expeditionary Fast Transport – EPF Flight II

DIMENSIONS

LENGTH	103.0m	(337.9 ft)
BEAM	28.5 m	(93.5 ft)
DRAFT	3.92 m	(12.85 ft)

PERFORMANCE

SPEED @ 90% MCR
- Average 33 knots with Payload
- Maximum 43 knots without Payload

RANGE (CDD/Design)

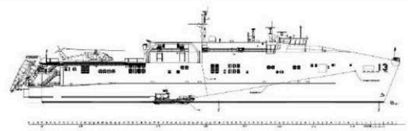
Maximum Transit (33 knots)	1200 nm
Self-Deployment (21 knots)	4700 nm
Medical Mission (21 knots)	2000 nm
SURVIVAL THROUGH	SS-7

ACCOMMODATIONS

CREW	38 p
Single SR	9
Double SR	4
Quad SR	6
MEDICAL WARD BEDS	23 p
INTENSIVE CARE UNIT BEDS	10 p
QUIET / ISOLATION BERTHS	8 p
MEDICAL PERSONNEL BERTHS	147 p
GALLEY & MESSING	76 p

MACHINERY
- (4) MTU 20V8000 M71L Diesel Engines (9.1 MW each, 36.4 MW total)
- (4) ZF 60000NR2H Reduction Gears (2.156:1)
- (4) Wartsila WLD 1400 SR Waterjets
- (4) IF V1312C2ME-HPCR Diesel Generators (600 kW each, 2.4MW total)

BOATS AND STOWAGE SYSTEMS
- Navy 11m RHIB / STBD 02 LVL Launch and Recovery Station
- Twin 7MT SWL telescoping davits



ROLE 2E MEDICAL FACILITIES
- OR-1 Surgical Suite containing (2) operating tables
- OR-2 Minor Procedures Room (1) operating table
- Combination ICU & Ward Area with Nurse's Station
- Patient Triage, Patient Administration, Medical Laundry
- Ancillary Services (Medical Laboratory, Pharmacy, Blood Bank)
- Patient Elevator between 02LVL Ward Area & Mission Bay

AVIATION FACILITIES
- NAVAIR Level 1 Class 2 Certified Flight Deck for one Helicopter
- MV/V22 H-60 H-46 MH/CH53E
- Helicopter Control Station /Aviation VLA / Advanced GSI

C4I SYSTEMS
- IFF / TACAN / MORIAH
- C4I Spaces - 104 m^2 (1120 ft^2)
- ISNS (NIPRNET/SIPRNET/CENTRIXS)
- VHF/UHF LOS
- UHF SATCOM / CBSP SATCOM
- TVS / EKMS / ADNS
- CANES Light

Commercial Electronic and Navigation Systems
- VMS / ECDIS-C
- MK-27F Gyrocompass and Jupiter Magnetic Compass
- Surface Search RADAR (X-Band and S-Band)
- Dual GPS
- Vessel Automatic Identification System (AIS)
- Autopilot
- Voyage Data Recorder
- GMDSS (Sea Area A1, A2 and A3)
- Integrated Voice Communication System
- Entertainment and Training System
- FLIR EO/IR

WEIGHTS

FULL LOAD (Load Line)	2500 mt	(2460 Lt)
FUEL (98%)	605,519L	(159,961 gal)
	503 mt	(495 Lt)
JP-5 (95%)	71,362 L	(18,852 gal)
	58 mt	(57 Lt)
MAX TRANSIT PAYLOAD	300 mt	(331 st)
MEDICAL PAYLOAD	231 mt	(255 st)

AUXILIARY SYSTEMS

ACTIVE RIDE CONTROL
- Transom Interceptors
- Foils: 3.24 m^2 (34.9 ft^2) each, forward on inboard sides of demi-hulls

VEHICLE RAMP
- Articulated Slewing Stern Ramp
- Straight Aft to 45° Starboard

TELESCOPING BOOM CRANE
- 12.3 mt @ 15m, 18.2 mt @ 10 m (13.6 st @ 49.2 ft, 20.1 st @ 32.8 ft)

