NAVAL POSTGRADUATE SCHOOL

MONTEREY, CALIFORNIA

THESIS

A SIMULATION BASED ANALYSIS OF U.S. ARMY WATERCRAFT CAPABILITIES IN A 2022 FOREIGN HUMANITARIAN ASSISTANCE/DISASTER RELIEF OPERATION

by

Paul T. Beery

September 2011

Thesis Advisor:	Eugene Paulo
Second Reader:	Jeffrey Appleget

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REPORT DOCUMENTATION PAGE			*Form Approved OMB No. 0704–0188*
Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instruction, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202–4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704–0188) Washington DC 20503.			
1. AGENCY USE ONLY	**2. REPORT DATE** September 2011	**3. REPORT TYPE AND DATES COVERED** Master's Thesis	
4. TITLE AND SUBTITLE A Simulation Based Analysis of U.S. Army Watercraft Capabilities in a 2022 Foreign Humanitarian Assistance/Disaster Relief Operation			**5. FUNDING NUMBERS**
6. AUTHOR(S) Paul T. Beery			
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Naval Postgraduate School Monterey, CA 93943–5000			**8. PERFORMING ORGANIZATION REPORT NUMBER**
9. SPONSORING /MONITORING AGENCY NAME(S) AND ADDRESS(ES) N/A			**10. SPONSORING/MONITORING AGENCY REPORT NUMBER**
11. SUPPLEMENTARY NOTES The views expressed in this thesis are those of the author and do not reflect the official policy or position of the Department of Defense or the U.S. Government. IRB Protocol number __NA__.			
12a. DISTRIBUTION / AVAILABILITY STATEMENT Approved for public release: distribution is unlimited			**12b. DISTRIBUTION CODE**

13. ABSTRACT

This thesis utilizes the operational context established by Expeditionary Warrior 2010 (EW10), a United States Marine Corps operational level seminar planning game, to analyze a 2022 United States Army Watercraft Foreign Humanitarian Assistance/Disaster Relief (FHA/DR) Operation. The EW10 Wargame was conducted over four days and in order to ensure complete analysis of the entire scenario within the time constraints, the composition of forces was explicitly defined. This thesis considers the full range of possible force compositions. A full functional and physical architecture is developed, using EW10 as an operational basis. Corresponding Measures of Outcome, Measures of Effectiveness, and Measures of Performance for U.S. Army Watercraft FHA/DR Operations are defined. The current U.S. Army Watercraft Master Plan is used to develop a 2022 U.S. Army Watercraft Force Structure, to include the integration of the Office of Naval Research's Transformable Craft (T-Craft). A discrete event simulation is developed using Imagine That's ExtendSim software to analyze the impact of variations in the projected force structure as well as the performance gains and losses associated with the introduction and removal of the T-Craft from the force structure. Simulation analysis indicates that, if the T-Craft is available in 2022, U.S. Army FHA/DR response forces should be defined by: 8 or more T-Craft, 4 or more Joint High Speed Vessels (JHSVs), and 4 or more Logistics Support Vessels. In the absence of T-Craft, the response force should be defined by: 7 or more JHSVs and 13 or more Landing Craft Utility 2000s.

14. SUBJECT TERMS Transformable Craft, Army Watercraft, Humanitarian Assistance/Disaster Relief, ExtendSim, Efficient Experimental Design, Nearly Orthogonal Latin Hypercube, Discrete Event Simulation			**15. NUMBER OF PAGES** 109
			16. PRICE CODE
17. SECURITY CLASSIFICATION OF REPORT Unclassified	**18. SECURITY CLASSIFICATION OF THIS PAGE** Unclassified	**19. SECURITY CLASSIFICATION OF ABSTRACT** Unclassified	**20. LIMITATION OF ABSTRACT** UU

NSN 7540–01–280–5500

Standard Form 298 (Rev. 2–89)
Prescribed by ANSI Std. 239–18

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A SIMULATION BASED ANALYSIS OF U.S. ARMY WATERCRAFT CAPABILITIES IN A 2022 FOREIGN HUMANITARIAN ASSISTANCE/DISASTER RELIEF OPERATION

Paul T. Beery
Civilian, Department of the Navy
B.A., Rutgers University, 2009

Submitted in partial fulfillment of the
requirements for the degree of

MASTER OF SCIENCE IN SYSTEMS ENGIEERING ANALYSIS

from the

NAVAL POSTGRADUATE SCHOOL
September 2011

Author: Paul T. Beery

Approved by: Eugene Paulo, PhD
Thesis Advisor

Jeffrey Appleget, PhD
Second Reader

Clifford Whitcomb, PhD
Chair, Department of Systems Engineering

Robert Dell, PhD
Chair, Department of Operations Research

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ABSTRACT

This thesis utilizes the operational context established by Expeditionary Warrior 2010 (EW10), a United States Marine Corps operational level seminar planning game, to analyze a 2022 United States Army Watercraft Foreign Humanitarian Assistance/Disaster Relief (FHA/DR) Operation. The EW10 Wargame was conducted over four days, and in order to ensure complete analysis of the entire scenario within the time constraints, the composition of forces was explicitly defined. This thesis considers the full range of possible force compositions. A full functional and physical architecture is developed, using EW10 as an operational basis. Corresponding Measures of Outcome, Measures of Effectiveness, and Measures of Performance for U.S. Army Watercraft FHA/DR Operations are defined. The current U.S. Army Watercraft Master Plan is used to develop a 2022 U.S. Army Watercraft Force Structure, to include the integration of the Office of Naval Research's Transformable Craft (T-Craft). A discrete event simulation is developed using Imagine That's ExtendSim software to analyze the impact of variations in the projected force structure as well as the performance gains and losses associated with the introduction and removal of the T-Craft from the force structure. Simulation analysis indicates that, if the T-Craft is available in 2022, U.S. Army FHA/DR response forces should be defined by: 8 or more T-Craft, 4 or more Joint High Speed Vessels (JHSVs), and 4 or more Logistics Support Vessels. In the absence of T-Craft, the response force should be defined by: 7 or more JHSVs and 13 or more Landing Craft Utility 2000s.

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LIST OF ACRONYMS AND ABBREVIATIONS

ACV	Air Cushion Vehicle
AWMP	Army Watercraft Master Plan
BAA	Broad Agency Announcement
BCT	Brigade Combat Team
CBA	Capabilities Based Assessment
CMOC	Civil-Military Operations Center
CONOPS	Concept of Operations
COTS	Commercial Off-the-Shelf
DoD	Department of Defense
DOTMLPF	Doctrine, Organization, Training, Materiel, Leadership, Personnel, and Facilities
EW10	Expeditionary Warrior 2010
FAA	Functional Area Analysis
FHA/DR	Foreign Humanitarian Assistance/Disaster Relief
FIFO	First In-First Out
FNA	Functional Needs Analysis
FSA	Functional Solutions Analysis
GHN	Government of Host Nation
GO	Governmental Organization
HN	Host Nation
IAW	In Accordance With
INP	Innovative Naval Prototype
IDP	Internally Displaced Person
LCAC	Landing Craft Air Cushion
LCU	Landing Craft Utility
LCU 2000	Landing Craft Utility
LHD	Landing Helicopter Dock
LPD	Landing Platform Dock
LSD	Landing Ship Dock
LSV	Logistic Support Vessel

MOE	Measure of Effectiveness
MOO	Measure of Outcome
MOP	Measure of Performance
NGO	Non-Government Organization
NOLH	Nearly Orthogonal Latin Hypercube
OFDA	Office of Foreign Disaster Assistance
ONR	Office of Naval Research
SEA	Systems Engineering Analysis
SES	Surface Effect Ship
SME	Subject Matter Expert
T-Craft	Transformable Craft
USAID	United States Agency for International Development
VSB	Vessel-to-Shore Bridging

EXECUTIVE SUMMARY

In February 2010, the United States Marine Corps conducted Expeditionary Warrior 2010 (EW10), an operational level seminar planning game. The game was set from 2020–2025 and focused on Security Force Assistance/Building Partner Capacity, Foreign Humanitarian Assistance/Disaster Relief (FHA/DR), Non-Combatant Evacuation Operations, and Stability Operations. The operational scenario outlined in EW10 was used as the factual basis for this thesis and to define a hypothetical African Host Nation (HN). Further, the research conducted by LT Nathan Beach in his thesis, "Systems Architecture of a Sea Base Surface Connector System in a 2020 Humanitarian Assistance/Disaster Relief Joint Operational Environment" outlined a probable strategic approach, defined by an Army Brigade Combat Team (BCT) and Army Strategic Flotilla forces being centrally tasked with providing FHA/DR support to the Host Nation's southwest region.

This thesis developed a functional and physical architecture appropriate to support a United States Army Watercraft FHA/DR Operation, as defined by EW10 and LT Beach. The functional architecture is shaped by the Government of Host Nation (GHN) requirements, as defined by EW10, as well as current U.S. FHA/DR policy, as defined by United States Agency for International Development (USAID) publications, DoD Joint Publications, and U.S. Army Field Manuals (U.S. Army FM 3–07: Stability Operations, U.S. Army FM 100–23–1: Multiservice Procedures for Humanitarian Assistance Operations, U.S. Army FM 8–42: Combat Health Support in Stability Operations and Support Operations, Joint Publication 3–07: Interagency, Intergovernmental Organization, and Nongovernmental Organization Coordination During Joint Operations, JP 3–07.6: Joint Tactics, Techniques, and Procedures for Foreign Humanitarian Assistance, and the USAID Field Operations Guide (FOG) for Disaster Assessment and Response). That guidance indicated that the two major roles of the U.S. Army in a FHA/DR scenario are: point-to-point-lift and disaster relief. Security for United States

Army forces is also necessarily included. Thus, the complex problem is scoped from a multinational FHA/DR operation to a more straightforward FHA/DR supply and force security transportation problem.

The current United States Army Watercraft Master Plan (AWMP) indicates that the current U.S. Army fleet will require modernization and upgrade to extend system life cycles until at least 2024. Further, the AWMP is based on a U.S. Army Transportation Capabilities Based Assessment (CBA) that concludes that the current United States Army Watercraft assets cannot satisfy the full range of Army Watercraft tasks, and thus a materiel solution will most likely be required to satisfy those capability gaps.

In 2005, the Office of Naval Research released Broad Agency Announcement (BAA) 05–020 detailing the desired capabilities of the Transformable Craft (T-Craft). The T-Craft is intended to serve as a "Game Changing" Innovative Naval Prototype by advancing the concepts of Operational Maneuver from the Sea and ship-to-objective maneuver. The T-Craft could provide a greater carrying capacity than the Landing Craft Air Cushion (LCAC) and provide a greater speed capability than the Landing Craft Utility (LCU).

Per the capability gaps outlined in the CBA, the T-Craft is integrated with the current projected force structure outlined in the AWMP to develop a notional 2022 Army Watercraft Force Structure. Army Air Transportation assets are integrated with the watercraft assets to define potential force structures for the FHA/DR response.

A discrete event simulation is developed to evaluate the effectiveness of various force structure combinations within the context of the EW10 scenario. Recent advances in efficient experimental design are used to generate Nearly Orthogonal Latin Hypercube (NOLH) designs capable of filling the entire solution space defined by the 2022 Army Watercraft Force Structure. While traditional designs only enable analysis at extremes, NOLH designs enable examination of nonlinear responses as well as allow creation of high accuracy desirability functions for the force structure.

After developing a robust experimental design defined by 2,401 design points, each replicated 30 times (72,030 total simulation runs); several definitive conclusions can be reached. The objective of the analysis is to inform potential FHA/DR force compositions, however the analysis indicates that response forces should prioritize the establishment of landing zones at the objective area before commencing FHA/DR delivery. Further, given that the Transformable Craft is available for deployment in 2022, response forces should be characterized by:

1. 8 or more T-Craft
2. 4 or more Joint High Speed Vessels (JHSV)
3. 4 or more Logistics Support Vessels (LSV)

Note that if the T-Craft is available for use in 2022, the LCU 2000, H-47, and H-60 capabilities are redundant in this scenario. These conclusions may be altered for a different operational scenario, where increased distance between the staging area and the objective may capitalize on decreased transit and unload times offered by the air transportation assets.

If T-Craft is unavailable, response forces should be characterized by:

1. 7 or more JHSVs
2. 13 or more LCU 2000s

Note that when the T-Craft is unavailable the LSV capability becomes redundant. This reinforces the importance of landing zone availability. When T-Craft is available, the force structure is best augmented by low quantities of the LSV, a larger ship which will not occupy landing zones. When the T-Craft is unavailable, a larger number of LCU 2000s can be used because landing zones are not required for T-Craft. Again, the air transportation assets provide a redundant capability and are not recommended for inclusion in the force composition.

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ACKNOWLEDGMENTS

I would first like to thank my advisor, Dr. Gene Paulo, for his support and guidance throughout the entire thesis process. Not only did he provide me the opportunity to pursue my degree at NPS, but his ability to encourage experimentation and free thought while enforcing deadlines enabled me to develop a thesis that challenged and excited me, while ensuring that I developed a clear, directed vision for my research.

I would like to thank my second reader, Dr. Jeff Appleget. His direction always provided a clear and concise focus to my writing and my thinking, enabling me to maintain an operationally relevant and realistic focus without curtailing my academic freedom.

I would like to thank USMA Cadets Daniel Cashero, Mitchell Cucinotta, TeJay Espe, Michael Rodriguez, and Timothy Schmidt for their help defining and expanding my research. I hope you learned as much from me as I learned from you.

I would like to thank the Systems Engineering and Operations Research faculty for providing me the academic skill set that made it (almost) easy to complete my research.

I would like to thank the ONR T-Craft team, especially Kelly Cooper, Walt Beverly, Bob Wilson, and Steve Anderson. Without your help and support much of my research would have proved impossible and the operational relevance of my thesis would be lost.

I would like to thank MAJ Alex MacCalman, Dr. Santiago Balestrini-Robinson, Elise Beisecker, Dr. Gary Horne, Dr. Paul Sanchez, and Dr. Susan Sanchez for their help developing my simulation and experimental design as well as showing me the unlimited possibilities offered by JMP.

Finally, I would like to thank my friends and family for their unwavering love and support. Most importantly, I would like to thank my parents for instilling in me a lifelong commitment to excellence that has served as the motivation for everything I have ever accomplished.

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I. INTRODUCTION

A. BACKGROUND

This thesis develops a functional and physical architecture for a 2022 United States Army Watercraft Foreign Humanitarian Assistance/Disaster Relief (FHA/DR) operation, based on the scenario established in the Expeditionary Warrior (EW10) Wargame. These architectures are defined to enable development and analysis of a tactical level discrete event simulation. The simulation examines the scope of tactical level possibilities and is used to inform definition of possible force compositions, to include the implementation of the Transformable Craft.

In February 2010, the United States Marine Corps conducted the EW10 Wargame, an operational-level seminar planning game composed of five vignette based moves. The scenario was set from 2020–2025 and focused on Security Force Assistance/Building Partner Capacity, FHA/DR, Non-Combatant Evacuation Operations, and Stability Operations. For the purposes of this thesis, the operational scenario developed for EW10 is utilized to define a hypothetical coastal African Host Nation (HN).

In 2005, the Office of Naval Research (ONR) released Broad Agency Announcement (BAA) 05–020 detailing the desired capabilities of the Transformable Craft (T-Craft). The T-Craft is intended to provide a "game-changing" capability for the United States Navy's sea basing concept. T-Craft could advance the concepts of Operational Maneuver from the Sea and ship-to-objective maneuver, and provide a greater carrying capacity than the Landing Craft Air Cushion (LCAC) and provide a greater speed capability than the Landing Craft Utility (LCU).

B. THESIS OBJECTIVE AND RESEARCH QUESTIONS

This thesis considers the full range of possibilities concerning the composition of U.S. forces centered in the southwest region of the Host Nation. A full physical and functional architecture is developed, along with a discrete event simulation using EXTENDSim (Imagine That Inc, 2011) to examine the force compositions that provide the greatest functionality. Measures of Outcome (MOOs), Measures of Effectiveness (MOEs), and Measures of Performance (MOPs) that define functionality are developed in accordance with the Government of Host Nation (GHN) requirements outlined in the EW10 Player Book (United States Marine Corps, 2010, p. 121).

In order to satisfy those objectives, the following research questions are addressed:

1. What functions must be performed by each asset to support the employment stage of a multifaceted air, land, and sea FHA/DR operation?
2. What physical architecture is appropriate to support the employment stage of the operation?
    a. How do alterations in that architecture impact force effectiveness?
    b. What changes in Doctrine, Organization, Training, Materiel, Leadership, Personnel, and Facilities (DOTMLPF) impact force effectiveness?
    c. What does T-Craft add vs. force compositions without T-Craft?
3. What are the appropriate MOOs, MOEs, and MOPs for the FHA/DR mission requirements?

C. SCOPE AND METHODOLOGY

This thesis focuses on:

1. Defining the functional and physical architectures for a FHA/DR mission defined by EW10.
2. Developing MOOs, MOEs, and MOPs that provide insight into the functionality of the full scope of solutions, as defined by the physical architecture.

3. Developing a discrete event simulation capable of measuring defined MOPs that provides insight into the functionality of various solution configurations.

The methodology in this thesis follows the design process developed by Dennis M. Buede, presented in *The Engineering Design of Systems: Models and Methods* (2000, p. 37). This methodology was chosen based on successful implementation by Chris McCarthy, Russ Wyllie, Ravi Vaidyanathan and Eugene P. Paulo in “An Integrated Systems Architecture to Provide Maritime Domain Protection” (2006, p. 1). This process is particularly useful to designing robust systems, focusing on definition of functional, physical, and operational architectures. In particular, the Model Based System Engineering approach outlined by Buede is appropriate for this research. The process begins with a definition of the design level problem. While Buede notes that all of the subsequent processes are interdependent, and thereby cannot be viewed as a linear series, there is an element of sequence. After the problem has been defined, a concurrent development of the system functional and physical architecture, along with the operational architecture, must take place. This parallel development approach allows the designer to ensure that the system integrates and meets system requirements. Finally, a qualification system for each of the proposed systems is developed.

That process is used as the baseline for the organization of this thesis. The EW10 scenario is detailed and used to develop a set of high level mission requirements. Those operational requirements are used in conjunction with current U.S. FHA/DR policy to develop an operational concept and functional architecture for a U.S. Army Watercraft FHA/DR Operation. The full spectrum of possible response forces are defined and used to develop potential physical architectures. The resultant architectures are used to develop appropriate, operationally relevant MOOs, MOEs, and MOPs. A simulation is developed and analyzed to provide recommendations concerning force structure, based on the MOOs, MOEs, and MOPs.

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II. BACKGROUND INFORMATION

A. SCENARIO INTRODUCTION

This thesis focuses on the events defined by Move 2 (June–August 2022) of EW10. Unusually heavy rains cause widespread flooding and cholera outbreak, straining GHN resources. In June 2022, a severe tropical storm devastates the coastal region of the Host Nation. The GHN requests international assistance. In response, a Multinational Task Force conducts FHA/DR operations.

The EW10 scenario was addressed by U.S. Navy LT Nathan Beach in his thesis, "Systems Architecture of a Sea Base Surface Connector System in a 2020 Humanitarian Assistance/Disaster Relief Joint Operational Environment" (2010). LT Beach's research indicates that the most likely strategic approach will be defined by the Army Brigade Combat Team (BCT) and Army Strategic Flotilla forces being centrally tasked with providing requested FHA/DR support to Host Nation's southwest region, most importantly the nation's largest coastal city, defined in this thesis as Degut (Figure 1).

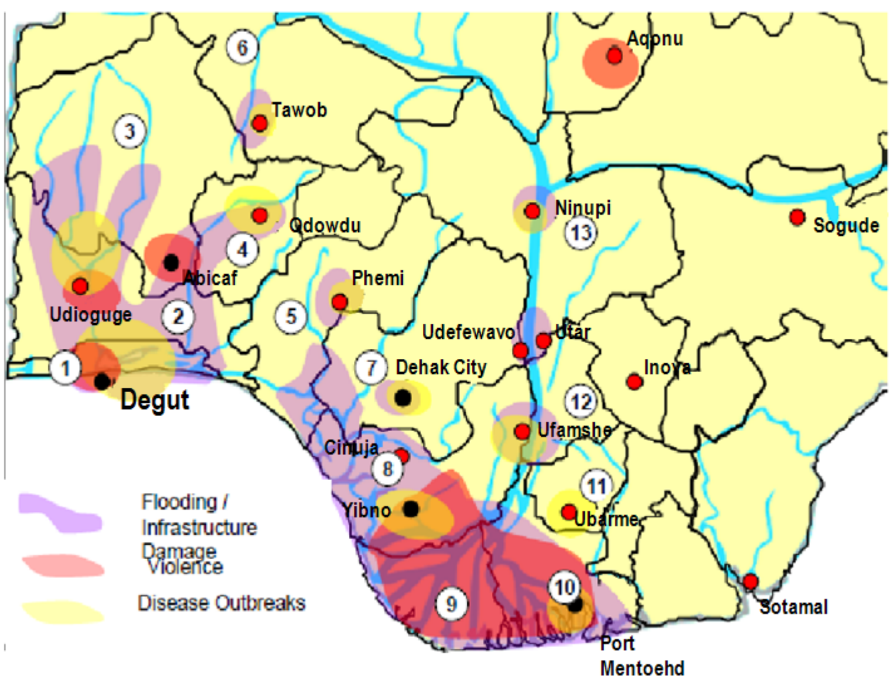

Figure 1. Host Nation Overview (After United States Marine Corps, 2010)

FHA/DR support will be provided from an advanced staging area located in a neighboring nation 150 nm west of Degut. U.S. Naval assets will support FHA/DR operations in the southeast delta region. This thesis focuses on the tasks required of the Army BCT and Army Strategic Flotilla in Move 2 of EW10, constituting the employment phase of the operation, and excluding the assembly and sustainment phases.

B. SCENARIO OPERATIONAL CONTEXT

This thesis is based on the operational context establish by EW10, adapted to a hypothetical African Host Nation in 2022. The operational progression established in EW10 is used to minimize error and ensure that the research is focused on an operationally relevant and complex problem. Scenario developments adapted from EW10 that are of particular interest to this thesis are:

1. Spring 2022: Exceptionally heavy rains, across the Host Nation, lead to widespread flooding and damage throughout the southern, coastal regions. This year's flooding is worse than normal. Across the coastal region, flooding results in: loss of life and the spread of waterborne diseases; displacement of tens of thousands of people; and damaged crops, roads, bridges and other infrastructure. Poor sanitation and drainage is affecting the clean water supply in many areas. The GHN and international aid agencies are so far able to manage the situation, but strained resource capabilities are a growing problem (United State Marine Corps, 2010, p. 12).
2. June 2022: Total affected population is estimated to be 3.3 million people spread across 13 states. Flooding is the "worst seen in living memory." 75% of the city of Yibno is under 2–3m of water and large portions of Degut are under water. Drainage from inland water moving downstream is likely to raise water levels in coastal regions. Reservoirs and lakes are filling to capacity. Cases of disease and infections are rising throughout the southern region (United States Marine Corps, 2010, p. 12).
3. The GHN and international aid agencies alone are not able to handle the crisis, causing the GHN to actively seek global support. Other neighboring states have

also been affected by heavy rains and flooding and are not able to assist (United States Marine Corps, 2010, p. 12).

4. June–August 2022: ***(EW 10 Move 2: FHA/DR)*** Multinational Humanitarian Task Force assists the GHN conducting FHA/DR throughout the coastal region of southern Host Nation (United States Marine Corps, 2010, p. 12).

The amount and nature of the FHA/DR provided by U.S. forces is defined by the need of the Host Nation. The scenario details adapted from EW10 that further define the situation include:

1. GHN requires: Medical/Veterinarian supplies and services, water and food supplies, water purification, shelter, clothing, hygiene supplies, power generation and fuel, infrastructure repair, transportation (Air, Ground, Sea), air & seaport repair and control (United States Marine Corps, 2010, p. 121).

