NAVAL POSTGRADUATE SCHOOL

MONTEREY, CALIFORNIA

THESIS

ANALYSIS OF THE REQUIREMENTS GENERATION PROCESS FOR THE LOGISTICS ANALYSIS AND WARGAME SUPPORT TOOL

by

Jonathan M. Swan

June 2017

Thesis Advisor:	Alejandro S. Hernandez
Co-Advisor:	Steven B. Hall
Second Reader:	Gary W. Parker

Approved for public release. Distribution is unlimited.

THIS PAGE INTENTIONALLY LEFT BLANK

REPORT DOCUMENTATION PAGE	*Form Approved OMB No. 0704-0188*

1. AGENCY USE ONLY ***(Leave blank)***	**2. REPORT DATE** June 2017	**3. REPORT TYPE AND DATES COVERED** Master's thesis

4. TITLE AND SUBTITLE ANALYSIS OF THE REQUIREMENTS GENERATION PROCESS FOR THE LOGISTICS ANALYSIS AND WARGAME SUPPORT TOOL	**5. FUNDING NUMBERS**
6. AUTHOR(S) Jonathan M. Swan	
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 number 2017.0013-DD-N.

12a. DISTRIBUTION / AVAILABILITY STATEMENT Approved for public release. Distribution is unlimited.	**12b. DISTRIBUTION CODE**

13. ABSTRACT (maximum 200 words)

This thesis conducts an analysis of the system requirements for the Logistics Analysis and Wargame Support Tool (LAWST). It studies the process used to develop those requirements and potential requirements if a systems engineering (SE) approach had been used. The original requirements for LAWST are found in documentation provided by the Marine Corps Expeditionary Energy Office (E2O) along with information indicating the sources of those requirements. As it is designed, LAWST may only be useful for a narrow scope, such as supporting seminar-type wargames where time is not a driving factor, while E2O is looking for a tool that is useful at the tactical edge to support wargaming as part of a high-paced planning process. A method based on the SE process is used to determine what the requirements for LAWST would be using this approach. When a system is developed using a set of requirements developed through an SE approach, it can address customer needs more completely and be produced at greater long-term cost savings than a system that has an incomplete set of requirements necessitating additional development. We recommend that E2O adopt a method for generating requirements based on the SE process for any future development.

14. SUBJECT TERMS systems engineering process, requirements generation, LAWST, wargaming, planning	**15. NUMBER OF PAGES** 101
	16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	**18. SECURITY CLASSIFICATION OF THIS PAGE**	**19. SECURITY CLASSIFICATION OF ABSTRACT**	**20. LIMITATION OF ABSTRACT**
Unclassified	Unclassified	Unclassified	UU

NSN 7540-01-280-5500 Standard Form 298 (Rev. 2-89) Prescribed by ANSI Std. 239-18

THIS PAGE INTENTIONALLY LEFT BLANK

ANALYSIS OF THE REQUIREMENTS GENERATION PROCESS FOR THE LOGISTICS ANALYSIS AND WARGAME SUPPORT TOOL

Jonathan M. Swan
Major, United States Army
B.S., Virginia Polytechnic Institute and State University, 2002

Submitted in partial fulfillment of the
requirements for the degree of

MASTER OF SCIENCE IN SYSTEMS ENGINEERING

from the

NAVAL POSTGRADUATE SCHOOL
June 2017

Approved by: Alejandro S. Hernandez
Thesis Advisor

Steven B. Hall
Co-Advisor

Gary W. Parker
Second Reader

Ronald E. Giachetti
Chair, Department of Systems Engineering

THIS PAGE INTENTIONALLY LEFT BLANK

ABSTRACT

This thesis conducts an analysis of the system requirements for the Logistics Analysis and Wargame Support Tool (LAWST). It studies the process used to develop those requirements and potential requirements if a systems engineering (SE) approach had been used. The original requirements for LAWST are found in documentation provided by the Marine Corps Expeditionary Energy Office (E2O) along with information indicating the sources of those requirements. As it is designed, LAWST may only be useful for a narrow scope, such as supporting seminar-type wargames where time is not a driving factor, while E2O is looking for a tool that is useful at the tactical edge to support wargaming as part of a high-paced planning process. A method based on the SE process is used to determine what the requirements for LAWST would be using this approach. When a system is developed using a set of requirements developed through an SE approach, it can address customer needs more completely and be produced at greater long-term cost savings than a system that has an incomplete set of requirements necessitating additional development. We recommend that E2O adopt a method for generating requirements based on the SE process for any future development.