FUELING AT SEA – Receive Only DFM & JP-5

ARMAMENT
- Four .50 Caliber Machine Guns
- AT/FP Magazine Space
- Reservation for Upgraded AT/FP System
- Reservation for Non-Lethal Effectors

FIREFIGHTING
- High Expansion Foam (HEF) for Mission Bay & Main Machinery Rooms
- AFFF on Flight Deck, Mission Bay
- Seawater Sprinkling in Habitability Spaces
- FM200 in SSDG / AUX Machinery Spaces

MISSION BAY

AREA (with Tie Downs)	1835m2	(19,750 ft2)
CLEAR HEIGHT	4.75m	(15.6 ft)
TURNING DIAMETER	26.2m	(86.0 ft)
ISO TEU STATIONS	6 Interface Panels	

SDM verified18FEB/2021

UNCLASSIFIED – DISTRIBUTION STATEMENT D (NAVSEA 05D)

Source: Office of the Deputy Chief of Naval Operations for Fleet Readiness & Logistics (2021), sponsor brief for The Naval Postgraduate School, Fall 2021 Resident Student Wargaming Course, unpublished PowerPoint, OPNAV N4, Washington, D.C.

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APPENDIX C. STEPWISE REGRESSION OF MEAN DELIVERY TIME EFFECTS SUMMARY TABLE.

Effect Summary

Source	LogWorth	PValue	
Num LAWs	65.867	0.00000	
LawPolicy{rsp_first&lazy-tri_b&tp_first}	44.635	0.00000	
HospLoc{pb1&ft&lp4-tpb&lp3}	39.508	0.00000	
Capacity{10pt20pl-20pt10pl}*LawPolicy{rsp_first-lazy}	18.975	0.00000	
Capacity{20pt20pl-10pt20pl&20pt10pl}	17.113	0.00000	
LawPolicy{tri_b-tp_first}	12.325	0.00000	
Num LAWs*LawPolicy{tri_b-tp_first}	11.529	0.00000	
Num LAWs*LawPolicy{rsp_first-lazy}	9.822	0.00000	
HospLoc{pb1&ft&lp4-tpb&lp3}*LawPolicy{rsp_first&lazy-tri_b&tp_first}	9.027	0.00000	
Num LAWs*LawPolicy{rsp_first&lazy-tri_b&tp_first}	8.318	0.00000	
Num LAWs*HospLoc{pb1&ft&lp4-tpb&lp3}	7.999	0.00000	
Capacity{10pt20pl-20pt10pl}*LawPolicy{rsp_first&lazy-tri_b&tp_first}	5.688	0.00000	
Capacity{20pt20pl-10pt20pl&20pt10pl}*LawPolicy{rsp_first-lazy}	4.789	0.00002	
LawPolicy{rsp_first-lazy}	4.677	0.00002	^
Num LAWs*Capacity{20pt20pl-10pt20pl&20pt10pl}	4.486	0.00003	
HospLoc{pb1-ft&lp4}	3.769	0.00017	
Capacity{10pt20pl-20pt10pl}*LawPolicy{tri_b-tp_first}	3.246	0.00057	
HospLoc{pb1&ft&lp4-tpb&lp3}*LawPolicy{rsp_first-lazy}	2.320	0.00478	
Capacity{20pt20pl-10pt20pl&20pt10pl}*HospLoc{pb1&ft&lp4-tpb&lp3}	1.991	0.01022	
Capacity{10pt20pl-20pt10pl}	0.433	0.36896	^

Note: The LogWorth value that has the greatest absolute value is the most influential factor. The Num LAWs affects Mean(DeliveryTime) the most with a LogWorth of 66.87. The next significant factor is the LAW transport policies, resupply first and patients first with opportunistic resupply.