2. GHN requests further assistance with: evacuation of people from affected areas; search and rescue; delivery of food, water, and medicine; delivery of clothes, shelter, and supplies; providing medical and veterinarian services; repairing/opening airfields and ports; providing air traffic control support; and repairing/engineering support (United States Marine Corps, 2010, p. 122).

3. Air traffic control radars and ports in the northwest region are closed due to storm damage, flooding, absent personnel, power outages, and possible computer network attacks. Runways are closed or degraded by debris on runway, flooding/mud, and temporary Internally Displaced Persons (IDP) camps (United States Marine Corps, 2010, p. 122).

4. Eighty-plus local and international Non-Government Organizations (NGOs), Governmental Organizations (GOs) and Private Voluntary Organizations are active in the Host Nation supporting relief efforts (United States Marine Corps, 2010, p. 121).

5. GHN and NGOs are running the IDP camps (United States Marine Corps, 2010, p. 122).

6. GHN and NGOs are responsible for distributing supplies from distribution centers to population (United States Marine Corps 2010, p. 122).

7. Table 1 summarizes the overall scenario across the Host Nation. States 1–4, highlighted below, comprise the Southwest region and the focus of the analysis.

State	Population (millions)	Dead	Injured	Diseased	IDP	People Affected
1	**18**	**80**	**900**	**3000**	**275,000**	**2,750,000**
2	**3.7**	**20**	**275**	**800**	**30,500**	**28,000**
3	**5.5**	**15**	**300**	**1000**	**22,700**	**61,000**
4	**3.4**	**10**	**25**	**100**	**19,000**	**35,000**
5	3.4	5	100	400	8,500	18,000
6	2.4	5	87	540	10,000	50,000
7	3.2	15	425	515	27,900	124,000
8	4.1	85	750	2000	97,000	243,000
9	1.7	5	150	300	17,000	25,000
10	5.2	35	350	600	19,600	34,000
11	3.9	5	50	125	7,500	31,000
12	4.2	10	175	350	11,000	48,000
13	3.3	15	205	175	28,000	120,000
Total	**62**	**305**	**3792**	**9905**	**573,700**	**3,497,000**

Table 1. Host Nation Situation (After United States Marine Corps, 2010)

C. LITERATURE REVIEW

1. Army Watercraft Master Plan

In April 2008, the U.S. Army published the current Army Watercraft Master Plan (AWMP). The objective of the AWMP is to identify key actions, set priorities, and guide decisions to ensure that the Fleet is properly equipped, organized, positioned, trained, and sustained (United States Army Transportation Office, 2008, p. xiii). For the purposes of this thesis, the AWMP is used as the primary reference for defining the capabilities of current and future Army Watercraft assets. This ensured consistent, reliable data for use in simulation development. Further, because the AWMP is targeted at examining Army

Watercraft capabilities from 2015–2024 (United States Army Transportation Office, 2008, p. 1) it served as the basis for determining possible future U.S. Army FHA/DR response force compositions. Finally, the AWMP is based on a Joint Capabilities-Based Assessment (CBA). This analysis of the CBA presented in the AWMP provided a definition of Army Watercraft Employment, as well as operational requirements of sufficient depth to serve as a basis for the introduction of prototype watercraft assets not currently under consideration by the Army into future Army force compositions.

The AWMP is used to project a realistic force structure for examination in a EW10 related scenario set in 2022. There are five major asset-related findings from the AWMP used in this thesis to develop the projected force structure in 2022. The Logistic Support Vessel (LSV), currently expected to reach the end of its projected life cycle in 2013, will undergo modernization upgrades, and the entire fleet of eight LSVs will remain operational through 2024 (United States Army Transportation Office, 2008, p. 1–6). The Landing Craft Utility (LCU 2000) fleet will receive critical upgrades from 2009–2013, extending the life of all 34 LCU 2000s through 2024 (United States Army Transportation Office, 2008, p. 1–8). All 40 Landing Craft Mechanized (LCM-8) units will be divested or replaced with new capability by 2016 (United States Army Transportation Office, 2008, p. 1–11). The Army will fund and acquire a full fleet of 12 Joint High Speed Vessels (JHSVs) by 2024, with a projected 10 being completed by 2022 (United States Army Transportation Office, 2008, p. A-4). The Army will also fund research into the Vessel-to-Shore Bridging (VSB) capability and acquire a full complement of 12 VSB systems to enable the JHSV fleet (United States Army Transportation Office, 2008, p. 2–5). The VSB systems enable the JHSV fleet to conduct amphibious operations.

The AWMP details the use of Army Watercraft in sustainment operations. LCU 2000s, LSVs, and LCMs provide a sustainment and distribution capability. They can distribute all classes of supply, to include bulk Petroleum, Oil, and Lubricants (United States Army Transportation Office, 2008, p. B-3). Further, the introduction of JHSV is intended to expand the maneuver capability of the current Watercraft Assets. The use of Army Watercraft in sustainment operations is detailed in Figure 2.

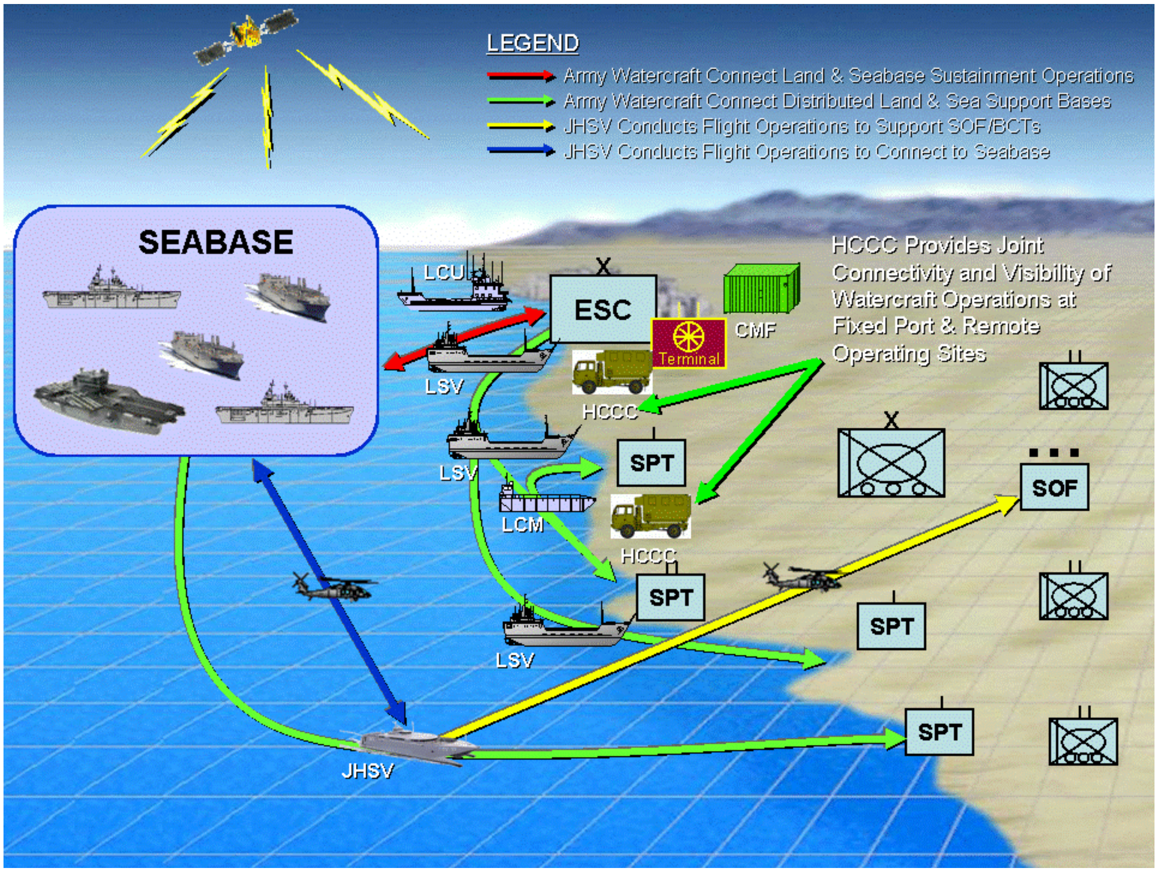

Figure 2. Army Watercraft Supporting Distributed Sustainment (From United States Army Transportation Office, 2008, p. B-3)

2. Army Watercraft Capabilities Based Assessment

The Army Watercraft Capabilities Based Assessment (CBA) was conducted from 2005–2007 and was comprised of a Functional Area Analysis (FAA), Functional Needs Analysis (FNA), and Functional Solution Analysis (FSA). Four findings from the CBA, detailing the desired capabilities of future Army watercraft operational requirements, are particularly relevant to this thesis (from Concepts and Doctrine Directorate, U.S. Combined Arms Support Command, 2007, p. iii):

1. The Joint Force is best served by a watercraft capability properly balanced between the services.

2. Role in Joint Operations is primarily defined by its mission – the Army on land power operations, Naval Forces on maritime power.

3. Non-materiel approaches alone will not address the capability gaps, but a number of changes in conjunction with the proper materiel programs, will help close the gaps. Primary among these changes is to better integrate Army Watercraft capability with Army maneuver and Joint operations doctrine.

4. Materiel approaches must develop capabilities for the following

    a. Intra-theater operational sustainment lift

    b. Vessel-to-shore bridging

    c. Tactical port and littoral main supply route operations.

More specifically, these operational requirements served as the basis for the development of the watercraft tasks that the Army must be able to perform to satisfy future Army required capabilities. These Army Watercraft Tasks are summarized in Table 2.

ARMY WATERCRAFT TASKS	
Task 1	Conduct Force Closure.
Task 2	Establish and maintain situational awareness and command & control with appropriate echelons in both maritime and land based domains (C4ISR).
Task 3	Support embarked force battle command on the move to include continuous interface with the COP and en route mission planning and rehearsal.
Task 4	Operate in open ocean and the littorals to include anti-access or area denial environments.
Task 5	Provide operational maneuver for combat configured forces throughout a JOA.
Task 6	Conduct distributed sustainment operations in support of Joint and Combined Forces throughout a JOA.
Task 7	Support terminal operations in fixed, austere, and degraded sea and water ports and during joint logistics over the shore operations.
Task 8	Conduct operations at a Seabase.
Task 9	Operate in a non-contiguous, uncertain threat environment to include extreme meteorological and maritime conditions.

Table 2. Army Watercraft Tasks (From Concepts and Doctrine Directorate, U.S. Combined Arms Support Command, 2006, p. 7)

These Watercraft Tasks were used to identify seven capability gaps currently facing U.S Army Watercraft. Those capability gaps are, in priority order (from Concepts and Doctrine Directorate, U.S. Combined Arms Support Command, 2007, p. 2–2):

1. The ability to rapidly close, employ, support, and sustain, Joint expeditionary forces.
2. Sufficient combination of speed, range, and payload to rapidly shift combat ready maneuver forces within a theater of operations.
3. The ability to provide initial sustainment replenishment operations during expeditionary phases of Joint Land Force operations.
4. Sufficient ability to rapidly provide emergency resupply of critical supplies to modular forces (Task Forces & Special Operations Forces) distributed along coastal and inland waterways.
5. Sufficient Command, Control, Communications, Computers, Intelligence, Surveillance, and Reconnaissance capability to provide Command and Control while performing watercraft operations in Joint, Combined, Coalition or Multi-national environments.
6. The ability to conduct two level maintenance In Accordance With (IAW) Army maintenance policies.
7. Sufficient Battle Command on the Move to establish and maintain situational awareness while performing watercraft operations in Joint, Combined, Coalition or Multi-national environments.

The full spectrum of DOTMLPF potential solutions was examined to determine potential solutions to satisfy the Army Watercraft Capability Gaps. The FSA identified 26 Doctrine Approaches, 13 Organization Approaches, 3 Training Approaches, 2 Leadership & Education Approaches, and 28 Materiel Approaches. The FSA found that a combination of materiel and non-materiel solutions are required to satisfy all seven capability gaps. However, two things must be noted for the purposes of this analysis. First, materiel solutions scored highest in six of the seven capability gaps. Scoring is based on Subject Matter Expert (SME) input and adapted to an Analytical Hierarchy Process. The only area where a materiel solution was not preferred was capability gap six, which addresses the ability to perform two level maintenance IAW Army maintenance policies. Second, among the materiel solutions proposed, the three highest scoring approaches are based on successful implementation and fielding of the JHSV. The fourth highest rated solution is to "Develop higher speed watercraft self deployable platform designed for heavy maneuver sustainment operations from a seabase and austere ports" (Concepts and Doctrine Directorate, U.S. Combined Arms Support Command, 2007, p. 2–28). Given that the proposed materiel solutions dominated the doctrine, organization, training, and leadership solutions, this thesis focused the top scoring materiel solutions. More specifically, special focus is given to an examination of the usefulness of JHSV and, per the findings of the FSA, another developmental higher speed, self-deployable watercraft capable of enabling intra-theater operational sustainment lift, vessel-to-shore bridging, and tactical port and littoral main supply route operations.

3. Transformable Craft Concept

The following list details the desired capabilities of the T-Craft, thresholds and objectives for asset performance, and other relevant information (from Office of Naval Research, 2005, p. 3):

1. Un-refueled range, in a no cargo condition, of 2,500 nautical miles in a Fuel Efficient/Good Sea Keeping Mode (20 knots, through Sea State 5)
2. Open ocean operations through Sea State 6 (through Sea State 4 in High Speed/Shallow Water Mode) and survivable in Sea State 8.
3. Maximum Speed, full load condition in High Speed, Shallow Water Mode = ~40 knots through top end of Sea State 4.
4. Amphibious capability, in Amphibious Mode, to traverse sand bars and mud flats thereby providing a "feet dry on the beach" capability.
5. Ability to convert between modes at-sea without any external assistance.

6. Maximum un-refueled range in High Speed/Shallow Water Mode = ~500–600 nautical miles (40 knots, through Sea State 4).
7. Ability to mitigate wave-induced motions in Sea State 4/5 to enable rapid vehicle transfer (loading/un-loading) between the T-Craft and a Maritime Prepositioning Force (Future)/Sealift ship.
8. To be used as an assault connector and a logistics connector.
9. No habitability/living spaces required.
10. No requirement to fit into Navy Amphibious Ship Well Decks (L-Class ships).

Several other threshold and objective values are summarized in Table 3 (from Office, 2005, p. 4).

Notional Requirements	**Threshold**	**Objectives**
Cargo Payload Weight	300 lt	750 lt
Cargo Payload Area	2,200 sqft	5,500 sqft
Crew Size	3	2
Beach Slope Climbing	0.5%	2%
Vehicle Ramp Angle	15.0 degrees	12.5 degrees
Vehicle Deck Loading	350 psf	550 psf

Table 3. T-Craft Thresholds/Objectives (From Office of Naval Research, 2005, p. 4)

These thresholds and objectives are of particular interest in comparing T-Craft to legacy assets. The T-Craft improves the concepts of Operational Maneuver from the Sea and ship-to-objective maneuver by providing greater cargo delivery than the LCAC and providing greater speed capability than the LCU. T-Craft is able to complete the entire mission set defined in the BAA by operating as a Surface Effect Ship (SES) while in extended transit and converting to an Air Cushion Vehicle (ACV) mode when it approaches the objective. A comparison of the T-Craft to current and planned U.S. Army and U.S. Navy assets is presented in Table 4, and a depiction of the overall T-Craft Concept of Operations (CONOPS) is presented in Figure 3.

Asset	Payload	Endurance	Self Deployable?
T-Craft	300–750 tons	500 nm @ 40 kts 2500 nm @ 20 kts	Yes
LCAC (U.S. Navy)	75 tons	300 nm @ 40 kts	No
LCU (U.S. Navy)	125 tons	1200 nm @ 8 kts	No
LSV (U.S. Army)	2000 tons	8200 nm @ 12.5 kts	Yes
LCU 2000 (U.S. Army)	350 tons	9200 nm @ 12 kts	Yes
JHSV (Joint)	600 tons	4700 nm @ 25 kts	Yes

Table 4. Comparison of T-Craft to Current/Planned Assets

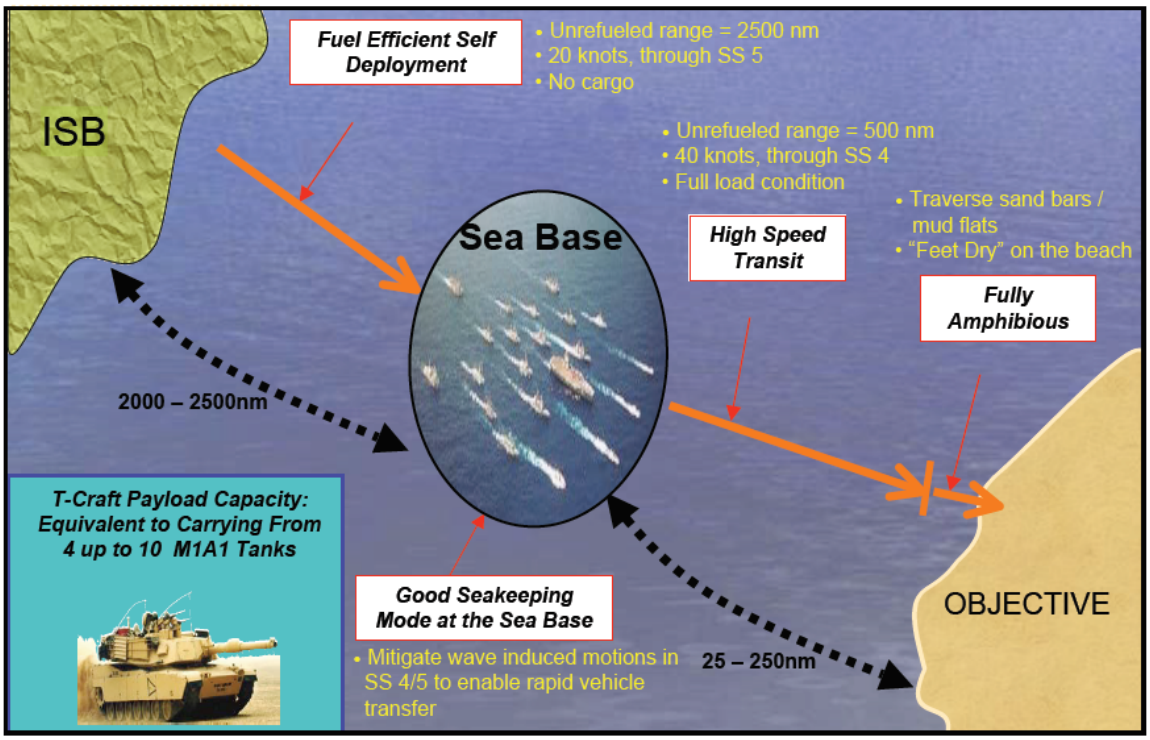

Figure 3. Notional T-Craft CONOPS (From Chang, 2008, p. 2)

4. Related Naval Postgraduate School Research

a. Systems Engineering Analysis Cohort 17A

In lieu of individual theses, Naval Postgraduate School Systems Engineering Analysis (SEA) students are organized into research cohorts to conduct interdisciplinary research projects into areas identified as operationally relevant to the U.S. Navy. SEA Cohort 17A, comprised of seven active duty U.S. Navy Officers, one Department of Defense (DoD) Civilian, and nine students from the Temasek Defence Systems Institute completed a capstone report relevant to this thesis, titled "Influence of Foreign Humanitarian Assistance/Disaster Relief in a Coastal Nation." This study also used EW10 as the operational basis for examination and modeling. Two major findings of the analysis are particularly relevant to this research.

First, the preferred course of action, with respect to FHA/DR delivery, is one that centers on the transport of aid and security to a distribution center by DoD assets and the distribution of aid to the population via distribution centers managed by the Host Nation, NGOs, and other GOs (Systems Engineering Analysis Cohort 17A, 2011, p. 154). Distribution strategies utilizing solely DoD assets for FHA/DR distribution and management were not preferred. Specifically, SEA Cohort 17A investigated courses of action where DoD assets provided, transported, managed, and distributed aid. These courses of actions had negative impacts on the ability to sustain the FHA/DR operation and negative impacts on perception of the operation by HN populations. The analysis indicated that DoD assets should focus only on transportation of aid and providing security for U.S. assets in the area.

Second, the total throughput of the T-Craft was determined to be most comparable to the total throughput associated with current U.S. Navy Amphibious Warfare Ships (Landing Helicopter Dock (LHD), Landing Platform Dock (LPD), and Landing Ship Dock (LSD)) with associated landing craft, not the LCAC, LCU, aircraft, or other landing craft operating in a standalone mode. Because the T-Craft essentially combines the capabilities of two assets (the self-deployable capabilities of the amphibious warfare ships with the landing capability of a landing craft) it was necessary to compare the performance capability of the T-Craft to the combined performance of those two assets (Systems Engineering Analysis Cohort 17A, 2011, p. 45). Because the amphibious warfare ships cannot operate without the use of landing craft (and the landing craft cannot operate without the amphibious warfare ships) it is not operationally relevant to compare either an amphibious warfare ship or a landing craft to T-Craft (Systems

Engineering Analysis Cohort 17A, 2011, p. 44). Thus, T-Craft is able to offer potential improvements in availability, reliability, etc. because the other ships must operate as co-dependent assets. Results of the study indicated that the autonomy provided by the T-Craft allowed for an increase in cargo throughput, provided sufficient cargo transfer zones and beach unloading spots are available.

b. Student Theses

Five student theses have been completed in support of the T-Craft project. In March 2010 LT Bakari Dale completed his thesis, "A Rough Order of Magnitude (ROM) Life Cycle Cost Estimate (LCCE) of the Transformable Craft (T-Craft) Concept" In December 2010, Major Chi Yon Ting completed his thesis, "Life Cycle Cost Estimate of the Transformable Craft." Of particular interest was the decision to develop a parametric cost estimate (based on ship displacement) for T-Craft based on surface combatants (ex: DDG, LCS) (Ting, 2011, p. 16). This reinforces the decision by SEA Cohort 17A to establish the larger LHD, LPD, and LSD as the comparison point for T-Craft, rather than the smaller LCAC or LCU.

In September 2010, LT Nathan Beach completed his thesis, "Systems Architecture of a Sea Base Surface Connector System in a 2020 Humanitarian Assistance/Disaster Relief Joint Operational Environment." LT Beach's thesis also utilized EW10 as an operational basis, and served as the foundation for the operational decision to divide the delivery of aid between Army and Navy Watercraft.

Major Sebastian Scheibe's thesis, "Assessment of the Operational Requirements for the Transformable Craft in Seabasing Missions" (2010) and Major Huntley Bodden's thesis, "A Survivability Assessment of the Transformable Craft in an Operational Environment" (2010) both centered on examination of T-Craft effectiveness in a combat situation, and therefore the results are excluded to prevent the combination of operational conclusions drawn from combat and FHA/DR models.

D. OVERVIEW OF SYSTEMS ENGINEERING PROCESS

The Systems Engineering Process used in this thesis is based on the Systems Engineering Design Process defined by (Buede, 2000). The process allows for non-linear, iterative architectures to be developed and checked throughout the research process. While all of the processes remain interdependent, there remains an element of sequence. Namely, the process follows a general strategy of: develop operational concept, develop system boundary, define systems requirements, define system architectures, and test system architectures. This general analysis approach is particularly useful in the context of a Model Based Systems Engineering framework.

A. Operational Concept

According to Buede, an operational concept is defined as "a vision for what the system is (in general terms), a statement of mission requirements, and a description of how the system will be used" (2000, p. 42). The operational concept is comprised of a system boundary, definition of external systems, input/output requirements for the system, the system context, and a system objectives hierarchy for a U.S. Army Watercraft FHA/DR Operation. The operational concept allows for a general visualization of the system's mission, specifically the individual watercraft assets, as well as the system's interaction with related systems, such as NGOs and Host Nation assets.

B. Functional Architecture

The functional architecture is used to define a hierarchical model of the system's functions, components, inputs, and outputs. Specifically the functional architecture is based on a functional decomposition of a U.S. Army Watercraft Operations from a FHA/DR perspective. This decomposition is then used to develop generic components that can be used to satisfy the requirements for a watercraft FHA/DR mission.