THIS PAGE INTENTIONALLY LEFT BLANK

TABLE OF CONTENTS

LIST OF FIGURES

THIS PAGE INTENTIONALLY LEFT BLANK

LIST OF TABLES

THIS PAGE INTENTIONALLY LEFT BLANK

LIST OF ACRONYMS AND ABBREVIATIONS

CADRG	Compressed Arc Digitized Raster Graphics
CIB	Controlled Image Base
COA	course of action
CONOP	concept of operations
DASM	Deputy for Acquisition and Systems Management
DOD	Department of Defense
DODI	Department of Defense Instruction
DON	Department of the Navy
DOTMLPF	Doctrine, Organization, Training, Materiel, Leadership and Education, Personnel, and Facilities
E2O	Expeditionary Energy Office
EF-21	Expeditionary Force 21
FFBD	functional flow block diagram
GAO	Government Accountability Office
JOA	joint operating area
LAWST	Logistics Analysis and Wargame Support Tool
M&S	Modeling and Simulation
MOE	measures of effectiveness
MGRS	military grid reference system
MOP	measures of performance
NPS	Naval Postgraduate School
SA	systems analysis
SE	systems engineering
SECNAV	Secretary of the Navy
SMC	Space & Missile Systems Center
V&V	verification and validation
VV&A	verification validation and accreditation

THIS PAGE INTENTIONALLY LEFT BLANK

EXECUTIVE SUMMARY

The Logistics Analysis and Wargame Support Tool (LAWST) was developed for the Marine Corps Expeditionary Energy Office (E2O) to use during the Expeditionary Force (EF)-21 Energy Study Operational Reach Wargame in 2015. The primary focus of the LAWST is to examine the fuel consumption of the logistics network to better understand the total energy demand of all forces operating in some area of operations. The Logistics Analysis and Wargame Support Tool is designed to complement the Marine Air-Ground Task Force (MAGTF) Power and Energy Model (MPEM), which models the energy consumption of various Marine Corps formations while deployed, whereas LAWST specifically examines the logistics network that supports those formations. However, a previous study reveals that LAWST does not satisfy stakeholder objectives and is in poor position to pass verification and validation needs. Findings from this past study stem from the vague definition of the system requirements.

Our research focuses on the system requirements for LAWST. The three primary objectives of the research are: to determine how the system requirements for LAWST were established, to determine what the requirements for LAWST would be had a systems engineering approach been used, and to determine the extent to which LAWST would meet requirements developed using a systems engineering approach. Additionally, the research compares the original requirements to a set of requirements developed using a systems engineering approach. It quantifies the difference in the two requirements sets. These requirements are the key link in the validity of the current system in meeting its original purpose.

The original purpose for LAWST is not explicitly articulated. However, there are eight *presumed* requirements that could be found in informal documents provided by E2O and the primary contractor for the system. The process used to develop those requirements is unclear, but the most direct linkages are to the questions posed in the EF-21 Energy Study and Operational Reach Wargame. LAWST meets four of the eight requirements and partially meets three others. There is little evidence that these presumed requirements are for the current version of LAWST and no trade-off analysis for any of these requirements.

There is no documented proof that LAWST meets its original purpose. These findings are consistent with an internal report that the Naval Postgraduate School provided to E2O. The report focused on the readiness of LAWST to undergo a verification and validation process.

A set of requirements was developed using a systems engineering approach. That approach consisted of defining the problem, analyzing the system's mission, determining the functions that the system needs to perform while conducting the mission, and developing requirements based on the mission and functional analysis. The process led to a set of 45 unique and traceable requirements that mapped back to the problem statement derived from needs and desires of the E2O.

The requirements developed using a systems engineering approach differ significantly from the original requirements for LAWST in both quantity and type. Most notably, the requirements developed using a systems engineering approach include nonfunctional requirements such as usability and interoperability as well as other functional requirement types, such as optimization. LAWST could meet 24 of those 45 requirements, but only partially meet the usability, interoperability, and optimization requirements. Additionally, as demonstrated using LAWST as an example in this research, the increased cost of developing a system with incomplete requirements and later changing those requirements is generally more expensive than developing a system using a more complete set of requirements in the beginning.

The primary recommendation from this research is that E2O adopt a more robust process for developing system requirements prior to committing additional resources to those future developments. A recommended framework for developing those requirements is based on the systems engineering process, which is also recommended by the Government Accountability Office (GAO) to reduce system costs due to unidentified requirements being identified after a system begins development (Government Accountability Office 2015).

The methodology of this research is founded on the systems engineering process, specifically the methods for requirements generation. The steps for that method as used in this thesis are problem definition, mission analysis, functional analysis and developing requirements. Every system has a purpose for its development, which is summed up in the problem definition that is produced after a careful analysis of the customer's needs. In this case, E2O is looking for a tool that will help plan, analyze, and optimize logistics networks for tactical units. The mission analysis, for the most part, focuses on the environment where a system resides and tasks that an operator will use the system to perform. The functional analysis determines the specific actions or functions that a system must perform as articulated by the task in the mission analysis. This includes both the tasks specified during the mission analysis and tasks that are implied by the environment and the interaction with the operator and other systems. The requirements are pulled directly from both the mission analysis and functional analysis. Those 45 requirements produced in this research are a basis for the development of a system. Additionally, it makes an effort to clearly show the requirements for the current system and their origin by examining the existing documentation from LAWST that was provided by E2O. The research then outlines a brief analysis of LAWST showing the extent to which the system meets both sets of requirements and where the shortcomings are for the system, as well as comparing the requirements sets to each other. Those differences are quantified by comparing both the resource investment needed to produce the system and the extent to which the system addresses the capabilities that the customer desires in the product.

Ultimately the research shows that, based on the original requirements, LAWST is insufficient to address the tasks that E2O wants it to do. LAWST does provide presumably useful information in evaluating logistics networks to determine the additional energy demand produced by the distribution of resources to operational units. However, LAWST is not sufficient to support battalions and brigades in planning, analyzing, and optimizing logistics networks during time-constrained planning windows in support of tactical operations.