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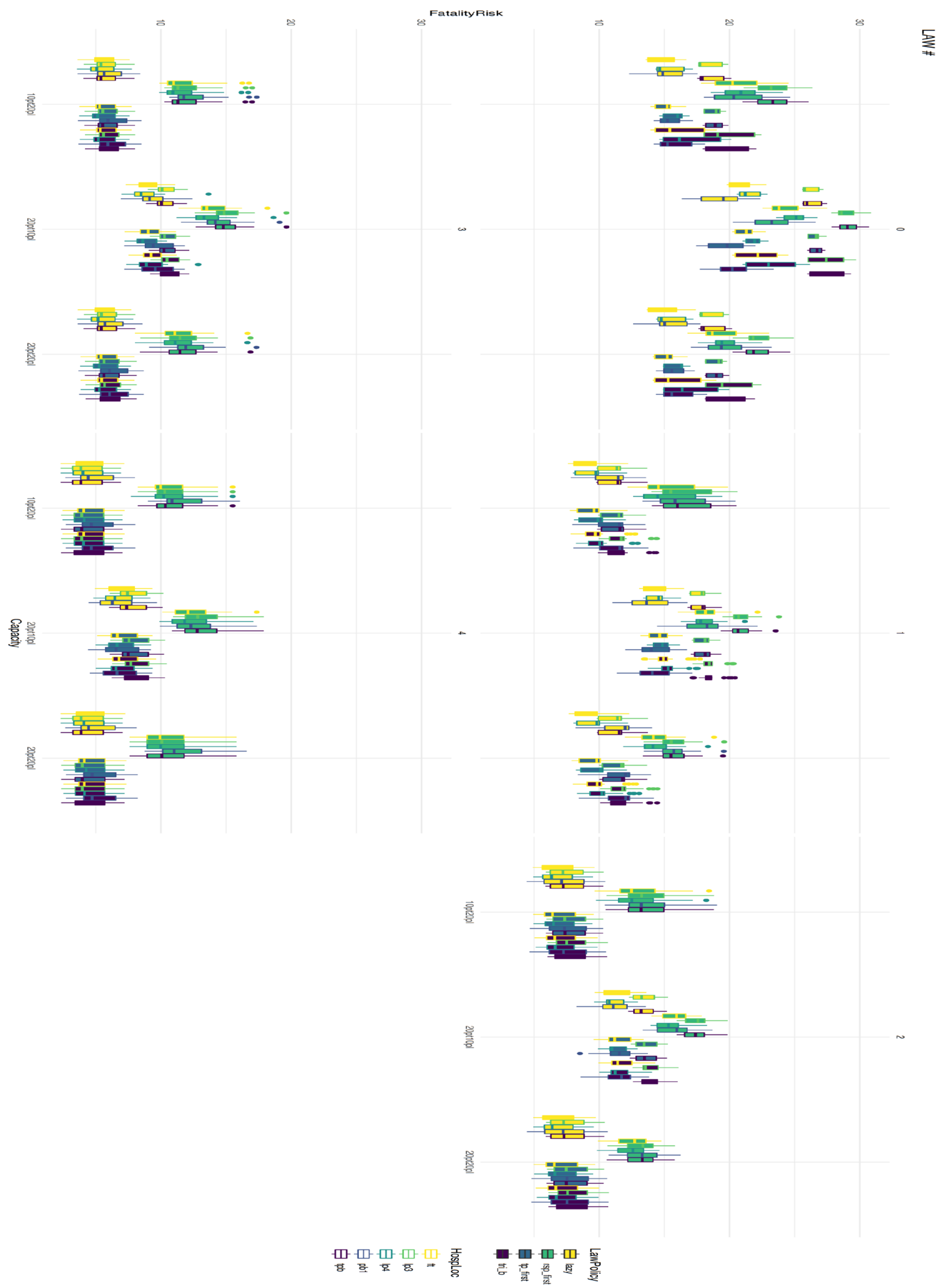
APPENDIX D. SUPER BOX PLOT OF FATALITY ROBUSTNESS



Source: Seater et al. (2022).

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APPENDIX E. SUPER BOX PLOT OF DELIVERY TIME ROBUSTNESS

Source: Seater et al. (2022).