C. Physical Architecture

The generic components developed in the functional architecture are further defined in a physical architecture. Unlike traditional, unconstrained physical architecture development, Army Watercraft architectures are limited by the existence of Army Watercraft assets. As such, the development of a physical architecture must be generalized and refined to a feasible range through another means (such as modeling or simulation). Effectively, given the constrained nature of the problem and the opportunities available from computer simulation and robust experimental design, physical architecture generation can be resolved to the generation of the maximum possible system configurations.

D. Operational Architecture

The objective of an operational architecture is to "integrate the requirements decomposition with the functional and physical architectures" (Buede, 2000, p. 245). Given the mature nature of the technologies considered in this research, the operational architecture is used to allocate functions to physical systems more explicitly and provide a basis for a comprehensive risk analysis.

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III. ARCHITECTURE DEVELOPMENT

A. OPERATIONAL CONCEPT

In order to evaluate the capabilities of U.S. Army Watercraft in a 2022 FHA/DR operational environment the mission requirements for the operation must be defined. Further, the scope of the operation must be defined as well. In order to keep the analysis operationally relevant, the FHA/DR scenario definition is taken from the EW10 Player Book. The timeline leading to the operation is shown in Figure 4.

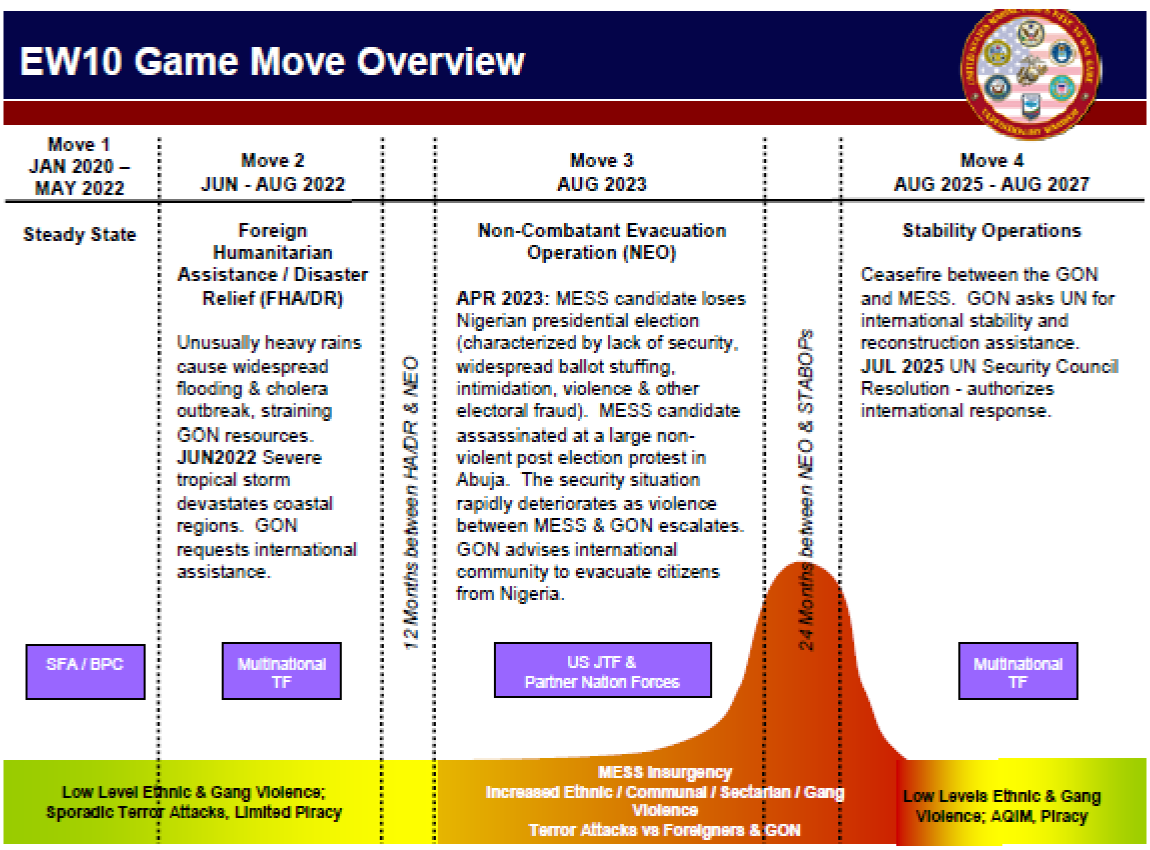

Figure 4. Scenario Timeline (From United States Marine Corps, 2010, p. 7)

Note that the acronym GHN is represented in Figure 4 as GON. The analysis in this thesis focuses on the events defined in Move 2 (June–August 2022). Steady State Operations, Non-Combatant Evacuation Operations, and Stability Operations are scoped out of the analysis. This is done to minimize the number of operational decisions made in the analysis and ensure a focus on a well-defined problem. Further, analysis of political situations and Human Social Cultural Behavior, as would be required for an analysis of Non-Combatant Evacuation Operations and Stability Operations, are beyond the scope of this thesis. Finally, the analysis in this thesis is limited to the Southwest Region of the HN based on the operational recommendation of LT Nathan Beach (Beach, 2010, p. 60). As a result, the operational concept is highly specific but only relevant in the above scenario. Generation of an operational concept based on a different sequence of events or a different operational scenario will result in a different operational concept.

1. Operational Concept Definition

EW10 provides a generalized set of DoD mission requirements for Move 2. The full list of mission requirements is detailed in Chapter II. Note that these requirements are stated from the perspective of the mission stakeholders and are framed in the context of an undefined set of system outputs, which are not necessarily the system outputs of the U.S. Army Watercraft Operation. However, they do define the larger operational concept of the system from the perspective of the mission stakeholders.

The mission requirements in Chapter II are used to define a more specific operational concept for a U.S. Army Watercraft FHA/DR Operation based on EW10. That operational concept is shown in Table 5.

Provide	Personnel Evacuation Search and Rescue Delivery of Food, Water, and Medicine Delivery of Clothes, Shelter, and Supplies Medical and Veterinarian Services Repair/Opening of Airfields and Ports Air Traffic Control Support Repair/Engineering Support
Do Not Provide	Aid Distribution to Population Management of IDP camps

Table 5. EW10 Based U.S. Army Watercraft FHA/DR Operational Concept

It is important to note that the EW10 mission requirements are entirely output requirements, and the operational concept resultantly takes the same form. There exist no explicit interface constraints, suitability requirements, cost requirements, or schedule requirements. Further, the mission requirements require delivery of food, water, medicine, clothes, shelter, and supply, but request that the distribution of those items is completed by the HN, NGOs, and GOs. It is therefore assumed that delivery of those assets requires a delivery to aid distribution centers. Definition of these "do not provide" operational requirements are extremely relevant, since the elimination of operational requirements helps scope the problem and define the system boundary.

2. System Boundary

The "do not provide" operational requirements from the operational concept help define the system boundary. The system boundary is represented visually in an IDEF0 diagram, meant to define the system with respect to inputs, outputs, controls, and mechanisms. The system boundary is presented as in Figure 5.

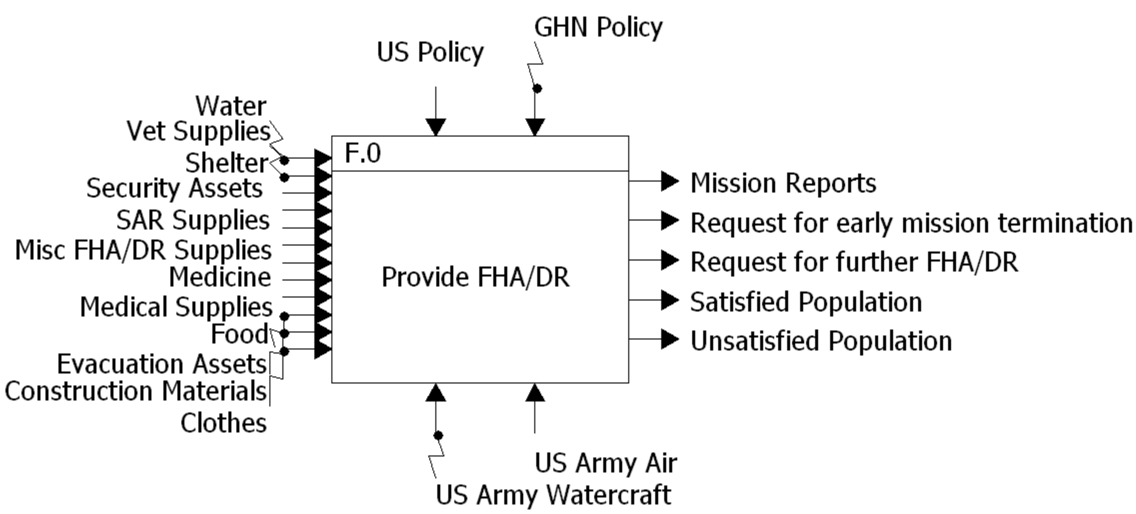

Figure 5. IDEF0 System Boundary

As shown above, the system inputs (left) are defined by the GHN requested assistance. The system outputs (right) define the full scope of potential outcomes, with respect to both the HN population and the subsequent actions of the Army Watercraft assets. The only restrictions on the actions of the system are policies defined by both the United States and the Host Nation. Note that associated external systems, such as the request for FHA/DR, the management of FHA/DR, and the reception of FHA/DR are not shown in the diagram. The objective is to focus on the system and functions performed by U.S. Army assets, not those performed by NGOs, GOs, GHN, or the HN population.

3. System Objectives Hierarchy

The purpose of a Systems Objectives Hierarchy is to define the required functions of the overall system and decompose and prioritize all of the system sub functions. As shown in Figure 5, the system is guided by U.S. policy and HN policy. For the purpose of this analysis, HN Policy is defined in the EW10 Player Book. U.S. policy is guided by: U.S. Army FM 3–07 (Stability Operations), U.S. Army FM 100–23–1 (Multiservice Procedures for Humanitarian Assistance Operations), U.S. Army FM 8–42 (Combat Health Support in Stability Operations and Support Operations), Joint Publication 3–07 (Interagency, Intergovernmental Organization, and Nongovernmental Organization Coordination During Joint Operations), JP 3–07.6 (Joint Tactics, Techniques, and Procedures for Foreign Humanitarian Assistance), and the United States Agency for International Development (USAID) Field Operations Guide (FOG) for Disaster Assessment and Response. This guidance is used to define the functions that can be typically expected of the U.S. DoD and U.S. Army in a FHA/DR scenario. Typically, DoD forces are primarily tasked with providing point-to-point logistical support, as well as airfield management, communications, medical support, or security (United States Agency for International Development, 2005, p. F-3). It is stressed in all publications that DoD will not provide support unless directly requested by the Office of Foreign Disaster Assistance (OFDA), the lead for FHA/DR within USAID. FM 3–07 stresses that unity of effort with all NGOs and GOs is essential to mission success (United States Department of the Army, 2008, p. A-9). Interaction between agencies will be guided by a Civil-Military Operations Center (CMOC). An extensive description of a CMOC is not necessary for this analysis; however there are several relevant CMOC characteristics. The CMOC is the focal point where U.S. military forces coordinate with other agencies (United States Department of the Army, 2006, p. I-4). A notional CMOC composition is shown in Figure 6. Note that the CMOC is a center for coordination, not command. However, U.S. DoD missions are restricted to those requested by OFDA and thus their guidance is used as the baseline for further analysis.

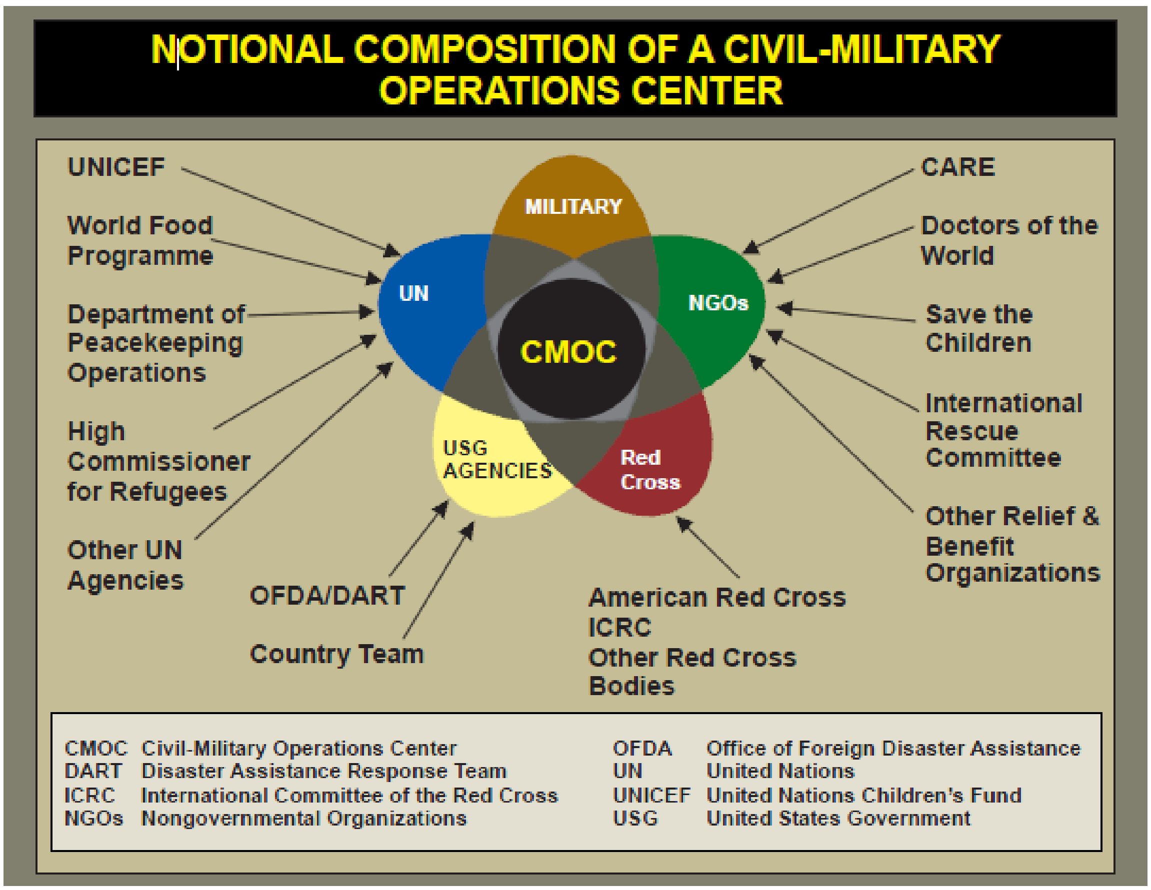

Figure 6. Notional CMOC Composition (From United States Department of the Army, 2006, p. III-18)

Figure 7 shows the objectives hierarchy generated from the collection of standards and publications. Note that several of the original functions of the system have been scoped out of the objectives hierarchy (assigned a weight of zero). This does not indicate that the functions have been scoped out of the mission requirements. This means that the functions have been scoped out of the operational requirements for a U.S. Army Watercraft Force based on the U.S. policy. These requirements are scoped out based on JP 3–07.6 and the USAID FOG. JP 3–07.6 stresses that, while unity of effort is the goal of the FHA/DR Operation and the motivation behind the establishment of a CMOC, USAID and OFDA remain the lead agencies for FHA/DR response. The FOG indicates that personnel evacuation and SAR are typically contracted out to agencies such as Los Angeles County Rescue. The FOG also stresses that DoD assets are preferred only when they provide a unique capability not otherwise possible and that disaster relief provided by the military is primarily intended to supplement ongoing relief efforts, not serve as a focal point of the relief effort. As noted above, construction related tasks are not included in the DoD's primary FHA/DR mission, and are thus scoped out as well.

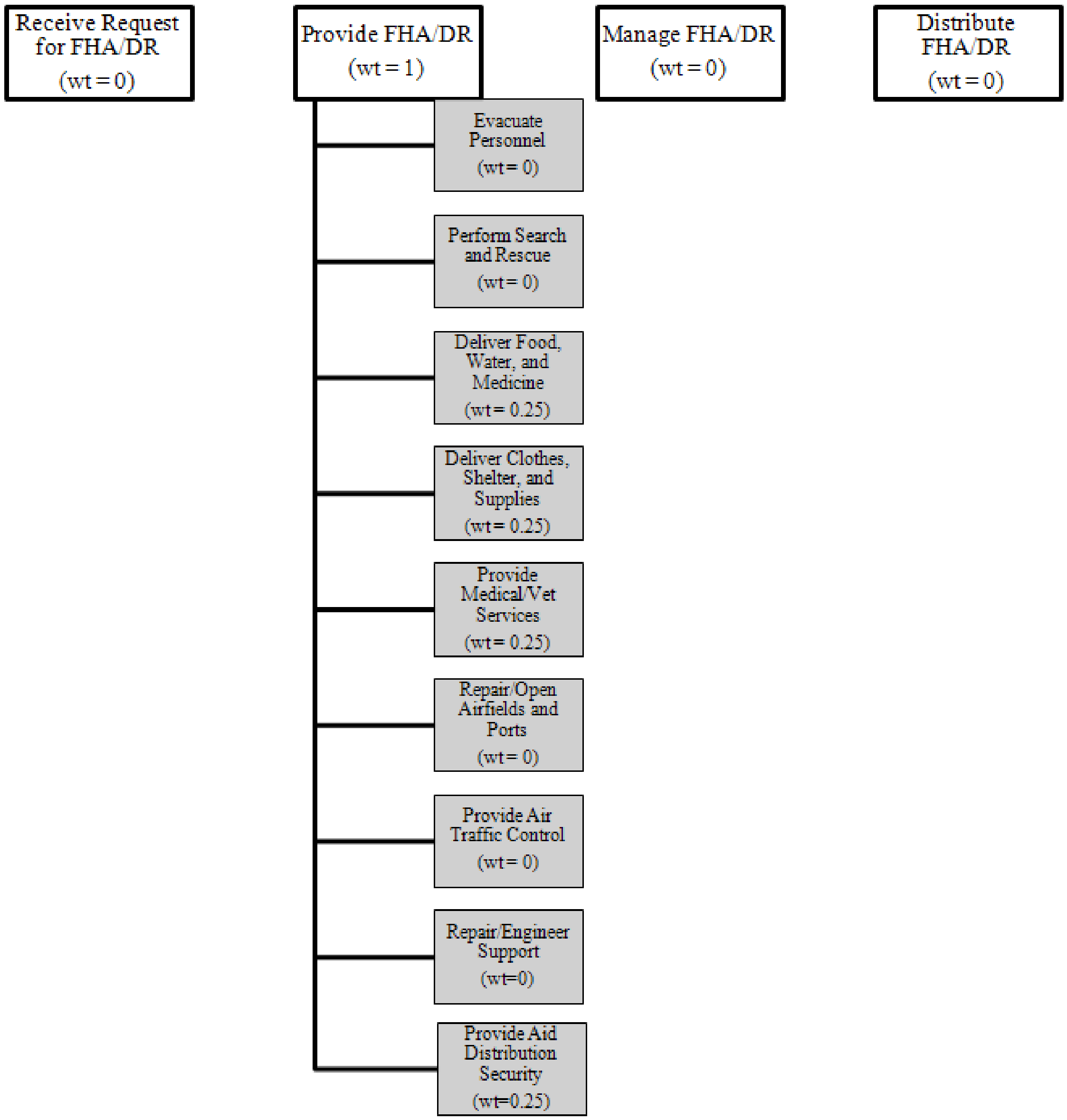

Figure 7. System Objectives Hierarchy

B. FUNCTIONAL ARCHITECTURE

The objective of the functional architecture is to provide traceability from the previously defined mission requirements through the functional activities performed by each of the U.S. FHA/DR response assets. It references the inputs defined by the operational concept with a focus on the intended outputs produced by the operation of each system component.

1. Functional Decomposition

Before defining the required functions for each system component, it is necessary to view the overall super system to ensure that all of the mission requirements are met. The tracing of overall mission requirements for a U.S. FHA/DR response to the U.S. FHA/DR response functions are shown in Table 6.

	Mission Requirements								
Complete US FHA/DR Response Functions	Provide Personnel Evacuation	Provide Search and Rescue	Provide Delivery of: Food, Water, Medicine	Provide Delivery of: Clothes, Shelter, Supplies	Provide Medical / Vet Services	Repair / Open Airfields and Ports	Provide Air Traffic Control Support	Provide Repair / Engineering Support	Provide Aid Distribution Security
F.0 Provide FHA/DR	X	X	X	X	X	X	X	X	X
F.1 Save Lives	X	X							
F.2 Provide Immediate Post Disaster Relief	X	X	X	X	X				X
F.3 Provide Long Term Post Disaster Relief						X	X	X	X
F.4 Provide Security									X
F.5 Interface With UN Management									X
F.6 Re-Settle Refugees									X
F.7 Establish Media Liason									X

Table 6. Map of Requirements to Functions for Complete U.S. FHA/DR Response

As defined by Table 6, the mission requirements applicable to a U.S. Army Watercraft FHA/DR Operation are:

1. Provide Delivery of Food, Water, and Medicine
2. Provide Delivery of Clothes, Shelter, and Supplies
3. Provide Medical/Vet Services
4. Provide Aid Distribution Security

The first three requirements for the U.S. Army portion of the operation are defined by EW10. The requirement for security is based on U.S. Army FM 100–23–1, which indicates that U.S. Army forces will not be deployed in an uncertain operating environment without an accompanying security element. That security element is included in the EW10 description and is assumed to be a BCT. A more refined mapping of mission requirements to functions is shown in Table 7, and focuses on the functions performed by U.S. Army forces.

U.S. Army FHA/DR Response Functions	Provide Delivery of: Food, Water, Medicine	Provide Delivery of: Clothes, Shelter, Supplies	Provide Medical / Vet Services	Provide Aid Distribution Security
F.0 Provide FHA/DR	X	X	X	X
F.2 Provide Immediate Post Disaster Relief	X	X	X	X
F.2.1 Transport Food	X			
F.2.2 Transport Water	X			
F.2.3 Transport Medicine	X			
F.2.4 Transport Clothes		X		
F.2.5 Transport Shelter		X		
F.2.6 Transport Misc Supplies		X		
F.2.7 Transport Medical Supplies			X	
F.2.8 Transport Vet Supplies			X	
F.2.9 Establish Aid Delivery Access	X	X	X	
F.4 Provide Security				X
F.4.1 Provide Security for Personnel				X
F.4.2 Provide Security for Supplies				X
F.4.3 Coordinate Security Procedures with CMOC				X

Table 7. Map of Requirements to Functions for U.S. Army FHA/DR Response

Table 7 shows that five of the major U.S. FHA/DR Response functions are beyond the scope of the U.S. Army mission. The remaining functions correspond to those that focus on the U.S. Army FHA/DR requirements, which are defined by the expected DoD tasks outlined in the OFDA FOG.

2. Functional Activities

A high level list of the functional activities required for a U.S. Army FHA/DR Operation is shown in Table 7. Those activities represent what a U.S. Army FHA/DR Response force must accomplish in order to achieve mission success and are based on past FHA/DR lessons learned as well as current U.S. FHA/DR policy.

a. Provide Immediate Post-disaster Relief

One of the unique capabilities offered by U.S. Army Watercraft assets is the ability to provide high speed point-to-point logistical support for FHA/DR Operations. JP 3-07-6, FM 100-23-1, and the USAID FOG stress that USAID is the lead agency for FHA/DR and is therefore responsible for providing FHA/DR supplies. The mission requirements detailed by EW10 state that GHN and NGO/GO assets are responsible for distribution of those supplies. This scopes the U.S. Army portion of the problem to a FHA/DR transportation mission. A high level description of this function is shown in Figure 8. An expanded view is shown in Appendix A.