Reference

Government Accountability Office. 2015. *Defense Acquisition Process; Military Service Chiefs' Concerns Reflect Need to Better Define Requirements before Programs Start*. GAO-15-469. Washington, DC: U.S. Government Accountability Office. June.

THIS PAGE INTENTIONALLY LEFT BLANK

ACKNOWLEDGMENTS

I am extremely grateful for the support I received from my advisor, Professor Hernandez. He provided continuous guidance that kept me on track and focused on the objectives of the research. I am also thankful for the time and energy that Professor Hall dedicated to our discussions. There were many days I found my truck sitting by itself in the parking lot when I went home. Also, I give my thanks to Professor Parker for the final objective insights that helped nudge me over the peak. I would also like to recognize my wife, Jenny, for the countless hours and red pens that she dedicated to this effort.

THIS PAGE INTENTIONALLY LEFT BLANK

I. INTRODUCTION AND BACKGROUND

A. PURPOSE

This research will articulate the ramifications to system utility when a systems engineering (SE) approach is not applied in requirements development. It will establish an actionable framework to develop requirements that are appropriate, to the greatest extent possible, and traceable to an overarching problem or gap for which a system is developed. Furthermore, a system developed using a systems engineering process, that is verified to meet said requirements, is also more likely to be valid in addressing the problem for which it was developed.

B. SCOPE

The focus of this research is to examine the system requirements development process for LAWST. The research will examine the problem(s) that the system was designed to address. It will examine the various uses for the system and the environment in which it will be used. Additionally, it will examine the various documents describing modeling, software, and verification and validation (V&V) within the Marine Corps and DOD to determine additional considerations in the requirements generation. The specific research questions that this thesis answers are as follows:

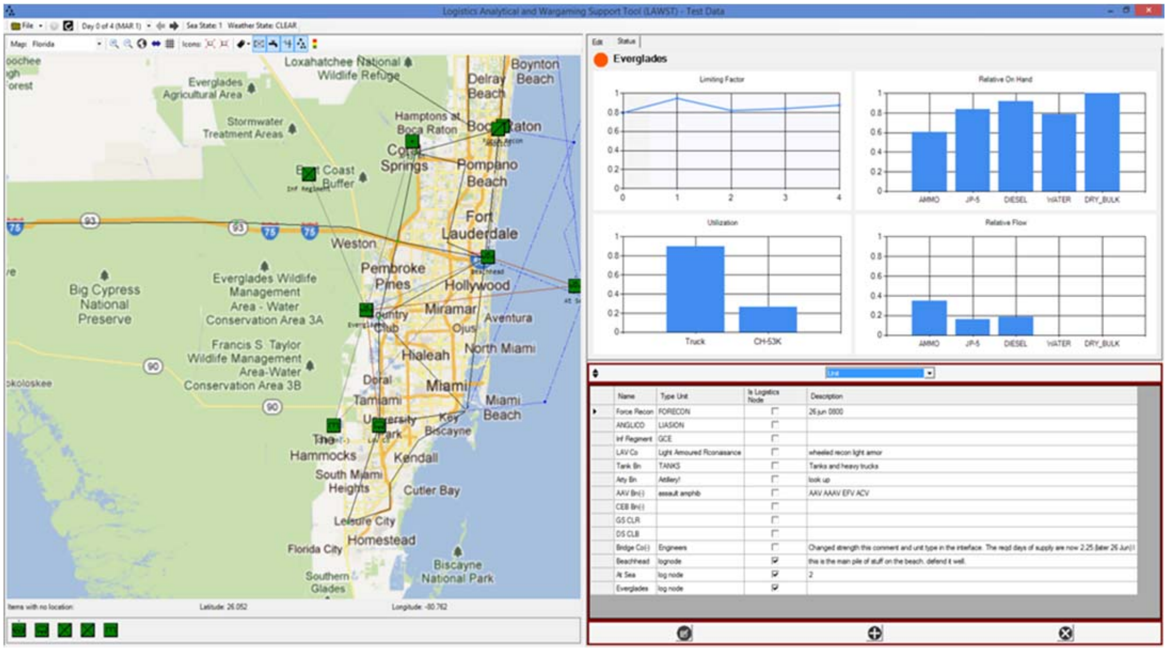
1. How were the design requirements established for the development of LAWST?
2. What would the system requirements for LAWST be if a systems engineering approach had been used?
3. Does the current version of LAWST address the system requirements that would have been developed through a systems engineering approach?

The boundaries of the problem (the use of systems engineering in system design) that this research addresses extend beyond the software and documentation for LAWST and the E2O's specific issues. The problem(s) that LAWST potentially addresses impact everything from strategic logistic operations down to the energy demands at the company level. It also looks at the force structure of the logistics elements that support the distribution of fuel and other supplies to the tactical edge. A number of documents outline guidance for modeling and simulation (M&S) development and verification, validation, and accreditation (VV&A) activities including MIL-STD-3002 Documentation of VV&A for M&S, DoDI 5000.61 DOD Modeling and Simulation (M&S) Verification, Validation, and Accreditation (VV&A), DoDI 5000.59 DOD M&S Management, SECNAV Instruction 5200.38A and Marine Corps Order 5200.28A both for M&S Management. LAWST is also subject to planning doctrine such as the MCWP 5–1, Marine Corps Planning Process, as it is a tool that may support wargame activities and analysis.