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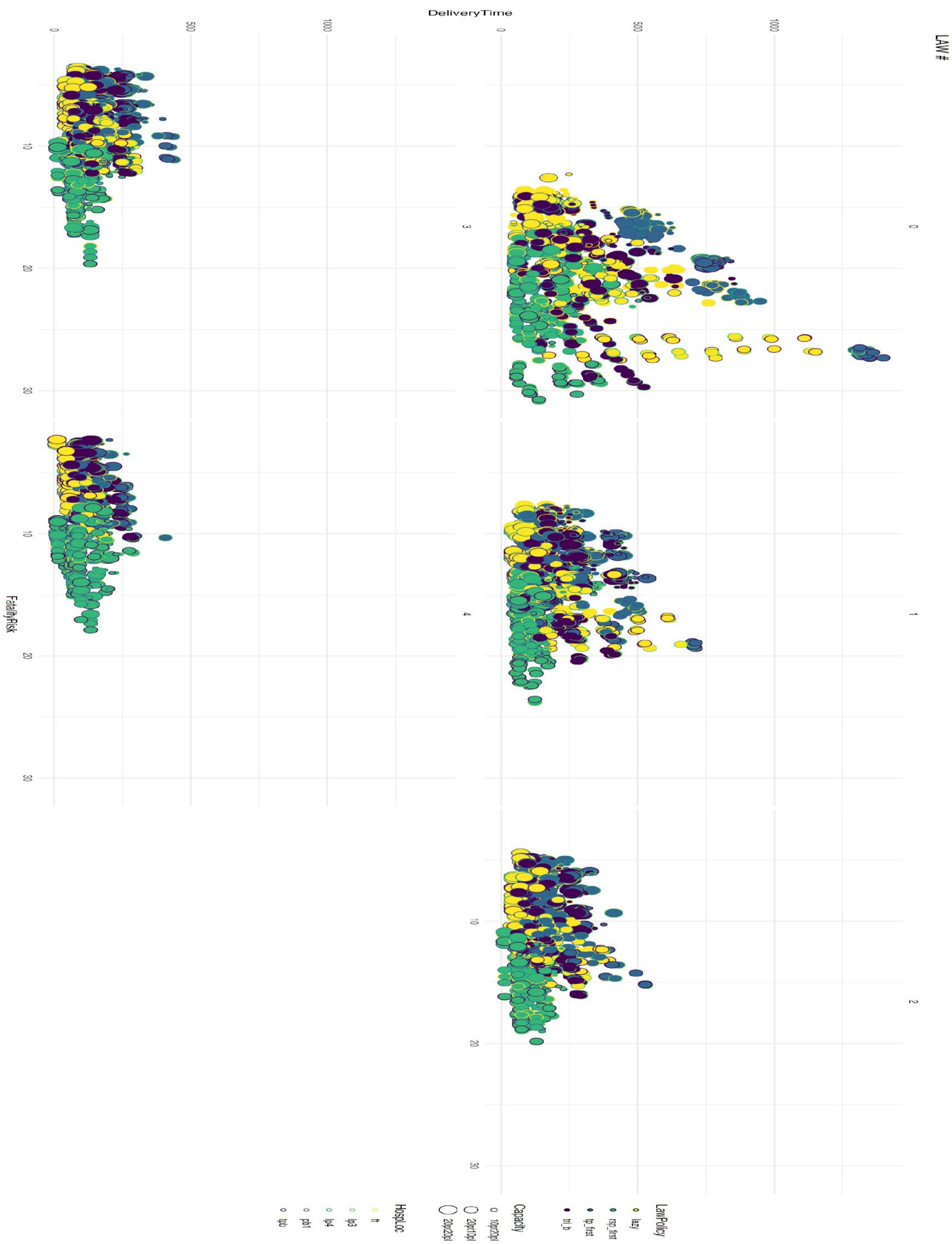
APPENDIX F. ROBUST SCATTER PLOT OF FATALITY RISK VERSUS DELIVERY TIME.



Source: Seater et al. (2022).

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