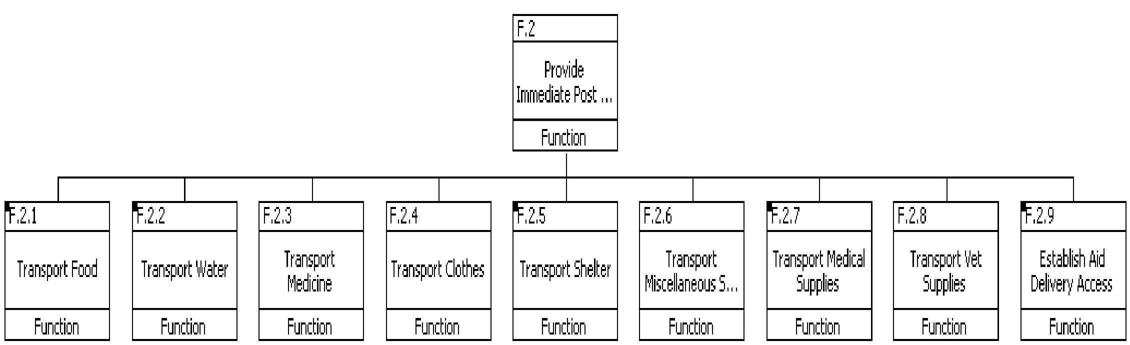

Figure 8. Functional Hierarchy of Provide Immediate Post Disaster Relief

b. *Provide Security*

Security in a FHA/DR environment can be divided into two distinct areas, security for personnel and security for supplies. Security must also be coordinated through the CMOC to ensure that USAID operations are not disrupted by force security measures. A high level description of U.S. Army provided security in a FHA/DR environment is shown in Figure 9. An expansion of Function F.4.2.3 is shown in Appendix A.

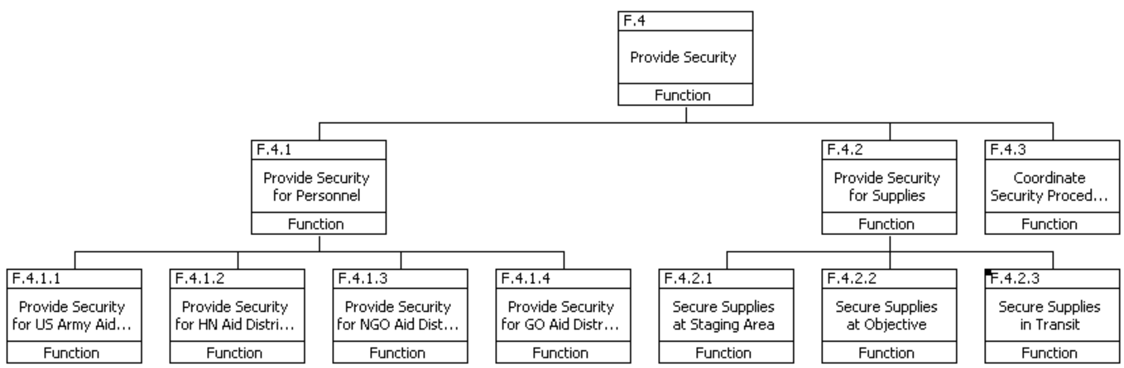

Figure 9. Functional Hierarchy of Provide Security

As shown in Figure 9, providing security for personnel is a multi-dimensional problem. Personnel security must be provided for U.S. Army Assets, as well as the other aid agencies contracted by USAID. The USAID FOG does not explicitly state that force protection measures are required by DoD, however FM 100-23-1 stresses that security for U.S. assets remains a priority for U.S. Army FHA/DR responses. Demonstration of the aid capabilities of the U.S. military, as well as a restriction on overt military operations, ensures that U.S. military aid is accepted and U.S. military forces are seen as neutral agencies (United States Department of the Army, 1994, p. 1–5). As such, it is assumed that security for personnel and security for supplies would be restricted to the BCT defined in EW10. Further, the BCT assets will not be deployed beyond the staging area and the objective (aid distribution sites). This ensures that all major functions defined in Figure 9 can be met without violation of current USAID or DoD guidance.

C. PHYSICAL ARCHITECTURE

1. System Descriptions

The objective of a traditional physical architecture is to "provide a hierarchical description of the resources that comprise the system" (Buede, 2000, p. 215). The physical architecture is intended to provide traceability from the functional architecture, through the system's top level components, down to the configuration items that define the physical elements of the system. Given that the functional architecture has scoped the problem from a multinational FHA/DR operation to a more straightforward transportation and throughput problem, the solution space can be reduced. The top level components of the system are the same as the low level configuration items. Namely, the physical elements that comprise the system are defined by the full complement of available Army transportation assets. Further, the configuration items for an Army transportation operation centered on Army Watercraft are defined by the Army Watercraft and transportation assets in existence at the time of that operation. As such, the solution space is necessarily reduced further to existing Army Watercraft assets and Army transportation assets.

Rather than assign each asset a particular transportation function, the decision was made to allow all assets to transport all types of FHA/DR cargo. This is seen as more operationally realistic and less dependent on operational decisions made by the author. Further, given the weather conditions associated with natural disasters and the degradation of the road systems, as defined by EW10 (United States Marine Corps, 2010, p. 49), the use of ground transportation assets is deemed unrealistic. As such, the full complement of available assets for a 2022 FHA/DR Watercraft based Army Transportation Operation is limited to existing Army Watercraft and Air assets. These assets are defined in Appendix B. A summary of the available assets is presented in Table 8. Note that the mission scenario restricts Air Assets to intra-theater rotary wing Army Air Transportation Assets. As a result, Attack, Recon, Unmanned Aerial System, and Fixed Wing Assets are not shown. The projections of Force Structure are based on the Army Watercraft Master Plan and the 2010 Army Modernization Strategy.

Category	Ship	Number
High Speed Vessels		
	JHSV	10
	T-Craft	10
Lighters		
	LSV	8
	LCU 2000	34
	Causeway Ferry	3
Floating Craft		
	MCS	6
	Floating Causeway	3
	LT800	6
	ST900	16
	BD115	5
	Warping Tug	18
	VSB	4
Air Assets		
	H-47	513
	H-60	2127

Table 8. Projected 2022 Army Watercraft/Air Force Structure

2. Alternative Physical Architectures

The alternative physical architectures for this analysis are based on the full complement of available Army Watercraft and Army Air Transportation Assets presented in Table 8. However, the only assets of interest for a FHA/DR throughput analysis are those that transport cargo. As such, the physical elements of interest are:

1. JHSV
2. T-Craft
3. LSV
4. LCU 2000
5. H-47
6. H-60

While T-Craft is not a currently planned U.S. Army acquisition program, the capabilities of T-Craft, as presented in Chapter II, fulfill the capability gaps currently facing U.S. Army Watercraft, and is thus included in the analysis. All other systems are either current or planned Army programs. Traditional physical architecture development suggests that identification of combinations of these assets should be chosen and tested to determine which asset combinations provide the greatest performance, with respect to the MOOs, MOEs, and MOPs defined by the functional architecture. However, the use of high speed simulations, as well as utilization of recent advances in efficient experimental design (Cioppa, 2002 and Hernandez, 2008), allows for examination of a more extensive solution space. Utilization of simulation and these designs is presented in Chapters IV and V.

Although efficient experimental design may allow for examination of a solution space defined by all of the Army Watercraft and Air Transportation Assets existing in 2022, it is not operationally realistic to suggest that the Army would commit 100% of its transportation assets to a FHA/DR operation. However, in order to provide insight into the impact of each asset, a range of potential force compositions must be examined. Historical FHA/DR scenarios indicated that a response force composition would be based on asset availability at the time of the disaster. SMEs were consulted and a recommendation of no more than 8 JHSVs, 5 LSVs, 17 LCU 2000s, 40 H-60s and 40 H-47s would participate in the mission. Lack of familiarity with the T-Craft prevented an accurate estimate by SMEs. Given that T-Craft is most similar to the JHSV, a maximum of 8 available T-Craft is used. Table 9 shows the final range of potential force compositions used in this analysis.

Category	Ship	Minimum	Maximum
High Speed Vessels			
	JHSV	0	8
	TCraft	0	8
Lighters			
	LSV	0	5
	LCU 2000	0	17
Air Assets			
	H-47	0	40
	H-60	0	40

Table 9. Range of Asset Quantities Available for 2022 FHA/DR Operation

D. OPERATIONAL ARCHITECTURE

The Operational Architecture, as defined by Buede, is used to provide a high level description of the total system, specifically defining how the elements of the physical architecture satisfy the functions defined by the functional architecture. Given the unorthodox development of the physical architecture and the assumption that all crafts are capable of transporting all forms of FHA/DR material, the development of an operational architecture must focus on definition of system desired end states, rather than allocation of system components to system functions. For completeness, Table 10 is presented to demonstrate that all required system functions are satisfied by the physical architecture.

	US Army FHA/DR Response Functions														
Physical Architecture Components	F.0 Provide FHA/DR	F.2 Provide Immediate Post Disaster Relief	F.2.1 Transport Food	F.2.2 Transport Water	F.2.3 Transport Medicine	F.2.4 Transport Clothes	F.2.5 Transport Shelter	F.2.6 Transport Misc Supplies	F.2.7 Transport Medical Supplies	F.2.8 Transport Vet Supplies	F.2.9 Establish Aid Delivery Access	F.4 Provide Security	F.4.1 Provide Security for Personnel	F.4.2 Provide Security for Supplies	F.4.3 Coordinate Security Procedures with CMOC
JHSV	X	X	X	X	X	X	X	X	X	X	X	X	X	X	
T-Craft	X	X	X	X	X	X	X	X	X	X	X	X	X	X	
LSV	X	X	X	X	X	X	X	X	X	X	X	X	X	X	
LCU 2000	X	X	X	X	X	X	X	X	X	X	X	X	X	X	
H-47	X	X	X	X	X	X	X	X	X	X	X	X	X	X	
H-60	X	X	X	X	X	X	X	X	X	X	X	X	X	X	

Table 10. Range of Asset Quantities Available for 2022 FHA/DR Operation

Note that coordination with the CMOC is not accomplished by any of the components defined in the physical architecture. It is assumed that this function will be accomplished by the mission commander, who is not necessary to include in the physical architecture.

1. MOO/MOE/MOP Definition

Traditionally, measures of effectiveness (MOEs) and measures of performance (MOPs) are used to define system performance within a given operational environment. MOEs are quantitative measures used to assess how well the system performs with respect to a set of operational tasks, typically external to the system as a whole. MOPs are focused within the system itself, and are used to measure the performance of system components. In order to identify militarily relevant solution spaces, the concept of measures of outcome (MOO) must be introduced. MOOs are used to examine how well a system achieves high level operational requirements. Thus, while improvements in MOP and MOE performance may seem desirable, they may show no practical significance with respect to MOOs.

The MOEs and MOPs for a system must be mapped to the required functions for the system to ensure that the goals and priorities are congruent with mission requirements. That mapping is presented in Appendix A. Note that all MOPs are defined as subsets of the larger MOE (Time to Provide Aid). This MOE describes the performances of the entire FHA/DR delivery system in a large enough context to envelope all of the functions required of the system. This is extremely desirable, as one MOE can now be used to assess the performance of the system as a whole. However, Time to Provide Aid must be defined further and expanded as an MOO to ensure that system performance is assessed from a militarily relevant perspective.

Time to Provide Aid is defined as the time required to provide 120,000 tons of FHA supplies to the objective. This is based on the work of Systems Engineering Analysis Cohort 17A, which concluded that, for a similar scenario, a total of 3.1 pounds of aid, per person, per day is required, along with a onetime need of 39.0 pounds per person (SEA Cohort 17A, 2011, p. 175). Given that a total of 2,874,000 people are affected in the region of interest, a total of approximately 120,000 tons of aid is required. Time to Provide Aid is defined as the time for the FHA/DR response force to transport 120,000 tons of aid.

Time to Provide Aid is expanded as a MOO based on the security requirement for U.S. forces and the distribution sites. It is assumed that the BCT is capable of self-sustainment for a period of 14 days. After that 14 day period, the BCT must withdraw or request resupply. Historical evidence from FM 100-23-1 and JP 3-07.6 suggest that 14 days may be sufficient to conduct the FHA/DR delivery phase of the operation. Given that the resupply demands imposed by the BCT are based on the operational requirements of the BCT and changing security situations, a mission completion time of 14 days is established as the threshold for mission success. Thus, Time to Provide Aid is redefined as a MOO, with mission completion times less than or equal to 14 days classified as mission success.

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IV. MODEL DEVELOPMENT

A. INTRODUCTION

This section describes the basic characteristics of an ExtendSim model, as well as the simulation environment. ExtendSim is a dynamic process simulation capable of modeling complex processes and decision logic. The nature of the simulation lends itself to a discrete event queuing model capable of informing the performance characteristics of various physical architecture combinations in a FHA/DR environment. Further, the library based nature of ExtendSim allows for large batch runs, enabling an examination of large solution spaces. Further information about ExtendSim is available in the ExtendSim User Guide or at www.extendsim.com.

B. MODEL DESCRIPTION

The objective of this analysis is to create a discrete event queuing model capable of informing a decision maker about the throughput capabilities of various physical architectures. For the purpose of the model, Degut represents the objective and the staging area represents a port located 150 nm west of Degut. Each asset transitions through the model following the same discrete event process. A description of the simulation within the context of ExtendSim is presented in Appendix C.

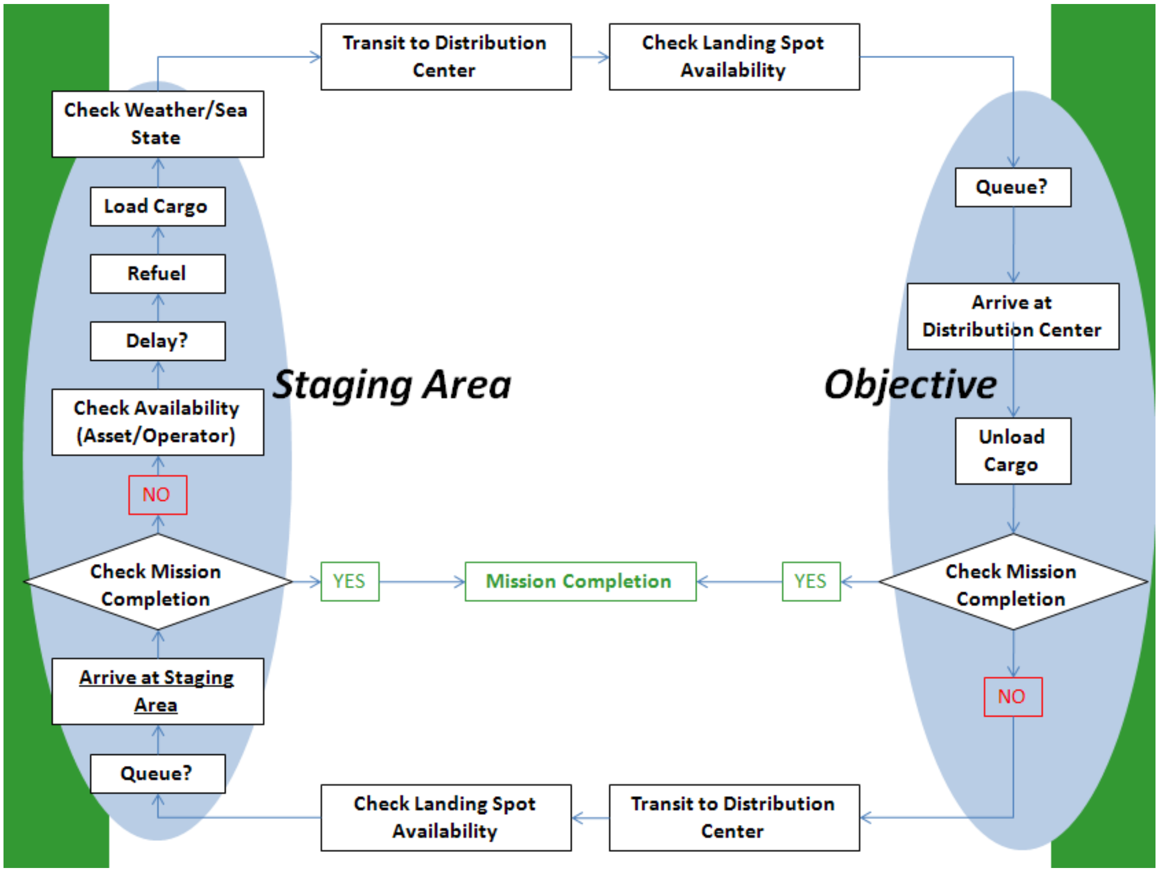

Figure 10. ExtendSim Model Process Description

The processes that define the simulation are shown above in Figure 10. The process steps are as follows:

1. Arrive at staging area (shown in the bottom left of Figure 10)
2. Check mission completion. Prior to loading cargo, the asset checks the status of the mission. The asset considers its mission complete if all of the FHA/DR material has left the staging area. Overall mission completion is recorded once all of the FHA/DR material reaches the objective.
3. Check the availability of the operator and the asset. For the purpose of the simulation, air assets may only operate for eight hours per day and watercraft assets may only operate for twelve hours per day. This logic ensures that operator flight/operation time restrictions are not violated.

Asset availability is also modeled in the simulation. Each asset has a projected availability and its ability to continue the mission without downtime is assessed concurrently with the availability of the operator. Refueling time is combined with the delays associated with asset and operator rest time. The associated delays are constant for each asset within a simulation run.

4. Load cargo. The load time is based on the size of the asset. In order to reduce the number of operational decisions made by the author, a load rate of 85 tons per hour is assumed for all watercraft assets. Both the H-47 and H-60 are assumed to carry the majority of their payload via sling load and therefore each is assumed to load their cargo in one hour. The load times are varied between 100% of an asset's projected load time and 120% of the asset's projected load time. This is done in an attempt to model unexpected delays encountered when loading the asset. The associated delays are stochastic and based on an exponential distribution.

5. Check Weather/Sea State. For the purposes of the simulation, Weather and Sea State are established as performance modifiers. Sea State impacts the performance of watercraft assets and Weather impacts the performance of air assets. Sea State and Weather increases transit time by multiplying the asset Transit Time by a multiplying factor. The impact is described in Table 11.

Sea State / Weather Value	Impact on Transit Time
0	100%
1	102%
2	105%
3	110%
4	120%

Table 11. Impact of Sea State/Weather on Transit Time

6. Transit to distribution center. Each asset's transit time is a function of the speed of the asset and the increase in transit time due to Sea State/Weather. The associated transit times are stochastic and based on an exponential distribution.

7. Check landing spot availability. As watercraft assets approach the objective they enter a queue. The number of landing spots available at the objective is varied for each simulation run. Assets queue on a First In-First Out (FIFO) basis. There are no queues for the Air Assets. It is assumed that there will be unlimited distribution locations for Air Assets.

8. Arrive at distribution center and unload cargo. Once each asset reaches the end of the unloading queue, it unloads its cargo. In order to reduce the number of operational decisions made by the author, an unload rate of 55 tons per hour is assumed for all watercraft assets except T-Craft, which has an unload rate of 85 tons per hour. This demonstrates the increase in performance offered by the "feet dry on the beach" capability of T-Craft. Both the H-47 and H-60 are assumed to carry the majority of their payload via swing load and therefore each is assumed to unload their cargo in one hour. As with load times, unload times range from 100% of an asset's projected unload time to 120% of an asset's projected unload time. The associated delays are stochastic and based on an exponential distribution.

9. Check mission completion. The asset again checks to see if the mission is complete, using the same standards as previously.

10. Transit to staging area. The asset transits back to the staging area, using the same parameters as used for transit to the objective.

11. Check landing spot availability. It is assumed that, because the staging area is a port that ordinarily experiences high cargo throughput, there are unlimited loading spots available at the staging area.

12. Each asset continues the cycle until 100% of the FHA/DR material has exited the staging area.

Note that there is an additional delay associated with the T-Craft. Because the T-Craft must transition from Surface Effect Ship (SES) mode to Air Cushion Vehicle (ACV) mode when it reaches and exits the objective, an additional delay for conversion time must be modeled. Existing T-Craft demonstrator prototypes have conversion times of approximately one hour. Accordingly, a one hour delay is modeled for T-Craft before it enters the queue at the objective and after it unloads cargo at the objective. The delays are stochastic and are based on an exponential distribution. It is not necessary to model the delay for T-Craft at the staging area because it is assumed that T-Craft will be capable of loading at a port while still in SES mode.

C. ENTITIES AND ATTRIBUTES

In order to properly model FHA/DR transportation in an ExtendSim model, the entities that participate in the simulation must be defined. Each entity is defined by the attributes that characterize it and govern its actions within the simulation. In this model, each entity is defined by six attributes. Those attributes are:

1. Payload
2. Load Time
3. Unload Time
4. Transit Time
5. ACV Conversion Time
6. SES Conversion Time

The Army Watercraft Master Plan and Army Fact File are used to obtain the payload and speed of each asset. The payload is inputted directly as an attribute of each asset. The payload is divided by a load rate of 85 tons per hour and an unload rate of 55 tons per hour to obtain the Load Time and Unload Time attributes. Unload rates are appreciably slower for each asset because it is assumed that loading takes place in port and unloading takes place on an unimproved beachhead. The fully amphibious capability of T-Craft allows it to retain an unload rate of 85 tons per hour. The load and unload times are fixed at one hour for the H-47 and H-60. The Transit Time attribute is obtained by dividing 150 nm (the distance between the staging area and objective) by the speed of the asset. ACV Conversion Time and SES Conversion Time are set at one hour for T-Craft and zero for all other assets.

D. RESOURCES

The only resource of interest to the simulation is the amount of FHA/DR present at the staging area and at the objective (Degut). As discussed in Chapter III, there is a total of 120,000 tons of aid that must be delivered to Degut. A resource pool of 120,000 tons is established at the staging area and a resource pool of 0 tons is established in Degut. Each time an asset loads cargo at the staging area the associated resource pool is reduced and each time an asset unloads cargo in Degut the associated resource pool is increased. Mission completion is achieved when the Degut resource pool reaches 120,000 tons.

E. VARIABLES OF INTEREST

To examine the relative effectiveness of various force structures, the variables that define those force structures must be varied and the associated impact on the measures of effectiveness and performance must be analyzed. Decision factors are defined as those that can be controlled by a decision maker or mission commander. Noise factors are those variables that may have an impact on force effectiveness but cannot be controlled. Output variables are those that are used as measures of effectiveness.

1. Decision Factors

In order to determine the effectiveness of a particular force structure, that force structure must be defined. There are a total of seven decision factors. Given that the objective of the analysis is to recommend a force composition, the number of each asset is of particular interest and is therefore systematically varied for each simulation run.

1. Number of T-Craft (Range: 0 through 8)
2. Number of JHSV (Range: 0 through 8)

3. Number of LSV (Range: 0 through 5)
4. Number of LCU 2000 (Range: 0 through 17)
5. Number of H-47 (Range: 0 through 40)
6. Number of H-60 (Range: 0 through 40)
7. Payload Efficiency (Range: 0.7 through 1.0)

Payload efficiency requires additional explanation. The ExtendSim model is based on the throughput of total cargo, measured in tons. Each asset (entity) has a payload attribute that defines how much cargo it can transport at one time. However, maximum payload of an asset is not necessarily the limiting factor for cargo transport. Often, the amount of cargo that can be transported is limited by the footprint of that cargo (ex: 70 tons of M1A1 tank has a smaller cargo footprint than 70 tons of infantry). The payload efficiency variable attempts to account for the inefficiencies of cargo loading by degrading the maximum payload of each asset during a given simulation run. For a given run, the payload efficiency of each asset is varied between 70% of maximum payload and 100% of maximum payload. The 70% minimum was obtained through discussions with SMEs, which indicated that cargo usage in FHA/DR operations rarely falls below this value. Note that 100% of maximum payload can be achieved without 100% usage of the available cargo area if the cargo is particularly dense. This indicates that 100% payload efficiency is within an operationally realistic modeling range.

2. Noise Factors

The effectiveness of a force composition is also impacted by variables beyond the control of the mission commander. These variables are defined as noise variables. There are a total of six noise variables.