C. BACKGROUND

1. LAWST Description

LAWST is a simulation built as a deterministic model to help planners and logisticians ascertain the feasibility of a specific course of action from a logistics supply standpoint. According to the capability summary, LAWST is "designed to assist with operational planning and the conduct of wargames" (Group W, unpublished document). It models the distribution of supplies in a given area of operations with a user defined set of distribution assets and nodes within a distribution network in order to estimate the quantity of supplies (primarily fuel) that will be consumed by the *logistics process* itself in servicing the supply needs of the warfighters. Figure 1 shows a screenshot of a notional simulation scenario.



This shows a map of the area of operations along with graphs and information related to distribution assets and levels of supply.

Figure 1. Screen Shot of LAWST Simulation. Source: LAWST Capability Summary (Group W, unpublished document).

The graphical user interface displays a map, or more specifically, an image of a map over-laying a latitude/longitude or MGRS reference system rather than a geo-rectified map (LAWST accepts image files for this purpose). The user manually adds locations for supply nodes and transportation (e.g., roads) arcs between the nodes. While the arcs do not necessarily follow known routes on the map, the user can/may adjust factors to reflect the distance and time required to traverse the route during various operational conditions. The rates of consumption by tactical units (determined by MPEM) as well as logistics nodes are entered manually along with type of supplies and quantifying features of the supplies such as weight and volume.

2. Verification, Validation, and Accreditation

The verification, validation and accreditation (VV&A) process, is a mechanism by which models and simulations are certified to be used for some specific purpose.

Military Standard 3022, describing the standard practice for the VV&A for models and simulations, gives the following definitions for verification, validation and accreditation:

> Verification. The process of determining that a model, simulation, or federation of models and simulations implementations and their associated data accurately represents the developer's conceptual description and specifications.
>
> Validation. The process of determining the degree to which a model, simulation, or federation of models and simulations, and their associated data are accurate representations of the real world from the perspective of the intended use(s).
>
> Accreditation. The official certification that a model, simulation, or federation of models and simulations and its associated data are acceptable for use for a specific purpose. (Modeling and Simulations Coordination Office 2012)

In addition, DOD Instruction 5000.61 states that data associated with M&S that is used to support DOD activities shall go through a V&V process on a regular basis and be accredited for an intended use. Components are authorized to tailor the VV&A processes as necessary within the guidance from the instruction (Under Secretary of Defense [AT&L] (USD[AT&L]) (2009)).

In 2016, the Marine Corps E2O requested that the Naval Postgraduate School (NPS) conduct an assessment of the readiness of LAWST to undergo a V&V process. The report aimed to inform E2O if the simulation was ready to move through a more formal V&V process to be accredited for use, and to make recommendations for improvements to the simulation as it is developed.

The V&V assessment of LAWST is based on implied current and future uses rather than on explicitly stated system requirements (Hall 2016). The implied uses are based on the current version of LAWST as it exists. The V&V assessment addresses the question, "To what extent does LAWST do what it does?" rather than the more correct question: "To what extent does LAWST do what it was designed to do?" As stated in the V&V assessment:

> The requirements that drove these designs goals are neither specified here nor characterized by how well each of these functions would need to be

> performed in order to satisfy those requirements beyond the stated intent to 'support' COA generation and live wargame support. (Hall 2016)

Professor Hall describes how the lack of formal requirements and specifications makes it virtually impossible to perform a VV&A assessment of the simulation. The absence of traceability and objectivity of current capabilities or direction for future capabilities or changes to the system as it moves further along in development is a significant issue (Hall 2016).

The set of system requirements for the development of LAWST is undefined, thereby complicating, and perhaps precluding, the ability to proceed with its verification and validation. The ability to establish use cases for the end user that could lead to its accreditation is limited by the lack of context in which the system was developed. Evidence of any formal or documented process used to generate system requirements for the design and development of LAWST is unknown.

D. OBJECTIVES

This research will determine the system requirements for LAWST using an SE approach and to what extent LAWST meets those requirements. The objective of this research is threefold: to determine how the system requirements for LAWST were established, to determine what the requirements for LAWST would be had a systems engineering approach been used, and to determine the extent to which LAWST would meet requirements developed using a systems engineering approach.

The current instance of LAWST was developed to support the EF-21 Operational Reach 15 wargame according to Group W records. The set of current informal system requirements was obtained from the Marine Corps E2O office which oversees the development of the model. This informal approach to requirements development, that will be discussed in chapter IV, section D, results in a system that is inadequate to meet the needs of the stakeholder.

Our results articulate the ramification of not using a systems engineering approach to requirements development. Namely, LAWST does not meet E2O system objectives. LAWST is not postured to meet the demands of VV&A because there is little documentation on the process used in designing the system. Furthermore, the E2O requirements development provides an inadequate foundation for valid improvements to LAWST or as a means to assess the degree LAWST meets E2O needs.

II. LITERATURE REVIEW

System requirements come from a variety of sources and can be determined in a number of ways. The types of requirements vary from system to system and between types of systems. For instance, the requirements for a pen seem straight forward; however, they may vary depending on the context in which the pen will be used. Different requirements would be necessary for a pen used in space, as opposed to one used in a classroom. In other cases, two completely different objects can have the same requirements. A calculator and a slide rule are vastly different objects, used for many of the same purposes. While requirements themselves vary, requirements generation should follow a logical process such as systems engineering, regardless of the system or type of system.