1. Sea State. As discussed in the previous section, Sea State is used as a performance degradation factor, increasing the transit time of watercraft assets. (Range: 0 through 4)

2. Weather. As discussed in the previous section, Sea State is used as a performance degradation factor, increasing the transit time of air assets. (Range: 0 through 4)
3. Availability. Used to model failures and required maintenance for each asset. Availability is checked after each asset reaches the staging area. (Range: 0.85 through 0.95)
4. Number of Landing Spots. Used to determine the number of landing spots available from watercraft assets at the objective. If a landing spot is not available, watercraft assets will queue on a FIFO basis. Range: (0 through 12).
5. Load Time. A multiplying factor used to represent the unanticipated delays associated with loading an asset. Load Time increases an asset's loading time by a percentage. (Range: 1 through 1.2)
6. Unload Time. As with Load Time, a multiplying factor used to represent the unanticipated delays associated with loading an asset. Range: (1 through 1.2)

3. Output Variables

In order to evaluate the effectiveness of a particular force composition, only one variable is truly of interest, the time to complete the entire mission. Rather than focus on the amount or percentage of cargo transported by an individual asset, the analysis focuses on the total time to complete the mission. There are two major reasons for this focus. First, an asset may bring a large portion or percentage of the cargo but create queuing delays for other assets that may not have otherwise occurred. This decreases the performance of other assets while increasing the perceived performance of that asset. Second, the percentage of cargo brought by an individual asset holds no practical significance for a mission commander. The mission commander's primary concern for a cargo transport mission is to complete the mission quickly and successfully. Therefore, in order to provide operationally relevant conclusions, the analysis focused on the overall time to complete the mission. The time to complete the mission is defined as the number of hours elapsed from the beginning of the loading process for the initial asset to the end of the unloading process for the final asset.

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V. DECISION ANALYSIS

A. INTRODUCTION

In order to utilize simulation to provide operationally relevant conclusions to complex military problems, the simulation must examine a sufficient number of variables to be useful to a potential mission commander. More specifically, the simulation must have the capability to examine a large number of variables that impact the MOOs, MOEs and MOPs in the scenario. The variables examined in this simulation are presented in Chapter IV.

B. EXPERIMENTAL DESIGN

The experimental designs utilized in this thesis are based on the work of LTC Thomas M. Cioppa's PhD dissertation, *Efficient Nearly Orthogonal and Space Filling Experimental Designs for High-Dimensional Complex Models.* LTC Cioppa's dissertation served as the baseline for future work into Nearly Orthogonal Latin Hypercubes (NOLH). This thesis also makes use of a NOLH design generating Microsoft Excel spreadsheet developed by Professor Susan Sanchez. Professor Sanchez's spreadsheet makes use of LTC Cioppa's research as well as expanded work done by COL Alejandro S. Hernandez in his dissertation *Breaking Barriers to Design Dimensions in Nearly Orthogonal Latin Hypercubes.*

NOLH designs offer three desirable properties for high dimensional models. First, they are space filling designs. Traditional Design of Experiments focuses on examination of a solution space at the extremes of the dataset. Space filling designs focus on minimization of the distance between design points, allowing for examination of a solution space within the entire experimental region. This allows for examination of non-linear response surfaces. Second, the NOLH designs have highly orthogonal properties. This indicates that the columns generated by an NOLH design have very low correlations, which assures that the columns are nearly independent. Finally, NOLH designs require a relatively low number of design points to fill an entire solution space.

This allows for an increase in the number of variables analyzed without an increase in the number of runs required to conduct the simulation.

Table 12 summarizes the design variables examined for this thesis, as well as the range of factor levels for each variable.

Category	Variable Name	Minimum Value	Maximum Value
Decision Variables			
	# of T-Craft	0	8
	# of JHSV	0	8
	# of LSV	0	5
	# of LCU 2000	0	17
	# of H-47	0	40
	# of H-60	0	40
	Payload Efficiency	0.7	1
Noise Variables			
	Sea State	0	4
	Weather	0	4
	Availability	0.85	0.95
	Landing Spots	1	12
	Load Time	1	1.2
	Unload Time	1	1.2

Table 12. Summary of Simulation Variables

Rather than group all of the variables into one large design, the decision was made to cross the experimental design for the decision variables with an independent experimental design for the noise variables. This allows for each combination of decision variables to be run at each combination of noise variables. This is seen as the preferred approach because the uncontrollable nature of the noise variables suggested it would be useful to examine them at every level of decision variables to ensure that any noise variable impact would be apparent in the analysis.

For the seven decision variables, a 17 level NOLH design is required. To ensure more complete coverage of the solution space, the design is rotated twice, resulting in a total of 49 simulation runs. A comparison of design space coverage for rotated and non-rotated designs is shown in Figure 11.

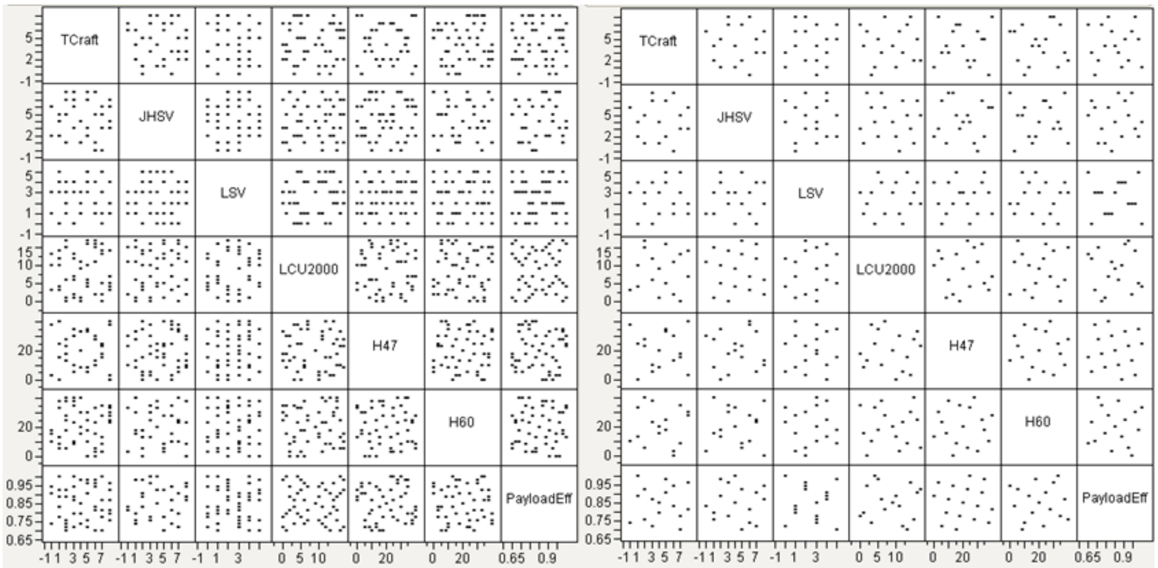


Figure 11. Comparison of Design Space Coverage

Visual inspection of the rotated scatter plot (left) against the non-rotated scatter plot (right) indicates superior coverage of the solution space. Examination of correlation matrices shows a reduction in correlation between variables (by approximately a factor of 10). This indicates that the additional design points provide value.

Initial data exploration supplemented the NOLH design with a fractional factorial design to ensure coverage of the extreme possible solutions. However, these runs resulted in extreme values for the decision variables. Further analysis indicated that factorial designs are inappropriate for decision variable analysis in this scenario. Factorial designs, which emphasize analysis at the extreme levels of the dataset, result in operationally unrealistic scenarios for this analysis. Inclusion of factorial designs for the decision variables resulted in design points such as (Table 13):

Variable Name	Run 1	Run 2	Run 3
# of T-Craft	0	8	0
# of JHSV	0	8	0
# of LSV	0	5	0
# of LCU 2000	0	17	0
# of H-47	0	40	0
# of H-60	0	40	40
Payload Efficiency	1	1	0.7

Table 13. Factorial Design Suggested Design Points

These design points require simulation runs for operationally unrealistic conditions. Run 1 requires that zero total assets are present. Run 2 requires that the maximum level of all assets are present. Run 3 requires that the operation is conducted only by H-60s. Because of the improbability of a mission being conducted under these conditions, factorial designs are not used for the decision variables.

The noise variable NOLH design also requires 17 design points. This design is rotated once and supplemented by a resolution 4 fractional factorial design for a total of 49 design points. The resolution 4 fractional factorial design is chosen to ensure that there is coverage of the noise variables at the extreme values, with predictive properties through two way interactions. Because the noise variables are uncontrollable, it is useful to include an analysis of variables such as Sea State, Weather, Availability, Landing Spots, and Load/Unload Times at extreme conditions. This allows for examination the impact of extreme values for uncontrollable variables on any conclusions. This design does sacrifice predictive power for high level interactions between variables, but the nature of the simulation suggests that these interactions are improbable.

The decision variable design and noise variable design are crossed, resulting in a total of 2401 design points. Each design point is replicated 30 times, resulting in a total of 72,030 simulation runs. Figure 12 presents the scatterplot matrix for the full design. Figure 13 presents the correlation matrix for the design. Note that the NOLH designs show full coverage of the entire design space and the correlation matrix shows that all correlations between variables are below 0.05, except for the correlation between Sea State and Availability, which have a correlation of 0.0528. The objective correlation value is <0.05, with a threshold of <0.10. Given that this value is extremely close to the objective and well below the threshold, the design is accepted. If either variable becomes extremely important in further analysis a new design may be considered.

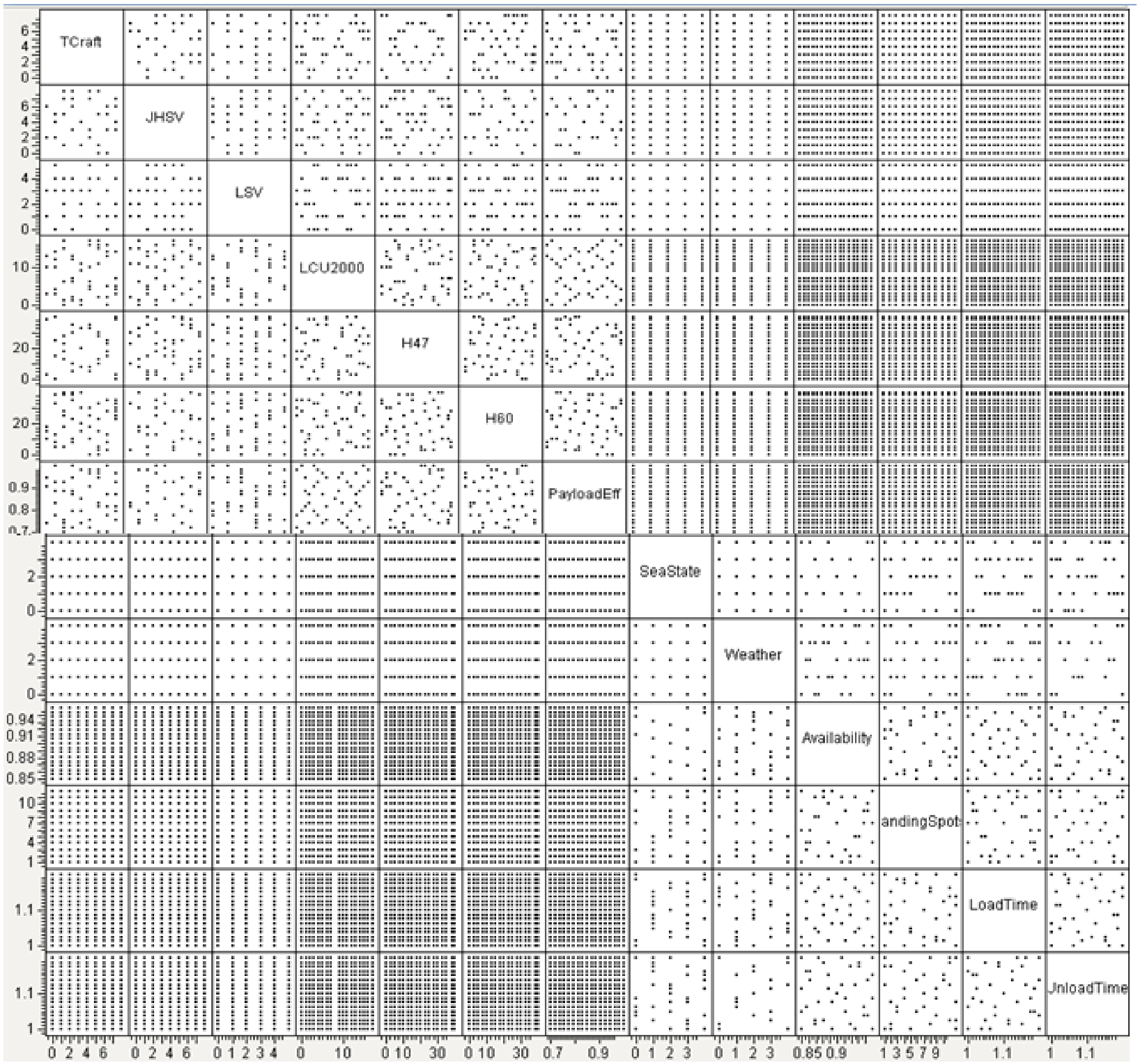


Figure 12. Scatterplot Matrix for Full Design

	TCraft	JHSV	LSV	LCU2000	H47	H60	PayloadEff	SeaState	Weather	Availability	LandingSpots	LoadTime	UnloadTime
TCraft	1.0000	-0.0063	0.0097	-0.0121	0.0000	0.0000	0.0000	-0.0000	-0.0000	0.0000	-0.0000	0.0000	-0.0000
JHSV	-0.0063	1.0000	0.0461	-0.0062	0.0000	0.0000	-0.0000	-0.0000	0.0000	-0.0000	-0.0000	-0.0000	-0.0000
LSV	0.0097	0.0461	1.0000	0.0126	-0.0158	0.0103	0.0261	-0.0000	0.0000	-0.0000	-0.0000	-0.0000	0.0000
LCU2000	-0.0121	-0.0062	0.0126	1.0000	-0.0075	0.0060	-0.0045	-0.0000	-0.0000	0.0000	0.0000	0.0000	0.0000
H47	0.0000	0.0000	-0.0158	-0.0075	1.0000	-0.0001	0.0000	0.0000	-0.0000	0.0000	-0.0000	0.0000	-0.0000
H60	0.0000	0.0000	0.0103	0.0060	-0.0001	1.0000	-0.0000	-0.0000	0.0000	-0.0000	-0.0000	-0.0000	-0.0000
PayloadEff	0.0000	-0.0000	0.0261	-0.0045	0.0000	-0.0000	1.0000	-0.0000	-0.0000	0.0000	-0.0000	0.0000	0.0000
SeaState	-0.0000	-0.0000	-0.0000	-0.0000	0.0000	-0.0000	-0.0000	1.0000	-0.0273	-0.0528	0.0083	0.0000	0.0029
Weather	-0.0000	0.0000	0.0000	-0.0000	-0.0000	0.0000	-0.0000	-0.0273	1.0000	-0.0088	-0.0299	-0.0029	-0.0235
Availability	0.0000	-0.0000	-0.0000	0.0000	0.0000	-0.0000	0.0000	-0.0528	-0.0088	1.0000	-0.0153	0.0000	-0.0000
LandingSpots	-0.0000	-0.0000	-0.0000	0.0000	-0.0000	-0.0000	-0.0000	0.0083	-0.0299	-0.0153	1.0000	0.0153	0.0153
LoadTime	0.0000	-0.0000	-0.0000	0.0000	0.0000	-0.0000	0.0000	0.0000	-0.0029	0.0000	0.0153	1.0000	-0.0000
UnloadTime	-0.0000	-0.0000	0.0000	0.0000	-0.0000	-0.0000	0.0000	0.0029	-0.0235	-0.0000	0.0153	-0.0000	1.0000

Figure 13. Correlation Matrix for Full Design

C. INSIGHTS INTO RESEARCH QUESTIONS

1. Overview

In Chapter I, three distinct research questions are defined. Questions 1 and 3 have been addressed previously in this thesis. The sub questions posed in Question 2 are of interest to the simulation analysis. Recall that those questions are:

1. How do alterations in the physical architecture impact force effectiveness?
2. What changes in Doctrine, Organization, Training, Materiel, Leadership, Personnel, and Facilities (DOTMLPF) impact force effectiveness?
3. What does T-Craft add vs. force compositions without T-Craft?

2. Initial Analysis

Initial data exploration is performed in an attempt to identify those factors that have the largest impact on force effectiveness. As discussed in Chapter III, the MOP of interest for this analysis is the overall time to complete the mission. Traditional data analysis suggests that the preferred method to examine this MOP is to perform linear regression on the time to complete the mission to determine the best possible model as well as the most significant factors. However, as noted by Susan M. Sanchez in *Robust Design: Seeking the Best of all Possible Worlds* (2000), robust design can be preferable to traditional regression for complex simulations given that the simulations are based on system inputs and assumed distributions that "are unlikely to be completely accurate." Robust design is "a process of simulation optimization, where the 'best' answer is not overly sensitive to small changes in the system inputs."

In order to perform a robust analysis of the decision space, a desired performance characteristic for the system must be defined. That performance characteristic corresponds to the MOO outlined in Chapter III, specifically that the initial 120,000 tons of FHA/DR supplies be delivered in 14 days. Therefore, 14 days is set as the target value for mission completion. A quadratic loss function is defined as in Sanchez (2000). The objective of the loss function is to penalize those observations (by scoring high loss) that fall an extreme distance from the target value, while scoring low loss for those observations close to the target value. This approach does not attempt to identify an optimal solution; rather it identifies the factors that cause extreme variability in the response. However, it penalizes those observations that fall an extreme distance below the target value, which is inappropriate for this analysis. Despite that limitation, use of a loss function is valuable as a screening analysis method for initial data exploration, and to determine the factors responsible for MOP variability. Figure 14 shows a summary of the residual plots for the loss function.

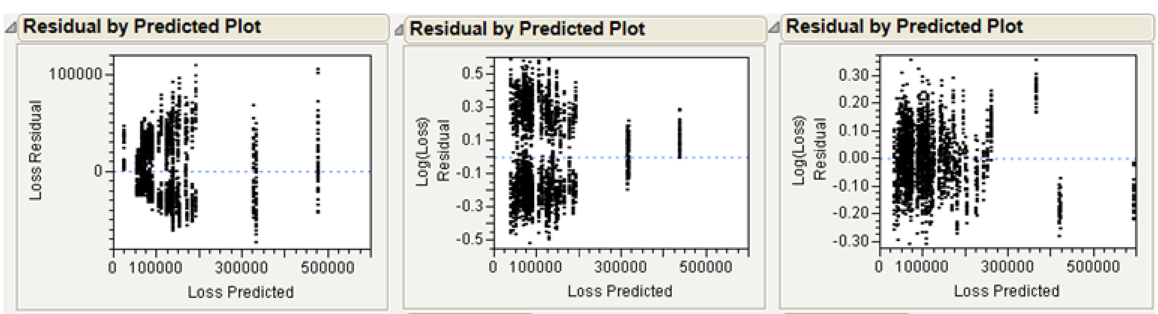


Figure 14. Residual Plots for Loss Function

The initial analysis is defined by three distinct stages. The full results from the fully transformed initial model are included in Appendix D as demonstration that the model provides an appropriate fit. The residual plots from the original model are shown on the left of Figure 14. The model shows an obvious pattern of extreme residual increases and decreases, indicating unequal variance in the model. A logarithmic transformation is applied to the data, resulting in the improved residuals shown in the center plot of Figure 14. This transformation removed the pattern, but two distinct clusters remain with a very large range in the data (Residuals ranging from -0.5 to 0.5). Further data exploration noticed that all of the data points with positive residual values corresponded to design points with the total number of Landing Spots ≤ 4 and the data points with negative residuals corresponded to design points with Landing Spots > 4. Parameter estimates (Appendix D) reaffirmed the suspicion that the Landing Spots variable was dominating the analysis. Accordingly, a third model was developed that set Landing Spots as an indicator variable (corresponding to design points with Landing Spots > 4 and design points with Landing Spots ≤ 4). The residual plots from that analysis are shown on the right of Figure 14. This model exhibits none of the negative characteristics associated with the previous models. The variance appears equal and there are no apparent patterns or clusters. Several extreme design points remain; analysis indicates that those design points are defined by an overreliance on air assets and an underutilization of watercraft assets. The prioritization of significant variables is shown in Appendix D. Appendix D also shows the results of analysis prior to the definition of Landing Spots as an indicator variable.

3. Expanded Analysis

Initial analysis indicates that the simulation results exhibited extreme variation and grouping due to the impact of landing spot availability. Analysis indicated that no other variables have a significant impact when landing spots are unavailable. This indicates that Landing Spots cannot be left as a noise variable. It must be controlled by the mission commander. Effectively, the mission commander must make clearing of landing spots at the objective the primary objective of the initial operation.

In order to provide insight into the research questions, the simulation was redone while holding landing spots constant. This allows for analysis of the impact of variation of physical architectures, provided that sufficient landing spots are available. In order to determine the level at which to hold landing spots constant, the analysis required expansion. While the loss function analysis provided insight into the impact of variations in each of the variables, it penalized design points with extremely low mission completion times, which is not representative of the objective of the MOO.

The desirability profiler in JMP allows for identification of design points that penalize design points with high mission completion times and rewards design points with low mission completion times. Per the JMP User's Guide, "desirability functions are smooth piecewise functions that are crafted to fit the control points. The target function is a piecewise function that is a scale multiple of a normal density on either side of the target (with different curves on each side), which is also piecewise smooth and fit to the control points." Effectively, the use of the JMP desirability function allows for a definition of mission success criteria, as defined by the MOO. Specifically, those design points with mission completion times ≤ 336 hours (14 days) have a maximum desirability value. Design points with mission completion times > 336 hours have correspondingly lower desirability values. Use of this function allows for identification of those design points that result in mission completion times that satisfy the MOO (and are therefore militarily acceptable). It also allows for increased penalization of design points with mission completion times far above the MOO standard.

Using this approach, a desirability function is created to determine which factor level should be used to fix Landing Spots as a constant. Figure 15 clearly shows that variations in the Landing Spots variable have the largest impact on the desirability function. Specifically, the desirability function indicates that Landing Spots must be fixed at or above 5.436 to achieve mission completion times under 336 hours. Given that Landing Spots is a discrete variable, 5.436 is rounded to 6. The simulation is redone with Landing Spots set at 6 to allow for analysis of the impact of alterations in force composition, provided that sufficient landing spots (in this scenario, more than 6 landing spots) are available.

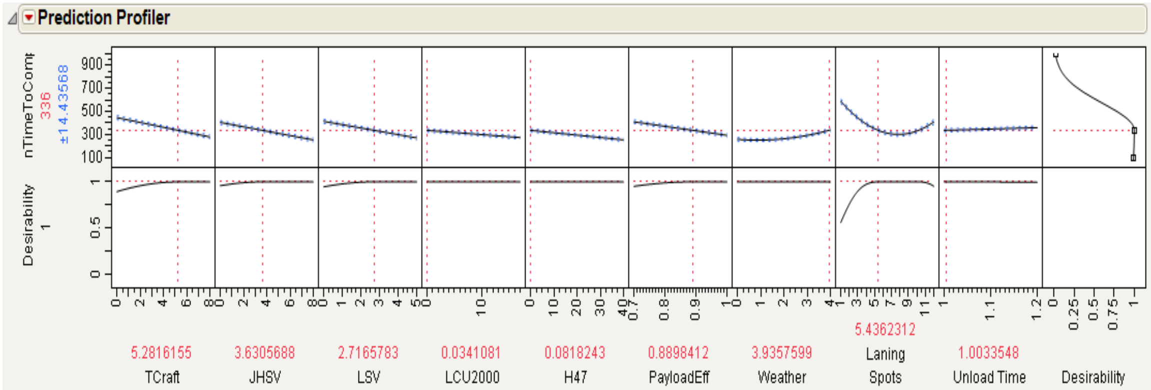


Figure 15. Desirability Profilers with Landing Spots as Noise Variable

Redefinition of Landing Spots as a constant in the simulation requires a revised experimental design. The design for the decision variables remains unchanged. The NOLH portion of the noise variable design changes but remains defined by 33 design points. Given that there are now only five noise variables, a Resolution 5 Fractional Factorial Design is used in place of the previous Resolution 4 design. This assures that all two way interactions can now be estimated. The total number of design points for the noise variables remains 49. As such, the total number of design points, without replication, remains 2,401. A total of 72,030 simulation runs is required for the full 30 replications.

Figure 16 shows a revised desirability profiler with Landing Spots fixed at six. The desirability parameters are changed. The simulation now models a scenario where six landing spots are available from the beginning of the simulation. It is assumed that clearing and preparing these landing spots will take approximately two days. Therefore, the desirability function is altered to represent this reality. All mission completion times ≤ 288 hours (12 days) have maximum desirability, desirability decreases following a normal curve from 288 to the maximum mission time).

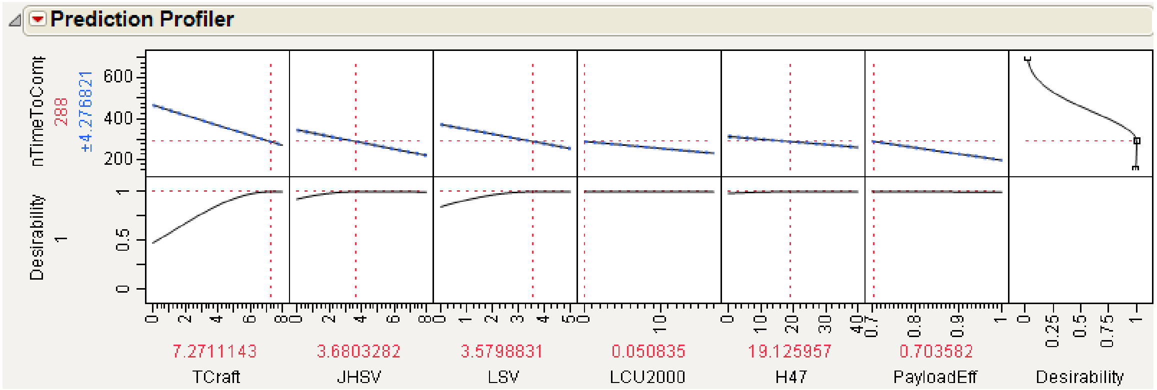
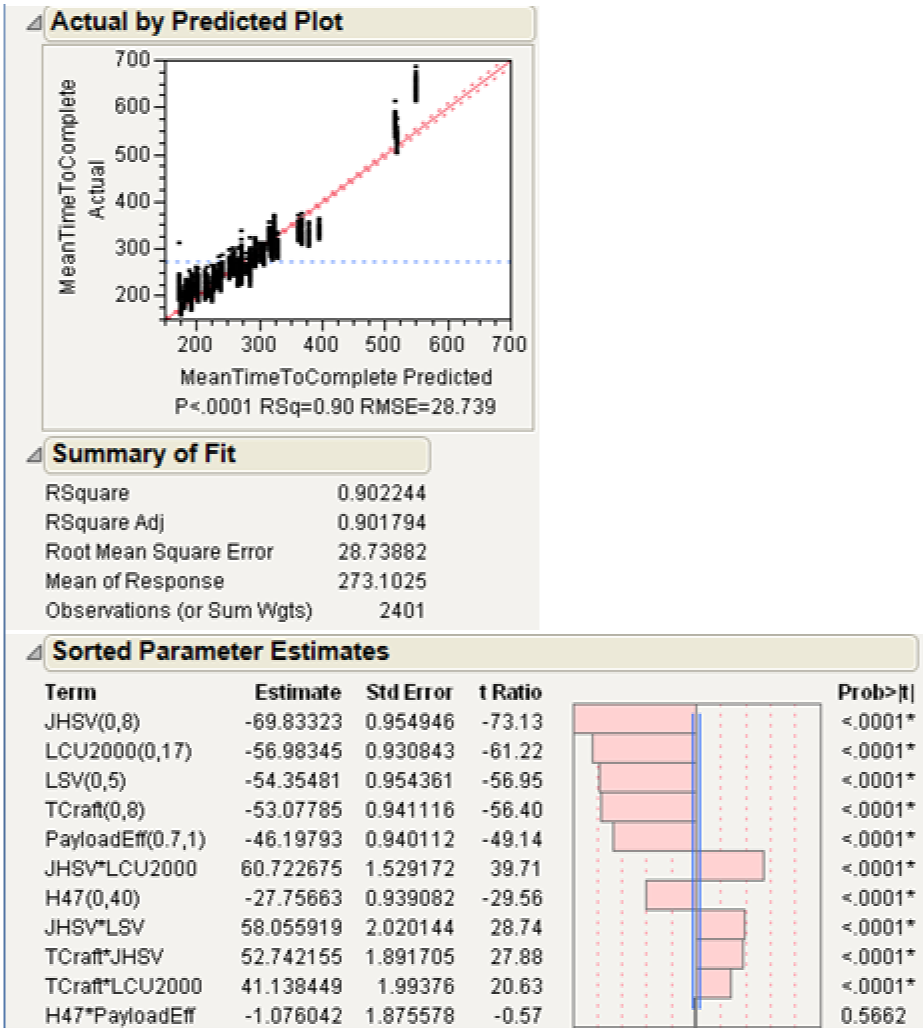


Figure 16. Desirability Profilers with Landing Spots as a Constant

Notice that curvature can now be seen for several of the decision variables (number of T-Craft, number of JHSV, and number of LSV). Figure 17 shows the sorted parameter estimates for the model, as well as the model prediction.



Summary of Fit

RSquare	0.902244
RSquare Adj	0.901794
Root Mean Square Error	28.73882
Mean of Response	273.1025
Observations (or Sum Wgts)	2401

Sorted Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
JHSV(0,8)	-69.83323	0.954946	-73.13	<.0001*
LCU2000(0,17)	-56.98345	0.930843	-61.22	<.0001*
LSV(0,5)	-54.35481	0.954361	-56.95	<.0001*
TCraft(0,8)	-53.07785	0.941116	-56.40	<.0001*
PayloadEff(0.7,1)	-46.19793	0.940112	-49.14	<.0001*
JHSV*LCU2000	60.722675	1.529172	39.71	<.0001*
H47(0,40)	-27.75663	0.939082	-29.56	<.0001*
JHSV*LSV	58.055919	2.020144	28.74	<.0001*
TCraft*JHSV	52.742155	1.891705	27.88	<.0001*
TCraft*LCU2000	41.138449	1.99376	20.63	<.0001*
H47*PayloadEff	-1.076042	1.875578	-0.57	0.5662

Figure 17. Expanded Model Prediction and Parameter Estimates

The model has an R-Square value of 0.90, indicating a high quality fit. The model uses only the main effects and five interaction effects, making it acceptably clear for presentation to a decision maker. Further, none of the noise variables are included in the regression, which indicates that the variables that have the largest impact on mission performance are under the control of the decision maker. The residuals appeared normal, indicating that a linear regression is acceptable.

Based on the model developed, the variables that have the largest impact on force effectiveness are: number of JHSV, number of LCU 2000, number of LSV, number of T-Craft, and Payload Efficiency. Interaction effects and effects from the H-47 are also significant. Notice that the order of the sorted parameter estimates differs from the variables that appear most important in the Desirability Profilers. The Desirability Profilers indicate that a reduction in the number of T-Craft has the largest negative impact on force effectiveness, followed by reductions in JHSV and LSV. This indicates that there are interactions between the variables. This is unsurprising, given that each asset must interact during the unloading portion of the simulation. Alternative Desirability Profilers are included in Appendix D. These profilers examine the impact on force composition when certain high impact assets are unavailable.

Analysis of Figure 16 indicates that the preferred physical architecture is defined by:

1. 8 or more T-Craft
2. 4 or more JHSVs
3. 4 or more LSVs

The other assets do not have a major impact on force effectiveness provided that T-Craft, JHSV, and LSV are available at the levels indicated above. This is the recommended force structure. It must be noted that alternative conclusions can be reached by altering the desirability function or the maximum number of assets available. The recommended force structure presented above is based on analysis of a full spectrum of potential alternatives. Several alternative force structures are defined in Appendix D for scenarios where individual asset availability may be limited.

It is interesting to note that Payload Efficiency is less important than the number of watercraft assets present. Changes in the prediction profiler value for Payload Efficiency do not seem to impact force effectiveness. This indicates that additionally loading delays experienced as a result of attempting to efficiently load cargo may not provide added value with respect to cargo throughput, as long as the cargo efficiency does not fall below 70%. Examination of potential solutions indicates that payload efficiency demonstrates a loose inverse relationship with the total number of assets. That is, if many assets are available, payload efficiency is less important. If few assets are available, payload efficiency becomes quite important.

An examination of scenarios where T-Craft is unavailable is included in Appendix D, however the results are summarized here to address research question 2c.

1. The number of JHSV available dominates the analysis if T-Craft is unavailable. Given that the presence of the two assets together dominates the original analysis, this suggests that development of both assets is reasonable, although development of one asset in sufficiently high quantities provides the same performance, with respect to throughput operations.
2. If T-Craft is unavailable and JHSV is only available in limited quantities, the number of LCU 2000s required to achieve a similar level of performance increases from 0 to 17.
3. If both T-Craft and JHSV are unavailable, both LCU 2000 and LSV must be present at near maximum levels (13 and 5) to achieve a similar level of performance.

VI. CONCLUSIONS

A. KEY POINTS AND RECOMMENDATIONS

This thesis develops a functional and physical architecture for a 2022 United States Army (USA) Watercraft FHA/DR operation, based on the scenario established in the Expeditionary Warrior (EW10) Wargame. These architectures are defined to enable development and analysis of a tactical level discrete event simulation. The simulation examines the scope of tactical level possibilities and is used to inform definition of possible force compositions, to include the implementation of the Transformable Craft.

The functional architecture is based on the high level mission requirements established by EW10. Those mission requirements were: evacuate displaced personnel; provide search and rescue; provide delivery of food, water, medicine, clothes, shelter, and supplies; provide medical and veterinarian services; repair airfields and ports; provide air traffic control support; and provide repair/engineering support. Current military doctrine and guidance from OFDA and USAID scoped the problem to a military FHA/DR transportation throughput problem. In FHA/DR scenarios DoD should expect to provide high speed point-to-point-lift/logistical support, as well as disaster relief. There is necessarily a security component included as well to ensure the safety of DoD assets. Management and distribution of aid, as well as secondary FHA/DR functions, such as SAR, personnel evacuation, and veterinarian services is provided by other agencies.

Given the inability to conduct live testing of a FHA/DR scenario, analysis of such scenarios lend themselves to high speed computer simulations. Recent advances in efficient experimental design, as well as the high speeds of the computer simulations, allow for an expansion of traditional physical architecture development. Rather than define distinct force compositions tasked with completing the tasks outlined in the functional architecture, the full spectrum of potential physical architectures is defined and analyzed through computer simulations. Given the transportation throughput problem defined by the functional architecture, it is determined that the appropriate physical architecture solution space is defined by the U.S. Army Watercraft and Air

Transportation 2022 force structure. This force structure is comprised of: JHSV, LSV, LCU 2000, H-47, and H-60. That force structure is augmented by the Transformable Craft, a current Innovative Naval Prototype which may satisfy many of the major capability gaps outlined by the U.S. Army Watercraft Capabilities Based Assessment and the current U.S. Army Watercraft Master Plan.

Efficient experimental design and high speed computer simulation is used to determine a force structure capable of providing 120,000 tons of FHA/DR supplies to aid distribution centers in a 14 day period. Rather than recommend a single, distinct force composition, the analysis is geared towards developing minimum standards for force structures. Mission success, if measured by the MOO, can be achieved provided that 6 landing spots are available at the objective and the following force structure standards are met (Table 14).

Scenario: T-Craft Available		Scenario: T-Craft Unavailable	
Asset	Required Quantity	Asset	Required Quantity
T-Craft	8	T-Craft	-
JHSV	4	JHSV	7
LSV	4	LSV	0
LCU 2000	0	LCU 2000	13
H-47	0	H-47	0

Table 14. Recommended Force Compositions

B. AREAS TO CONDUCT FUTURE RESEARCH

Because the T-Craft INP is currently in the developmental stage, opportunities exist to examine the desired performance characteristics of the T-Craft within the operational scenario and simulation defined in this thesis. An impact of variations to T-Craft performance characteristics within the operational scenario should be completed. Opportunities exist to examine JHSV using similar methodology.

The impact of air assets in the simulation is minimal. An increase in the number of available air assets may increase their impact in future analysis.

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APPENDIX A. FUNCTIONAL ARCHITECTURE

This Appendix details those functions that were not expanded in Chapter III. Figure 18 shows an expansion of function F.4.2.3 (Secure Supplies in Transit). The expansion is simple and stresses the need for the mission commander to provide protection for the Watercraft and Air Transportation Assets, which may not have organic self-defense capabilities. No operational decision concerning the protection of these assets are made in this thesis, it was assumed that the capabilities offered by the BCT are sufficient to satisfy this function. Any employment of forces to secure transiting supplies must not violate the neutral stance of the United States in FHA/DR operations.

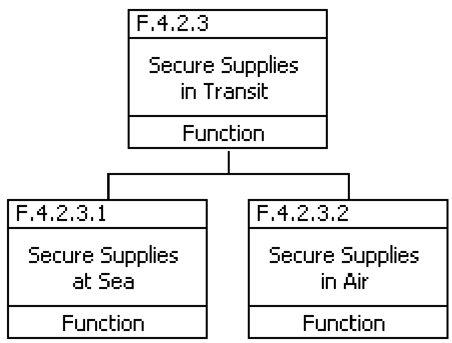

Figure 18. Expansion of: Secure Supplies in Transit

Figure 19 details the lower level FHA/DR transport. The expansion covers all of the details of transport for each of the major areas (Food, Water, Medicine, etc.) not shown in Chapter III. The description of the requirements for Aid Delivery Access are also shown and stress the need to establish loading areas as well as establish a mechanism for transfer of control of the FHA/DR supplies from DoD transport assets.

Table 15 presents a mapping of MOEs/MOPs to system functions.

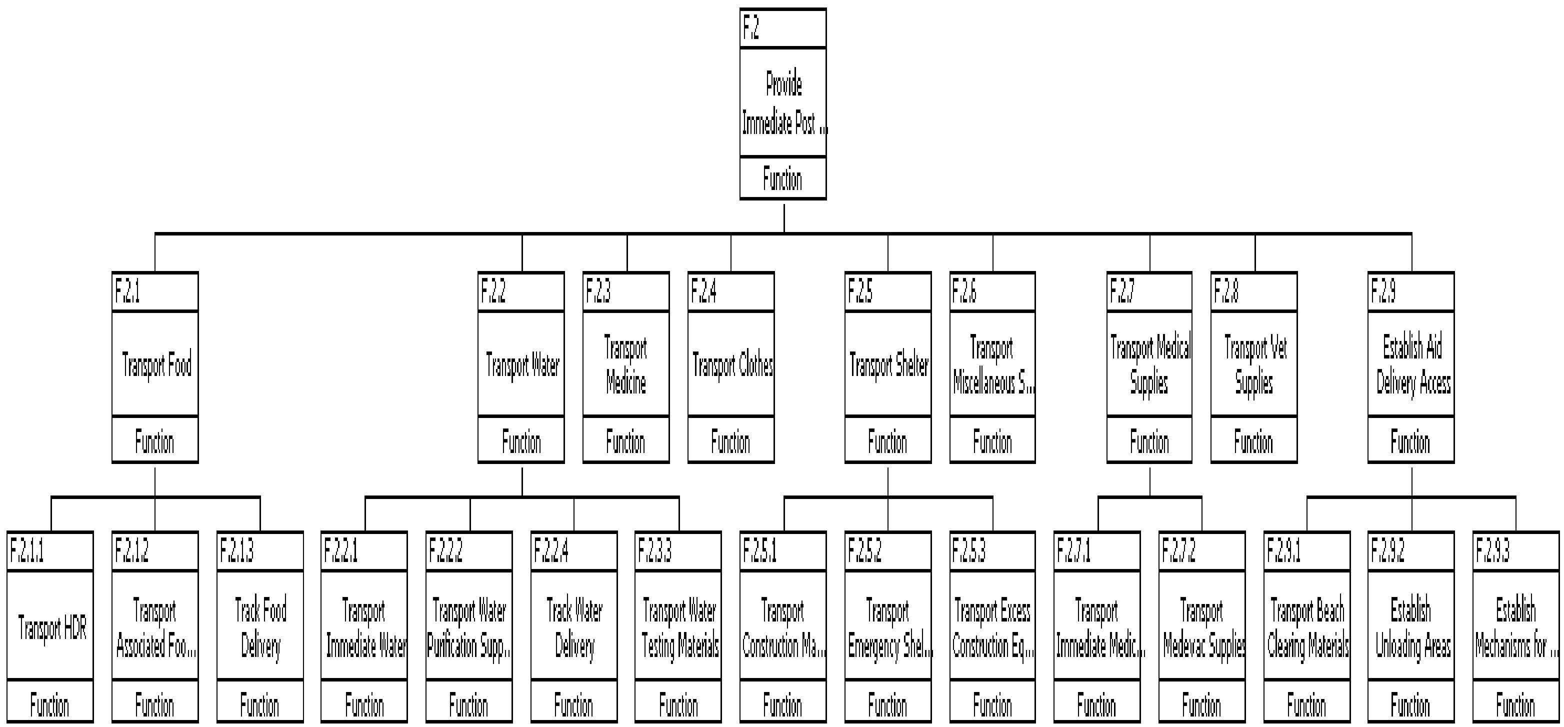

Figure 19. Expansion of: Provide Immediate Post Disaster Relief

	MOE/MOP											
US Army FHA/DR Response Functions	MOE 1: Time to Deliver Aid	MOP 1.1 Time to Transport Food	MOP 1.2 Time to Transport Water	MOP 1.3 Time to Transport Medicine	MOP 1.4 Time to Transport Clothing	MOP 1.5 Time to Transport Shelter	MOP 1.6 Time to Transport Misc Supplies	MOP 1.7 Time to Transport Medical Supplies	MOP 1.8 Time to Transport Vet Supplies	MOP 1.9: Time to Establish Beach Access	MOP 1.10 Time to Deliver Security to Distribution Centers	MOP 1.11 Time to Establish Security Procedures for US Assets
F.0 Provide FHA/DR	X											
F.2 Provide Immediate Post Disaster Relief	X											
F.2.1 Transport Food	X	X										
F.2.2 Transport Water	X		X									
F.2.3 Transport Medicine	X			X								
F.2.4 Transport Clothes	X				X							
F.2.5 Transport Shelter	X					X						
F.2.6 Transport Misc Supplies	X						X					
F.2.7 Transport Medical Supplies	X							X				
F.2.8 Transport Vet Supplies	X								X			
F.2.9 Establish Aid Delivery Access	X									X		
F.4 Provide Security	X										X	X
F.4.1 Provide Security for Personnel	X										X	X
F.4.2 Provide Security for Supplies	X										X	X
F.4.3 Coordinate Security Procedures with CMOC	X										X	X

Table 15. Mapping of MOEs/MOPs to Functions

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APPENDIX B. PHYSICAL ARCHITECTURE SYSTEM DESCRIPTIONS

A. PROJECTED 2022 ARMY WATERCRAFT ASSETS

The following figures are used to develop the baseline 2022 Army Watercraft Force Projection and are taken from the current Army Watercraft Master Plan. Figure 20 shows the overall 2022 Army fleet projection.

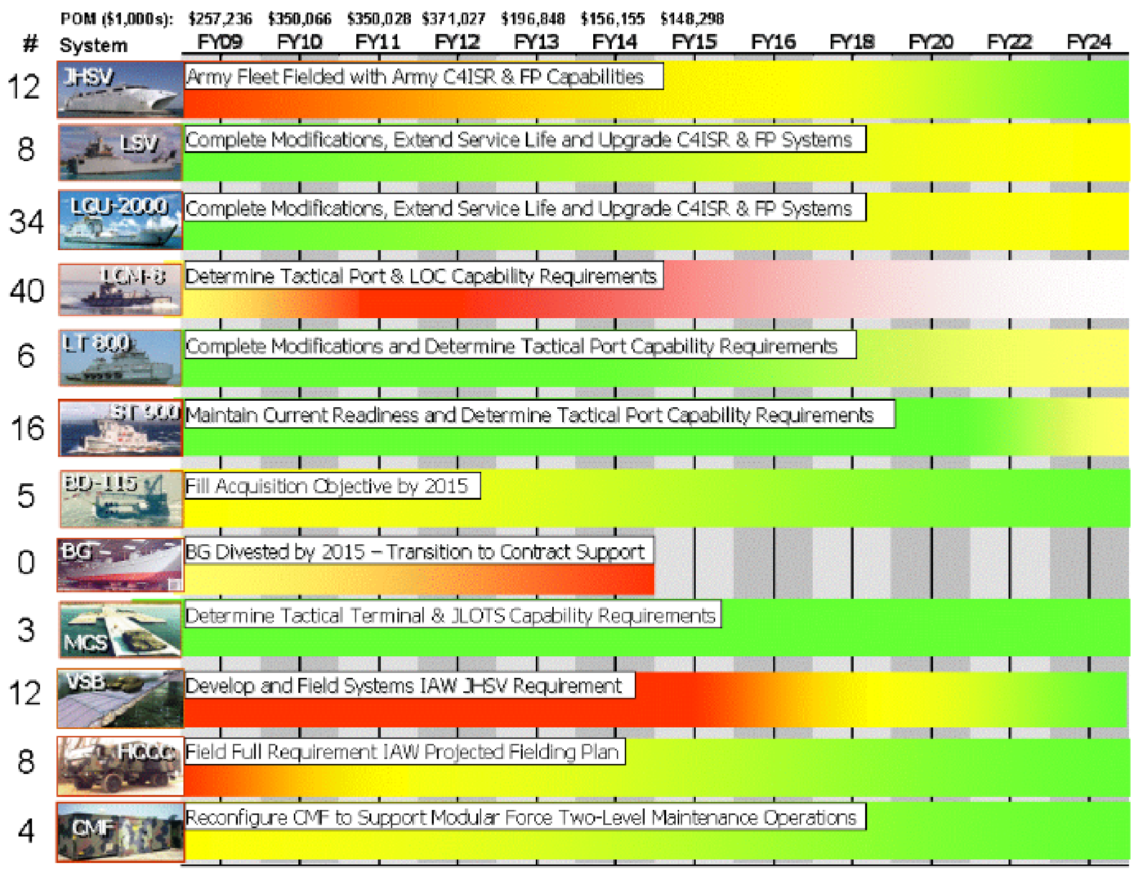


Figure 20. Army Fleet Assessment Projection Post Modernization (From U.S Army Transportation, 2008, p. 9)

Figures 21–23 show the current and modernization assessments for the LSV, LCU 2000, and JHSV system life cycles.