A. IMPORTANCE OF ACCURATE REQUIREMENTS

Accurate requirements are critical in every aspect of designing, building and testing a system. Requirements that describe what a system must do and to what degree it will provide those capabilities, provide developers and testers with an objective in building, and measures to evaluate a system. In the case of LAWST, Professor Hall (2016) describes the validation as being “made more difficult” by the lack of precision in defining what the system is supposed to do. The conceptual model that is provided with LAWST gives limited detail with respect to requirements other than “provide timely analytical support to wargames in which energy usage and distribution are of interest” (Group W, unpublished document). This statement does not specify measures of how fast, what type of analysis, or any useful information in designing or evaluating the system. More importantly, tracing from where this and other system requirements are derived is a challenge, but it is worth the time and effort. When a system is developed to a specific set of requirements and delivered to the customer, it is important that the system actually addresses the purpose that the customer desires.

Blanchard and Fabrycky (2011) outline a method for requirements definition in Figure 2. It shows a systems engineering process to decompose the problem into a set of system specifications that can be used for further research, simulation design, and enhancements. Central to this approach is properly defining the problem for which a systems engineering approach is applied.

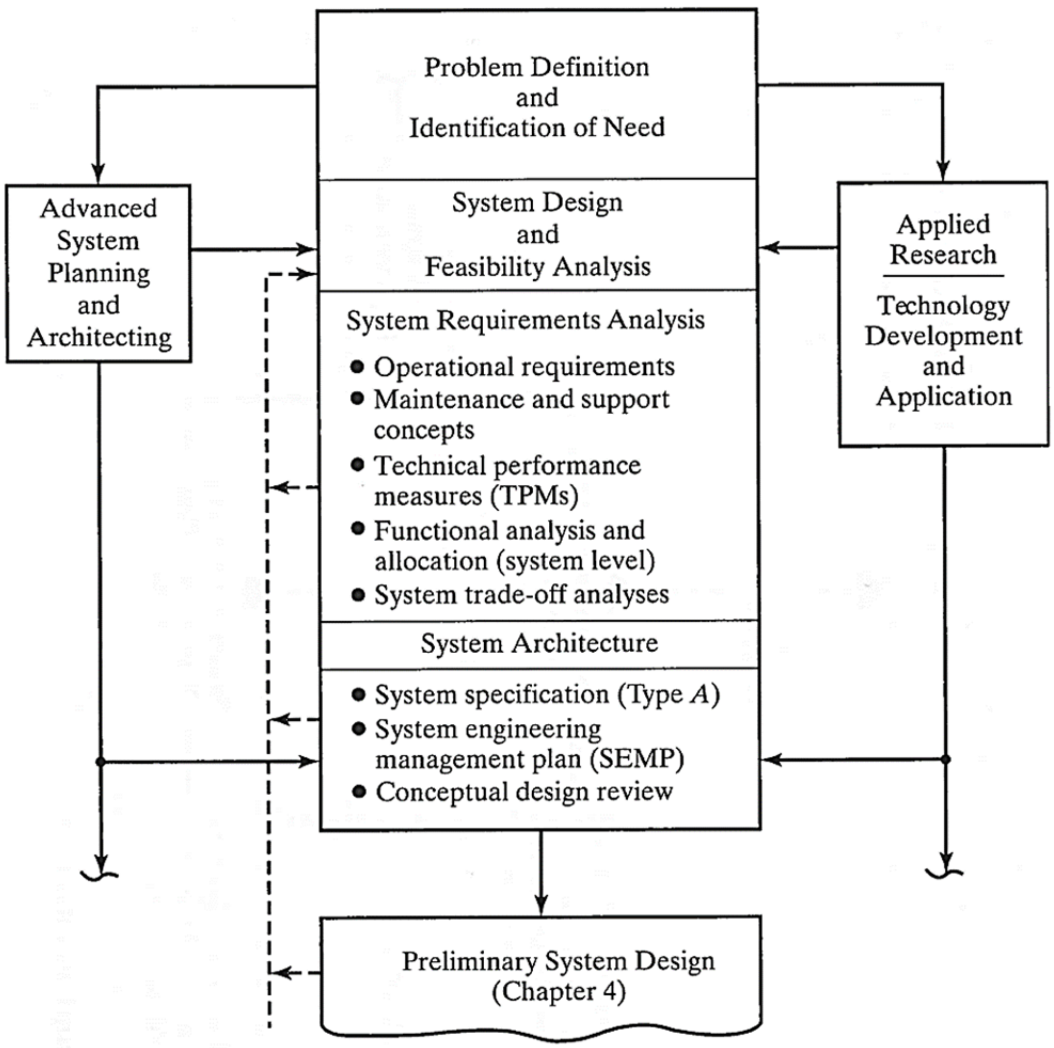


Figure 2. System Requirements Definition Process. Source: Blanchard and Fabrycky (2011).

The requirements generation process is the initial entry into the Systems Engineering “Vee,” as seen in Figure 3, where the problem and needs are decomposed into system specifications leading into the design of the system. System requirements are a critical component in the design as well as the V&V after the system realization when it begins to take shape.