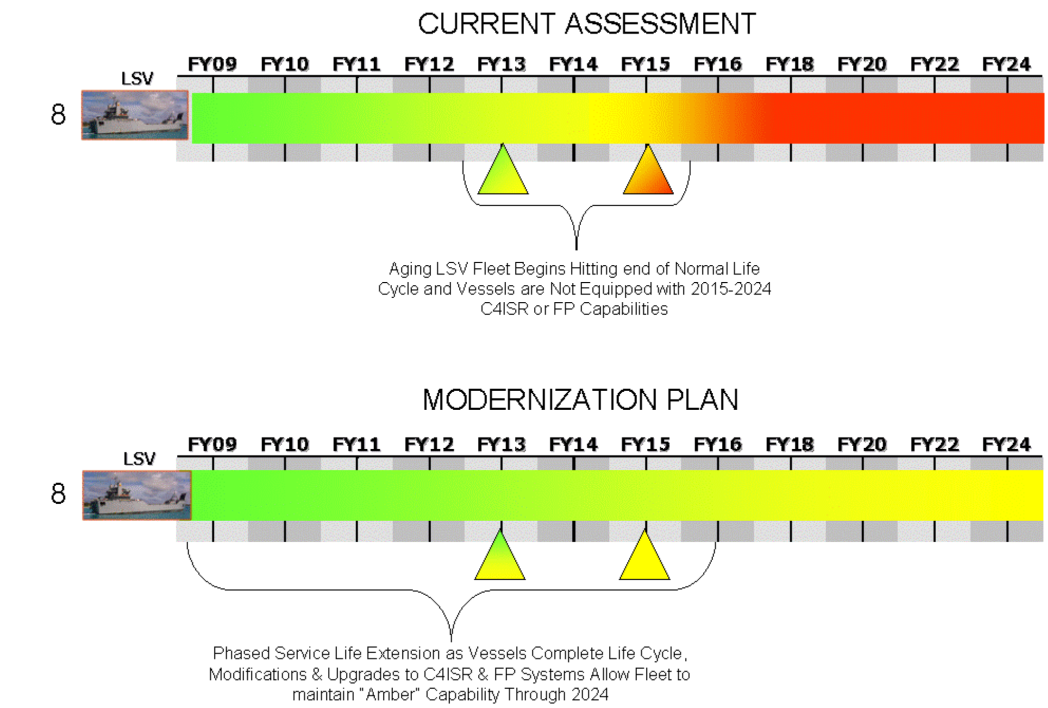


Figure 21. LSV Assessment and Modernization Plan (From U.S Army Transportation, 2008, p. 1–6)

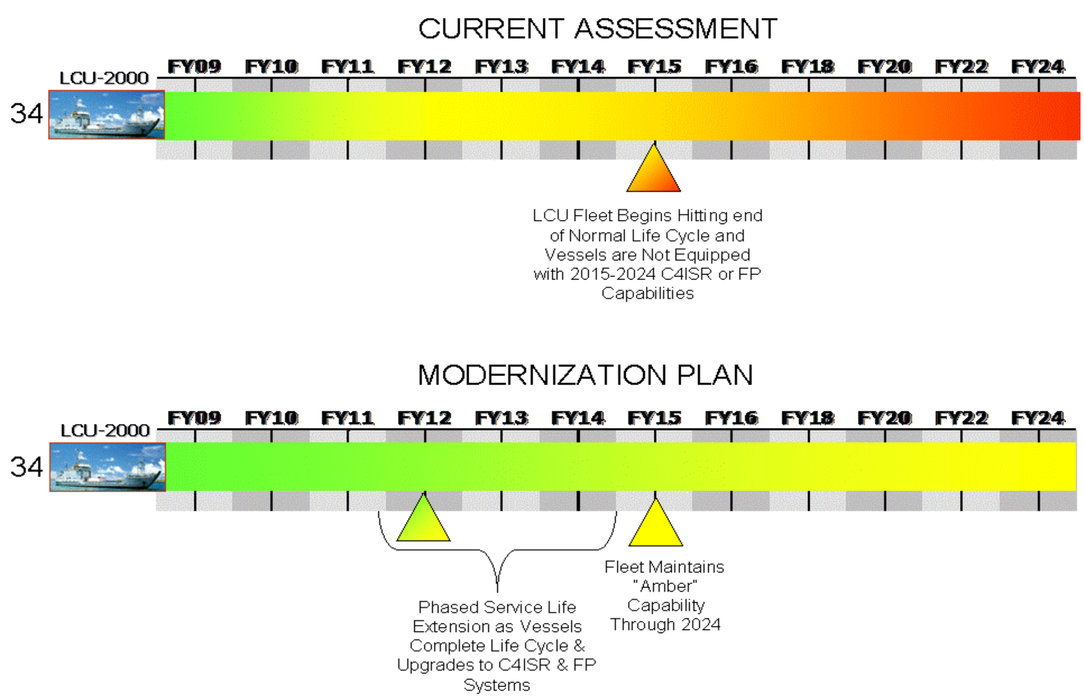


Figure 22. LCU 2000 Assessment and Modernization Plan (From U.S Army Transportation, 2008, p. 1–9)

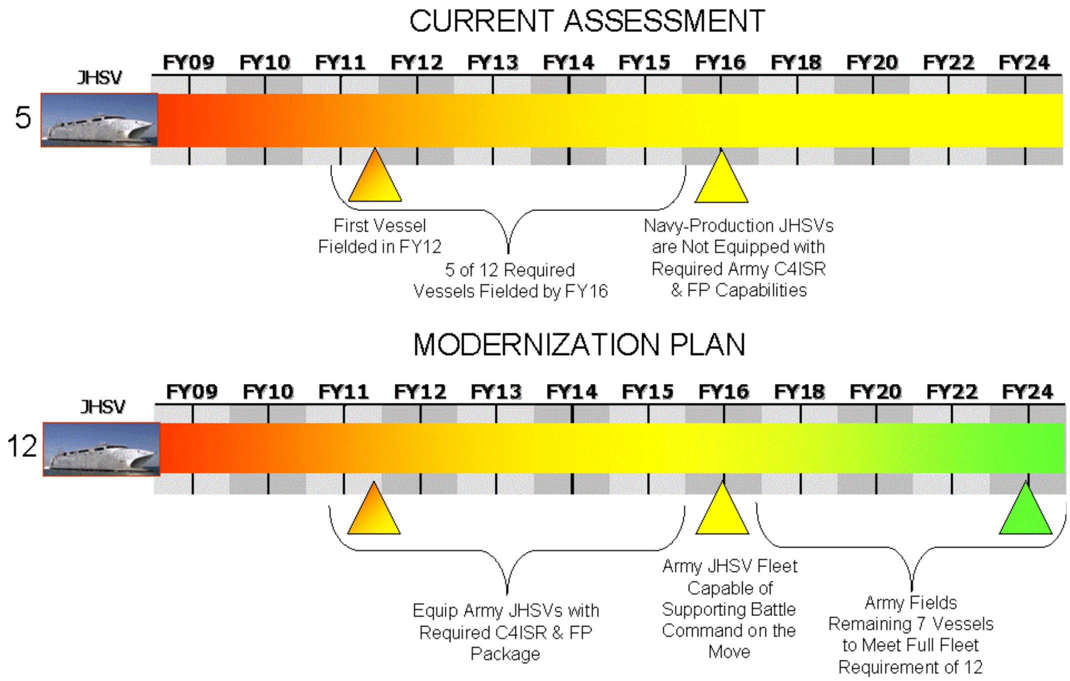


Figure 23. JHSV Assessment and Modernization Plan (From U.S Army Transportation, 2008, p. 2–2)

B. PROJECTED 2022 ARMY AIR TRANSPORTATION ASSETS

Figure 24 is taken from the 2010 Army Modernization Strategy and shows the current portfolio strategy for Army Air Utility, Cargo, and Fixed Wing Assets.

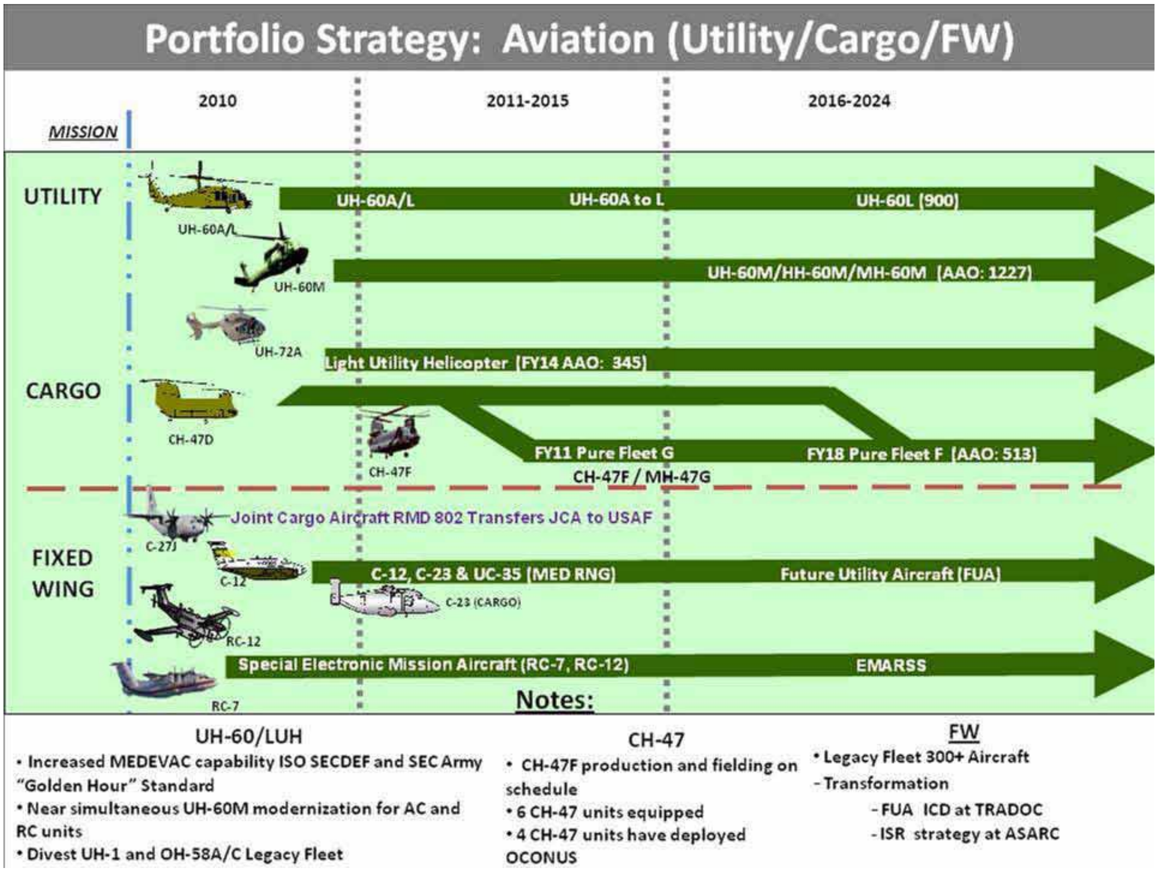


Figure 24. JHSV Assessment and Modernization Plan (From U.S Army Transportation, 2008, p. 2–2)

C. FORCE COMPOSITION PERFORMANCE CHARACTERISTICS

Performance characteristics of existing craft are taken from (Jane's Information Group Limited, 2006 and United States Army Fact, 2011). T-Craft performance characteristics are taken from the T-Craft BAA (Office of Naval Research, 2005).

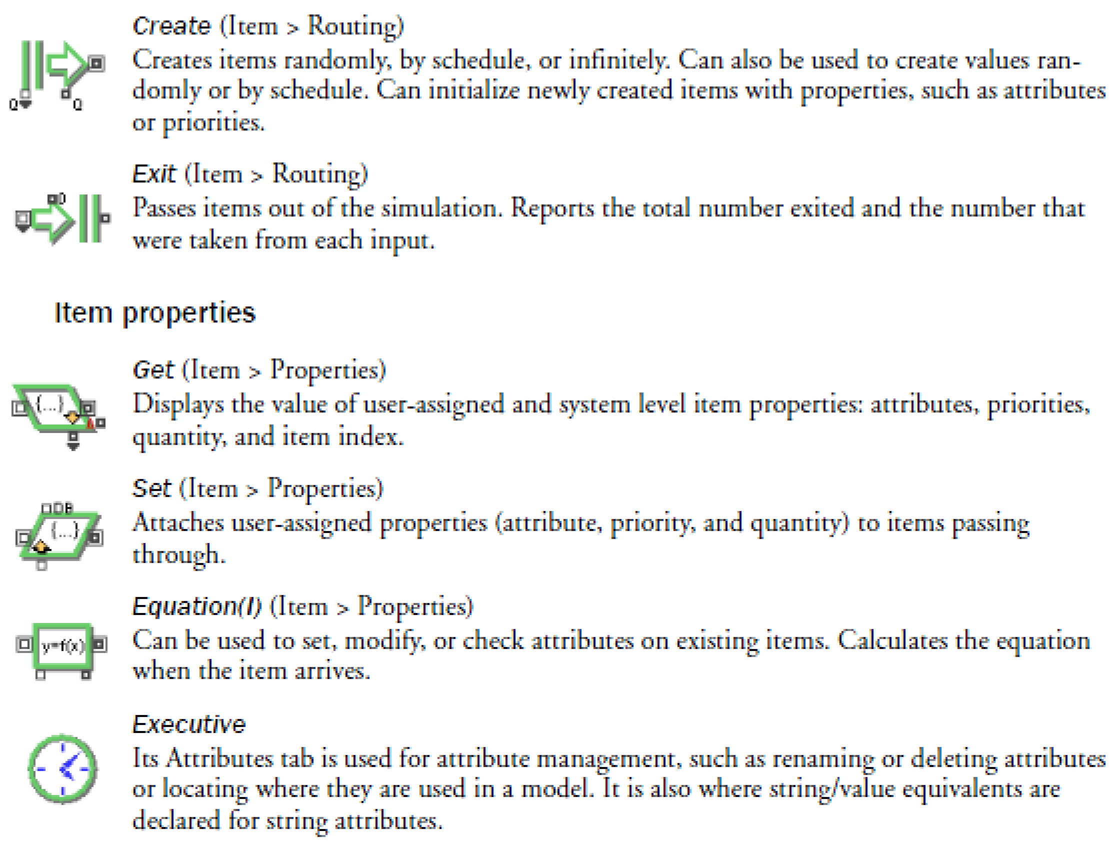
Category	Ship	Payload (tons)	Speed (kts)
High Speed Vessels	JHSV	600	35
	TCraft	450	40
Lighters	LSV	900	12
	LCU 2000	350	10
Air Assets	H-47	14	130
	H-60	5	150

Table 16. Army Transportation Asset Performance Characteristics

APPENDIX C. EXTENDSIM MODEL DESCRIPTION

A. EXTENDSIM COMPONENT OVERVIEW

As discussed in Chapter IV, ExtendSim simulations are useful for developing stochastic discrete event queuing models. This appendix is used to detail the simulation methodology, components, and processes used in the model. As mentioned previously, the assets (watercraft and air) transition through the model, experiencing delays and attribute redefinition based on each event block within the model. In order to explain the exact process each asset experiences throughout the model, it is useful to present the definition of the ExtendSim blocks used in the model. All figures are taken from (Imagine That Inc, 2007).



Create (Item > Routing)
Creates items randomly, by schedule, or infinitely. Can also be used to create values randomly or by schedule. Can initialize newly created items with properties, such as attributes or priorities.

Exit (Item > Routing)
Passes items out of the simulation. Reports the total number exited and the number that were taken from each input.

Item properties

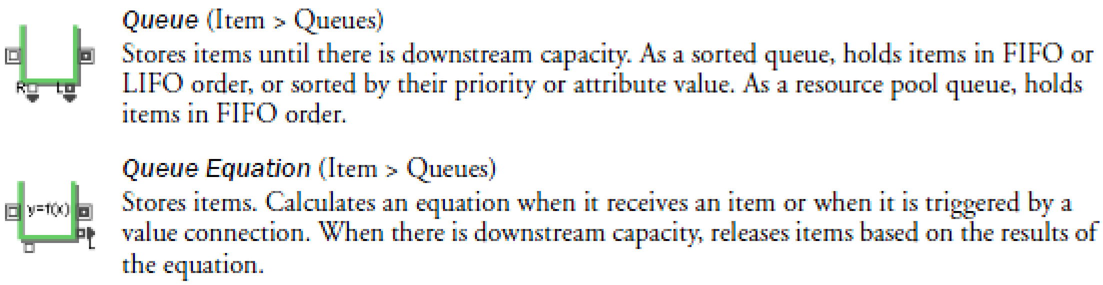
Get (Item > Properties)
Displays the value of user-assigned and system level item properties: attributes, priorities, quantity, and item index.

Set (Item > Properties)
Attaches user-assigned properties (attribute, priority, and quantity) to items passing through.

Equation(I) (Item > Properties)
Can be used to set, modify, or check attributes on existing items. Calculates the equation when the item arrives.

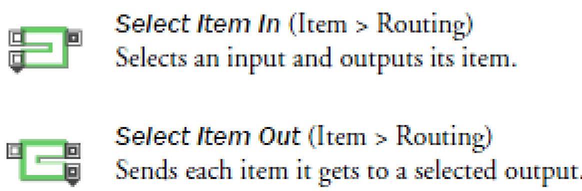
Executive
Its Attributes tab is used for attribute management, such as renaming or deleting attributes or locating where they are used in a model. It is also where string/value equivalents are declared for string attributes.

Figure 25. Entity Definition Blocks of Interest (From Imagine That Inc, 2007, p. 110)


Queue (Item > Queues)
Stores items until there is downstream capacity. As a sorted queue, holds items in FIFO or LIFO order, or sorted by their priority or attribute value. As a resource pool queue, holds items in FIFO order.

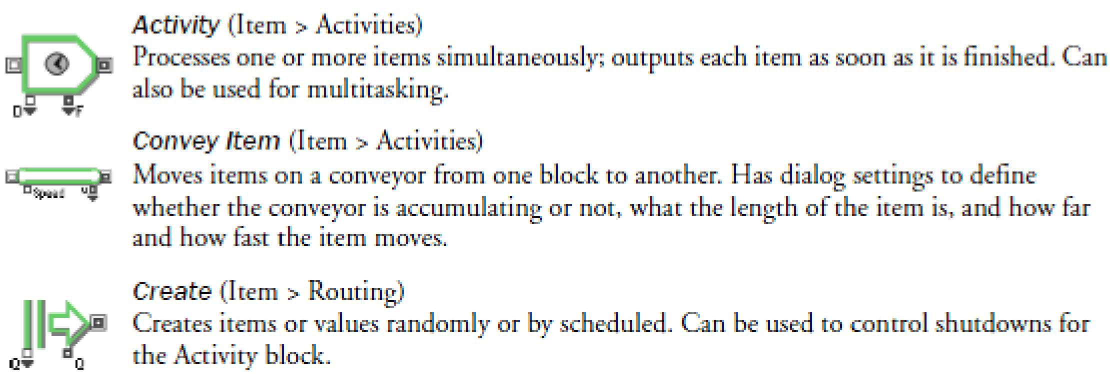
Queue Equation (Item > Queues)
Stores items. Calculates an equation when it receives an item or when it is triggered by a value connection. When there is downstream capacity, releases items based on the results of the equation.

Figure 26. Queuing Blocks of Interest (From Imagine That Inc, 2007, p. 128)


Select Item In (Item > Routing)
Selects an input and outputs its item.

Select Item Out (Item > Routing)
Sends each item it gets to a selected output.

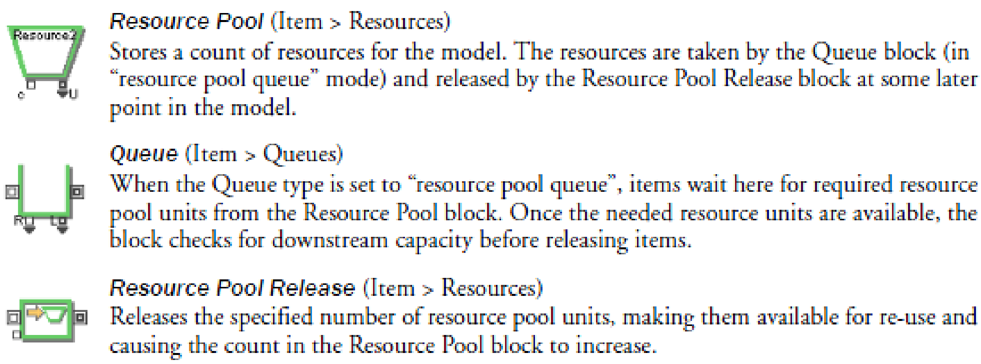
Figure 27. Routing Blocks of Interest (From Imagine That Inc, 2007, p. 144)


Activity (Item > Activities)
Processes one or more items simultaneously; outputs each item as soon as it is finished. Can also be used for multitasking.

Convey Item (Item > Activities)
Moves items on a conveyor from one block to another. Has dialog settings to define whether the conveyor is accumulating or not, what the length of the item is, and how far and how fast the item moves.

Create (Item > Routing)
Creates items or values randomly or by scheduled. Can be used to control shutdowns for the Activity block.

Figure 28. Processing Blocks of Interest (From Imagine That Inc, 2007, p. 164)

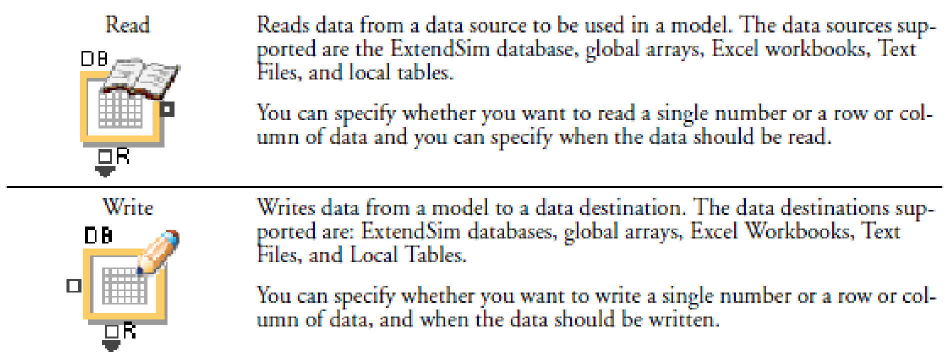


Resource Pool (Item > Resources)
Stores a count of resources for the model. The resources are taken by the Queue block (in "resource pool queue" mode) and released by the Resource Pool Release block at some later point in the model.

Queue (Item > Queues)
When the Queue type is set to "resource pool queue", items wait here for required resource pool units from the Resource Pool block. Once the needed resource units are available, the block checks for downstream capacity before releasing items.

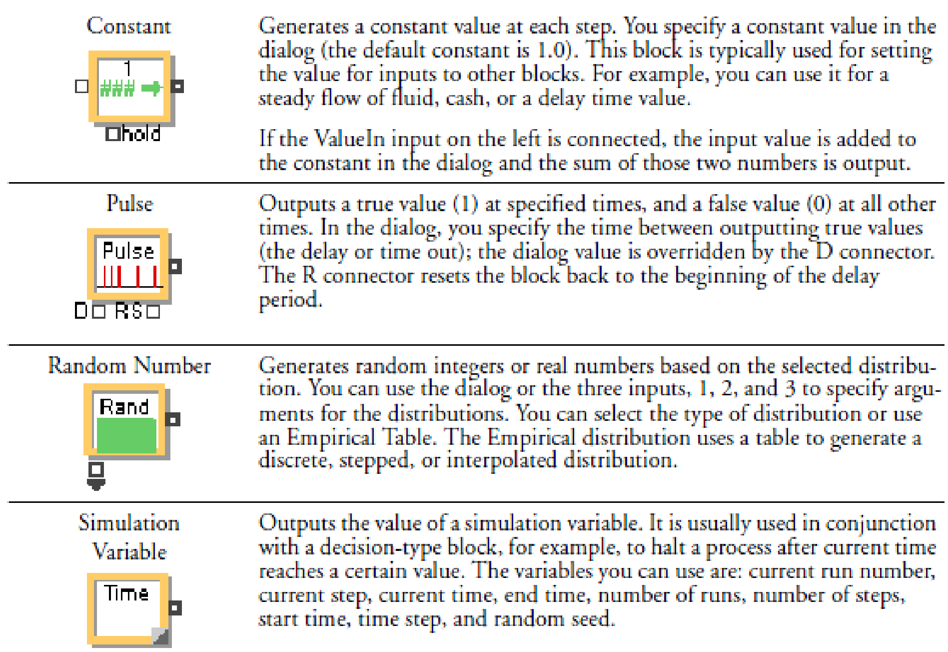
Resource Pool Release (Item > Resources)
Releases the specified number of resource pool units, making them available for re-use and causing the count in the Resource Pool block to increase.

Figure 29. Resourcing Blocks of Interest (From Imagine That Inc, 2007, p. 208)



Read	Reads data from a data source to be used in a model. The data sources supported are the ExtendSim database, global arrays, Excel workbooks, Text Files, and local tables. You can specify whether you want to read a single number or a row or column of data and you can specify when the data should be read.
Write	Writes data from a model to a data destination. The data destinations supported are: ExtendSim databases, global arrays, Excel Workbooks, Text Files, and Local Tables. You can specify whether you want to write a single number or a row or column of data, and when the data should be written.