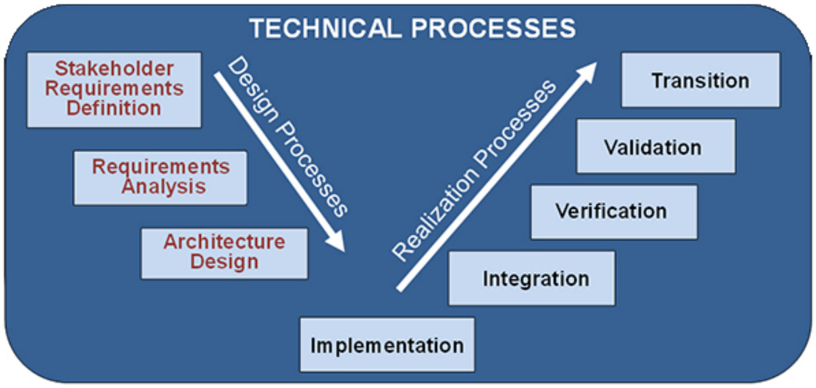


Figure 3. The Systems Engineering "Vee." Adapted from Defense Acquisition University (2017).

The systems engineering approach follows a logical, iterative, and recursive process that captures all the aspects of the system through its life cycle. The process will not only capture system functions and measures, but also include other system interactions, "-ilities" (such as interoperability, usability, supportability), and other administrative requirements. The SE requirements generation process ensures that often overlooked constraints on the system design, derived from the environment and other external systems with which it is to operate, are considered.

Current LAWST documentation does not confirm a specific problem definition used to begin its development. There are limited resources to develop these types of tools, and being able to justify specific capabilities is important to stakeholders. Therefore, it is critical for this system to be built upon a solid foundation of an appropriate problem definition and an accurate set of traceable requirements. These are the basis of a credible V&V for both the simulation and future improvements.

Every organization determines its own way of generating requirements that suits its timelines, resources, and way of doing business. Figure 4 outlines the Air Force Space & Missile Systems Center's (SMC) process for creating system requirements (2005).

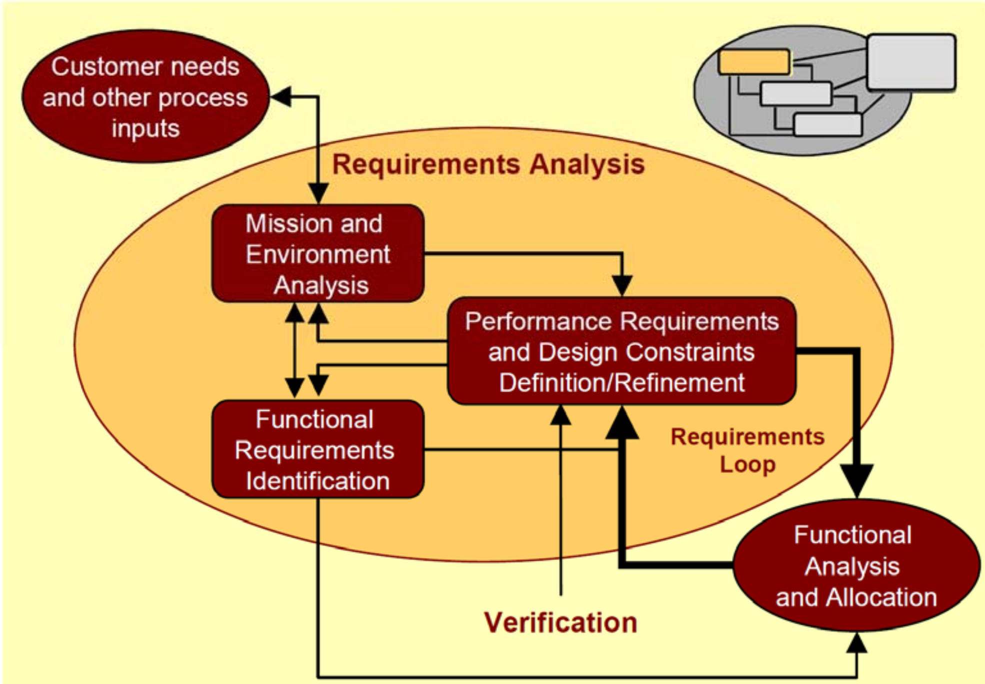


Figure 4. SMC Requirements Analysis Process. Source: SMC (2005).

This SMC process (Figure 4) is quite similar to that which Blanchard and Fabrycky describe in Figure 1. The verbiage does not quite line up between the two processes, but the basic concepts are the same. Figure 5 maps the elements of the Blanchard and Fabrycky process to the SMC process.