Figure 30. Data Access Blocks of Interest (From Imagine That Inc, 2007, p. 717)



Constant	Generates a constant value at each step. You specify a constant value in the dialog (the default constant is 1.0). This block is typically used for setting the value for inputs to other blocks. For example, you can use it for a steady flow of fluid, cash, or a delay time value. If the ValueIn input on the left is connected, the input value is added to the constant in the dialog and the sum of those two numbers is output.
Pulse	Outputs a true value (1) at specified times, and a false value (0) at all other times. In the dialog, you specify the time between outputting true values (the delay or time out); the dialog value is overridden by the D connector. The R connector resets the block back to the beginning of the delay period.
Random Number	Generates random integers or real numbers based on the selected distribution. You can use the dialog or the three inputs, 1, 2, and 3 to specify arguments for the distributions. You can select the type of distribution or use an Empirical Table. The Empirical distribution uses a table to generate a discrete, stepped, or interpolated distribution.
Simulation Variable	Outputs the value of a simulation variable. It is usually used in conjunction with a decision-type block, for example, to halt a process after current time reaches a certain value. The variables you can use are: current run number, current step, current time, end time, number of runs, number of steps, start time, time step, and random seed.

Figure 31. Data Input Blocks of Interest (From Imagine That Inc, 2007, p. 718)

B. EXTENDSIM FHA/DR SIMULATION DESCRIPTION

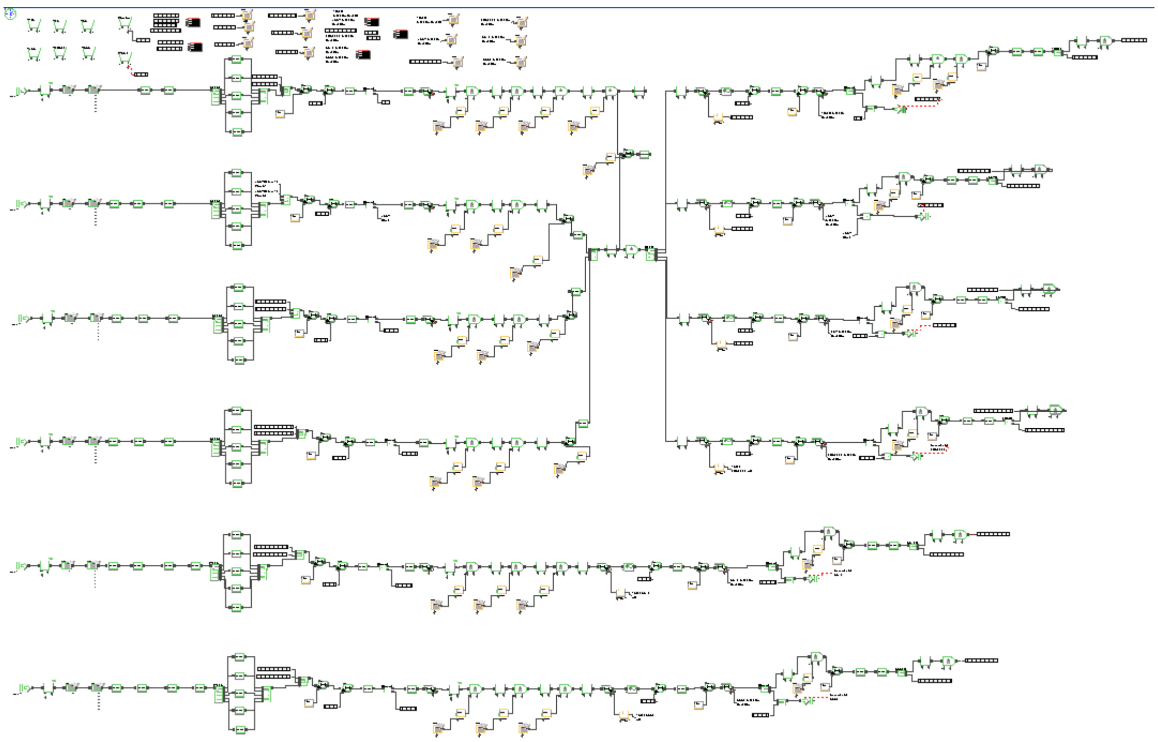


Figure 32. Logic Progression for All Entities in Model

Figure 32 presents a high level capture of the logic progression for all of the entities in the model. While not descriptive or helpful, it does illustrate several major modeling assumptions. Note that each asset is operating independently along an individual logic chain. There is only one point of interaction, which occurs between four of the chains. This is the unloading of cargo queue for the watercraft assets. Notice that the bottom two chains, which represent the H-47 and H-60, do not interface with the other chains at any point. Also notice that the top chain, which represents T-Craft, is composed of several more process blocks than any other chain. These process blocks represent the conversion from SES to ACV and from ACV to SES.

Figures 33–36 provide a detailed description of the logic progression for a T-Craft within the model. This progression is similar to that of all other assets. Figure 33 focuses on the assignment of attributes to each entity. Figure 34 focuses on the delays associated with loading, transit, conversion, and unloading. Figure 35 focuses on the calculation of aid provided, the check for mission completion, as well as delays for conversion and transit if the mission is not complete. Figure 36 focuses on the calculation of required operator rest times as well as the return to the staging area (referred to as Pomo within the model).

Note that each Activity block (seen most clearly in Figure 34) is connected to both a Read block and a Random Number block. Each Activity represents a delay (loading, transit, unloading, etc.). The value of that delay is inputted to the block through the Read block. The Random Number block redefines that value based on an exponential distribution, with the read in value set as the mean of the distribution. This is recalculated each time an entity enters the Activity block. This assures that the simulation is stochastic and provides different outputs for each simulation run, even if the input variables remain constant.

Note that the T-Craft is prompted to return to the staging area (Return to Pomo1 and Return to Pomo2, which are based on whether or not the T-Craft operators were forced to delay at the objective) at the end of the simulation. The prompts Return to Pomo1 and Return to Pomo2 are visible on the right hand side of Figure 33. After the delivery of aid, the asset returns to the beginning of the simulation, but does not have attributes reassigned. This assures that the each asset retains the same performance characteristics throughout each simulation run.

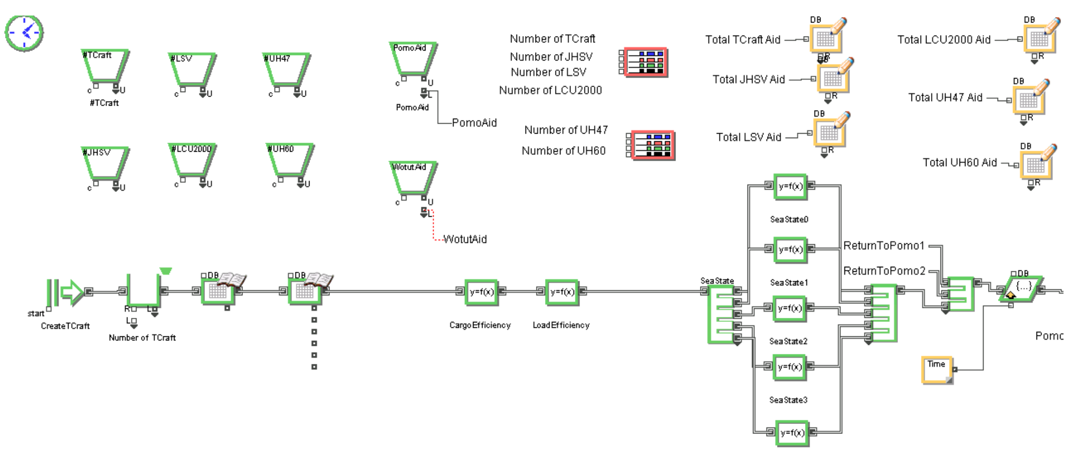


Figure 33. Attribute Assignment (T-Craft)

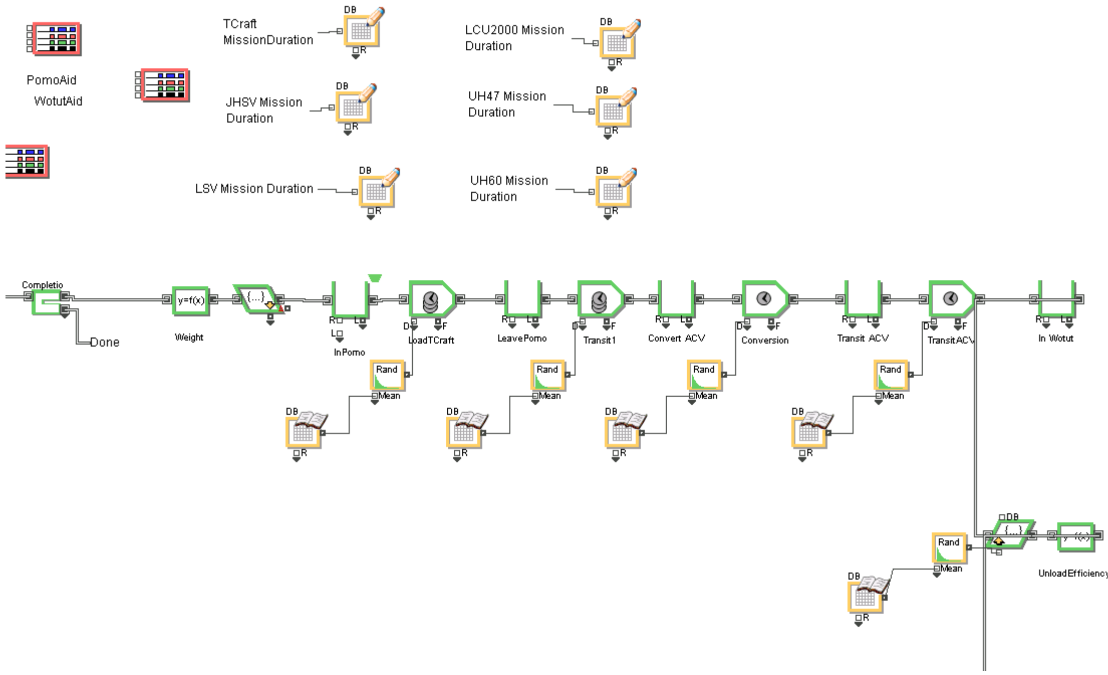


Figure 34. Load/Transit/Conversion/Unload Delays (T-Craft)

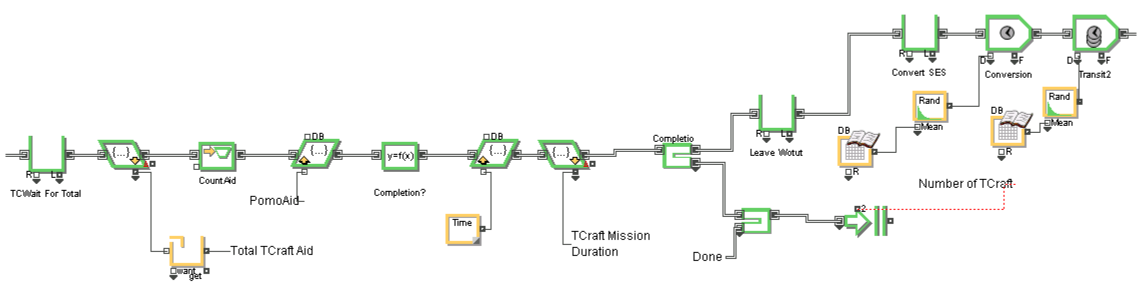


Figure 35. Aid Delivery Calculation/Mission Completion Calculation (T-Craft)

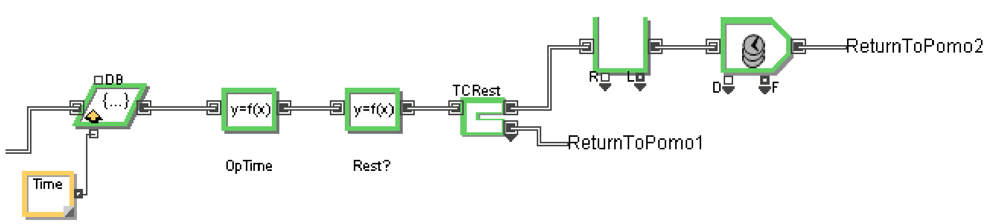


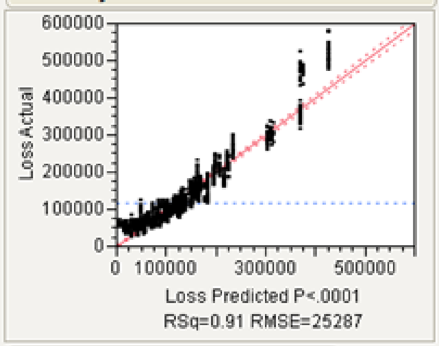
Figure 36. Asset/Operator Downtime/Return to Staging Area Prompt (T-Craft)

APPENDIX D. JMP ANALYSIS FILES

A. INITIAL ANALYSIS

Figures 37 and 38 present the results of the initial analysis. Figure 38 shows the sorted parameter estimates for the model after the redefinition of Landing Spots as an Indicator Variable. Figure 37 shows the sorted parameter estimates prior to the redefinition. Note that Landing Spots is the dominant variable in both cases. Also note that the impact of Landing Spots, when left as a noise variable, appears to be quadratic.

Actual by Predicted Plot



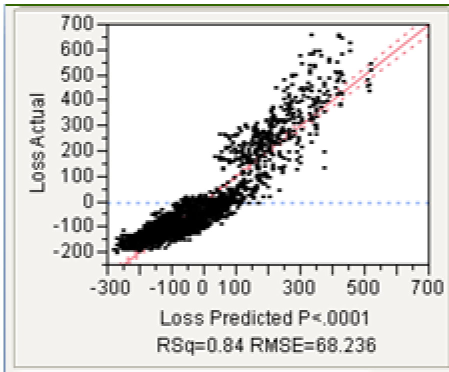
Summary of Fit

RSquare	0.909445
RSquare Adj	0.908722
Root Mean Square Error	25286.72
Mean of Response	117896.9
Observations (or Sum Wgts)	2401

Sorted Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
LandingSpotsIndicator[0]	0.2393847	0.008904	26.89	<.0001*
PayloadEfficiency	-2.353818	0.095369	-24.68	<.0001*
#TCraft	-0.08373	0.003578	-23.40	<.0001*
#JHSV	-0.076092	0.003583	-21.23	<.0001*
#LSV	-0.123505	0.005876	-21.02	<.0001*
#LCU2000	-0.034293	0.001646	-20.83	<.0001*
#H47	-0.011216	0.001154	-9.72	<.0001*
(#TCraft-4.2449)*(#TCraft-4.2449)	0.0205386	0.002653	7.74	<.0001*
(#LCU2000-8.5102)*(#LCU2000-8.5102)	0.0042119	0.000548	7.68	<.0001*
(#JHSV-4.2449)*(#LSV-2.5102)	0.0173098	0.003187	5.43	<.0001*
(#TCraft-4.2449)*(#LSV-2.5102)	0.0101148	0.00273	3.71	0.0004*
(#LCU2000-8.5102)*(#H60-12.5102)	0.0012003	0.000342	3.51	0.0008*
#H60	-0.003942	0.001159	-3.40	0.0011*
(#TCraft-4.2449)*(#JHSV-4.2449)	0.0058141	0.001865	3.12	0.0025*
(#JHSV-4.2449)*(#JHSV-4.2449)	0.009532	0.003111	3.06	0.0030*
(#LSV-2.5102)*(#LSV-2.5102)	0.0183303	0.007037	2.60	0.0110*
(#JHSV-4.2449)*(#H60-12.5102)	0.0011787	0.000486	2.42	0.0176*
(#H47-12.5102)*(PayloadEfficiency-0.85)	0.056824	0.024443	2.32	0.0227*

Figure 37. Initial Analysis Parameter Estimates (Landing Spots as Indicator)



Summary of Fit

RSquare	0.841207
RSquare Adj	0.839529
Root Mean Square Error	68.23569
Mean of Response	-5.14368

Sorted Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Laning Spots(1,12)	-129.8817	2.335971	-55.60	<.0001*
Laning Spots*Laning Spots	188.22628	4.606729	40.86	<.0001*
PayloadEff(0.7,1)	-56.76627	2.458396	-23.09	<.0001*
LCU2000(0,17)	-52.37096	2.405285	-21.77	<.0001*
JHSV(0,8)	-49.79086	2.429576	-20.49	<.0001*
H47(0,40)	-42.63299	2.438079	-17.49	<.0001*
TCraft(0,8)	-37.79317	2.426579	-15.57	<.0001*
Unload Time(1,1.2)	29.922857	2.142448	13.97	<.0001*
Laning Spots*Unload Time	-43.86863	3.181266	-13.79	<.0001*
Weather*Unload Time	-35.97992	2.679824	-13.43	<.0001*
LSV(0,5)	-30.58542	2.434037	-12.57	<.0001*
TCraft*LCU2000	46.603884	4.326167	10.77	<.0001*
H47*Laning Spots	36.281799	3.407387	10.65	<.0001*
JHSV*LCU2000	38.719722	3.805587	10.17	<.0001*
JHSV*Laning Spots	-33.18668	3.390721	-9.79	<.0001*
LCU2000*Laning Spots	-30.60256	3.324036	-9.21	<.0001*
LSV*LCU2000	41.81979	4.899492	8.54	<.0001*
Weather*Weather	36.14719	4.342288	8.32	<.0001*
JHSV*PayloadEff	21.716238	4.647811	4.67	<.0001*
Weather(0,4)	5.9920177	2.329927	2.57	0.0102*
H47*Unload Time	-8.388499	3.425039	-2.45	0.0144*

Figure 38. Initial Analysis Parameter Estimates (Landing Spots as Noise Variable)

B. DESIRABILITY PROFILERS FOR ALTERNATIVE FORCE COMPOSITIONS

The following profilers detail the force compositions recommended when certain high impact assets are unavailable. Specifically, they attempt to provide force recommendations for scenarios where: the T-Craft is unavailable, the JHSV has limited availability, and when both the T-Craft and JHSV are unavailable. They are achieved by fixing the values of the T-Craft and JHSV and examining the impact on the other variables.

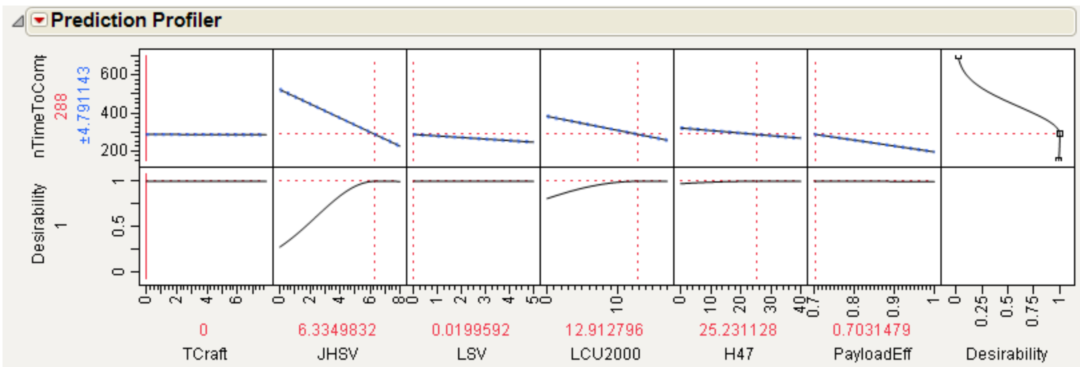


Figure 39. Desirability Profiler – T-Craft Unavailable

Figure 39 indicates that, if the T-Craft is unavailable, the JHSV becomes the most significant asset. The negative consequences associated with JHSV values below seven are indicated by the steep slope of the desirability profile. Note that the impact of the LCU 2000 becomes more pronounced when T-Craft is unavailable.

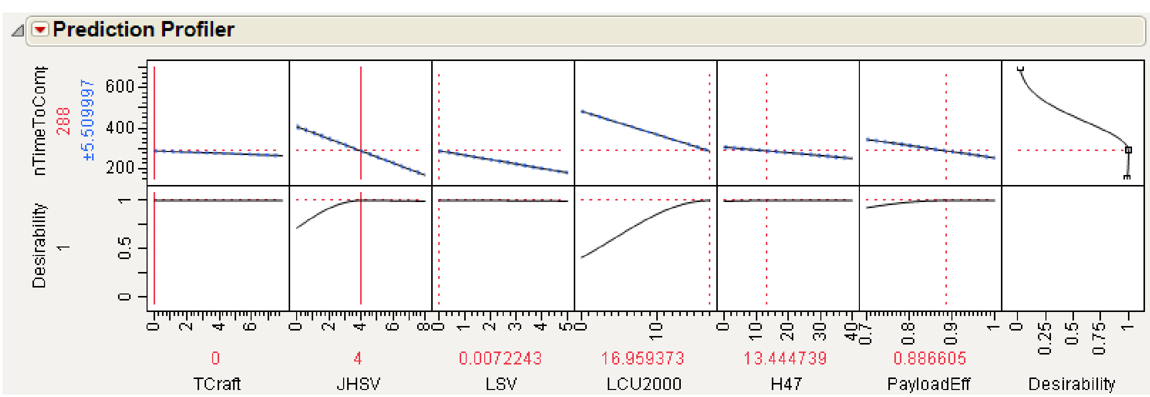


Figure 40. Desirability Profiler – T-Craft Unavailable/JHSV Limited Availability

Figure 40 indicates that, if the T-Craft is unavailable and the JHSV is only available in limited quantities, the LCU 2000 becomes the most significant asset. The negative consequences associated with LCU 2000 values below 17 are indicated by the steep slope of the desirability profile. This suggests that, if the T-Craft is unavailable and only 4 JHSVs are available, the maximum number of LCU 2000s must be present to achieve mission success.

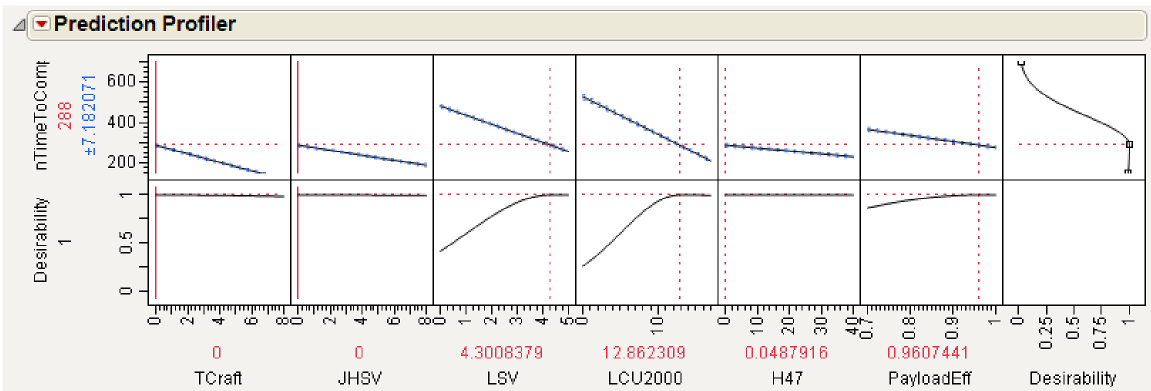


Figure 41. Desirability Profiler – T-Craft and JHSV Unavailable

Figure 41 indicates that, if the T-Craft is unavailable and the JHSV is unavailable, the LCU 2000 and the LSV become the most significant assets. The negative consequences associated with LCU 2000 values below 13 and LSV values below 5 are indicated by the steep slope of the desirability profiles. This suggests that, if the T-Craft and JHSV are unavailable, almost the maximum number of LCU 2000s and LSVs must be present to achieve mission success. Note that Payload Efficiency becomes more important as the number of assets present decreases. This reinforces that the importance of Payload Efficiency increases as the total number of assets available decreases. Note that the H-47 remains significant in the overall regression but does not show a major impact on force effectiveness with respect to the prediction profilers.

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