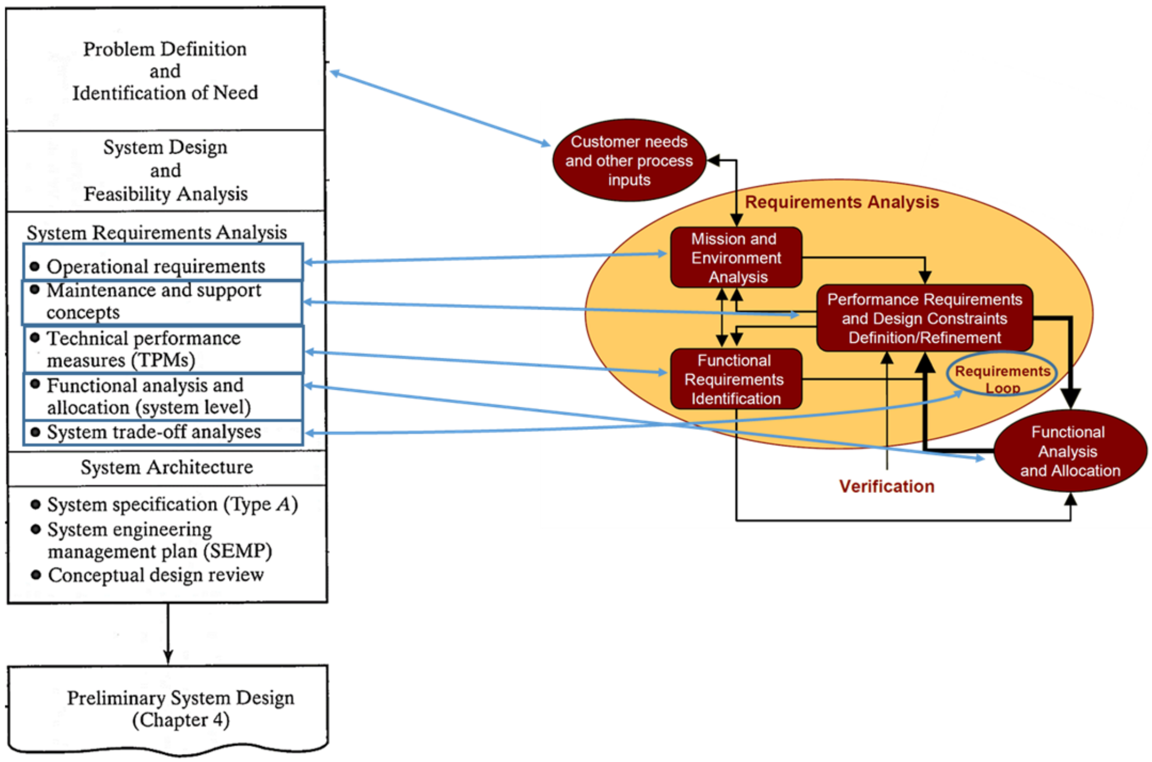


Figure 5. Comparison of SMC and Blanchard and Fabrycky Descriptions of Requirements Generation. Adapted from SMC (2005) (right) and Blanchard amd Fabrycky (2011) (left).

The processes described in Figure 5 can be summarized in five steps: problem definition, mission analysis, functional analysis, performance requirements, and requirements trade-off. This process is central to the research in this thesis. Further exploration of the steps can clarify the process.

(1) Problem Definition

Problem definition, or what Blanchard and Fabrycky (2011) call "Problem definition and identification of need" (74) and SMC (2005) calls "Customer needs and other process inputs," (46) describes the purpose behind developing the system. Raw customer inputs, sometimes called primitive needs statements, are analyzed to determine what the actual problem is and why the problem exists. This is the starting point for developing requirements.

(2) Mission Analysis

Mission analysis, what Blanchard and Fabrycky call “Operational requirements” and “Maintenance and support concepts” and SMC calls “Mission and Environmental Analysis” in essence, describes what the system needs to do and the context within which it will operate. This step should lay out the concept of operations for the system, including scenarios and vignettes describing how it is used, for what, by whom, where and why.

(3) Functional Analysis

Functional analysis is somewhat similar in that both the Blanchard and Fabrycky text and SMC handbook refer to this as “Functional analysis and allocation,” but SMC adds another step: “Functional Requirements Identification.” The Functional analysis decomposes the system into functions that it will be required to do to address the problem, as stated during Problem Definition, while doing the mission or tasks described in the mission analysis.

(4) Performance Requirements

In this step, called “Technical performance measures” and “Performance Requirements and Design Constraints Definitions/Refinement” by Blanchard and Fabrycky and SMC respectively, additional requirements are added that describe how well the system must perform the functions described in the functional analysis. In addition to describing the functions, additional requirements may be added in this step that describe how well, in terms of quantifiable measures, the system must perform in its mission.

(5) Requirements Trade-off

Blanchard and Fabrycky call this “System trade-off analysis” while the SMC puts it in a “Requirements Loop.” This step is often overlooked in system development to the detriment of the customer procuring the system. One GAO report on the Defense Acquisition Process expresses concerns from the service chiefs and other senior leaders that there is a lack of a systems engineering approach to requirements, specifically aimed at what technology and resources are available for a system (GAO 2015). A careful analysis needs to look at the resources that the customer has and the technology that is available and adjust the requirements of the system to ensure success in development.

Blanchard and Fabrycky present a generally well-accepted process that focuses on physical systems, but can also be applied to software systems. It is common for organizations to adapt the systems engineering process to their purposes. For example, the SMC systems engineering handbook describes the requirements generation process based on its own processes and procedures; however, it generally follows that of Blanchard and Fabrycky.

Regarding software systems specifically, Rajat Sud (2003), in his thesis on software requirements generation, calls the process "requirements engineering" and though the language is slightly different, the purpose and mechanisms are generally the same. Sud, as described, and others such as Sidky (2002), explain that there are other tools and processes in problem definition that can be used to explore more fully the problem space. These tools such as fishbone diagrams or cause-effect diagrams help designers get to the root of what the customer views as their problem (Sidky et al. 2002).

When it comes to the nature of requirements, Major General Greene (2003), a former Deputy for Acquisition and Systems Management (DASM), described that when a system is part of a system of systems, it is critical that requirements are developed from the top down to encourage an integrated view throughout development. With respect to program success and the importance of proper requirements, one GAO report indicates several senior leaders expressed concern that "systems engineering capabilities are generally lacking in the requirements development process," and that that leads to requirements creep, cost over-runs, and schedule slip (GAO 2015).

The report states that total system costs are typically not realized until after a systems engineering analysis is conducted. Prior to that, the high-level requirements only provide limited visibility into how the system will function and what the real cost and schedule will be. The GAO report also states "It is often at this point (after a systems engineering analysis)–when the technical specifications are finally understood and the design challenges are recognized—that cost and schedule increases materialize in a program” (14). So, it is important to have that work done prior to committing to a budget and\ or timeline for development.

In the case of LAWST, the documents that are examined in this literature review have a few purposes. First, the thesis examines the artifacts describing the development of LAWST and attempt to fit the development into an existing requirements generation model. Next, the processes that are presented in this literature will provide the framework for the methodology used to develop system requirements from a systems engineering standpoint. Both problem definition and a top-down approach are vital for creating requirements that are more integrated and complete.

B. APPLICATION

This chapter presents a number of different aspects of requirements. It articulates the importance of generating correct requirements using a systematic approach. It outlines the type of process that can be used to develop requirements. It also looks at the repercussions for not using a systems engineering approach prior to development. This information is the basis to support the methodology used for this study as articulated in Chapter III.

III. METHODOLOGY

A. OVERALL STRATEGY FOR ADDRESSING RESEARCH QUESTIONS

Our research begins with determining, from E2O, how the requirements for LAWST were derived and developed. The second and parallel effort will be determining the system requirements based on an engineering approach. We will make a comparison between the two requirements sets to identify the differences and determine as to why those differences exist.

LAWST will undergo an abbreviated systems analysis with the requirements generated from the systems engineering process and those requirements that were originally used to develop LAWST. This is in slight contrast to previous analysis where an attempt was made to derive system requirements from the actual performance of LAWST (Hall 2016). Normally, the goal of systems analysis is to determine the best system among a number of similar systems. In this case, the research will only evaluate LAWST capabilities against the system requirements to determine whether, and to what extent, LAWST meets the original requirements, as well as how it meets requirements developed using the systems engineering approach. We also identify any lost utility that was either not developed or not designed in LAWST.

The research quantifies the differences in the development of the two sets of requirements. The problem definition, the purpose for which LAWST was developed, is used in developing a set of system requirements that describe a system that will address that problem. Ultimately this problem definition is the basis for the system.

Determining what the requirements generation process was for the current version of LAWST is a straight-forward gathering of artifacts that led to the development of the tool. There should be relatively little synthesis of information to articulate what the process was, as this step is more of an investigation. The systems engineering approach to requirements generation will follow the process that was briefly described in Chapter II of this thesis. That is: problem definition, mission analysis, functional analysis, performance requirements, and requirements trade-off. Finally, a framework will be presented for E2O to follow in developing requirements for future systems.

B. DETERMINE ORIGINAL REQUIREMENTS

There are a number of documents that are available that indicate the original method for requirements generation. The original intent behind the requirements that were used to develop LAWST must be considered to understand the context in which the requirements were generated. The research should show the detailed process used in the original requirements generation process and be supported by artifacts leading up to the development.

C. REQUIREMENTS GENERATION

1. Problem Definition

The starting point for the systems engineering process is defining the customer's problem. It may seem like an easy prospect to ask the customer what the problem is; however, the customer in many cases may not be able to articulate the problem clearly. It is often the case that customers begin to solve their problem by looking for a solution that may only partially address what they want to solve. They may also start by offering a solution before defining the problem. In those cases, customers approach an engineer to build a solution that they think they (the customers) want. This usually leads to wasted resources because the solution the customers wanted does necessarily not solve their problem. It follows that novice designers usually give the customer what they ask for rather than identifying, then delivering what the customer actually desires (Cross 2011). Designers spend a significant amount of time thinking about a problem, framing it in different ways, and trying to fully understand it. Without spending an appropriate effort on analyzing and understanding the problem, any solution may be inappropriate or incomplete.

This research will begin with the primary customer for LAWST. The Marine Corps Expeditionary Energy Office was responsible for the development, through Group W, of the current version of LAWST. The primary mission of E2O, based on its website (http://www.hqmc.marines.mil/e2o/Mission-Vision) , is to improve the effectiveness of the Marine Corps by investing in ways to improve the energy consumption of combat systems and efficiency of the support structure on which Marine expeditionary forces rely.

Since E2O is part of the Marine Corps and its mission and outcomes are nested within those of the Marine Corps, other sources that will help define the problem include future operational concepts for the Marine Corps, regulations and field manuals related to planning and wargames, and instructions and orders related to modeling and simulation.

2. Mission Analysis

The Analysis of a system's mission explores the context of the system. The system will be used for some task that needs to be thoroughly explored. Questions that need to be answered here include:

Who performs the task?

Who else is involved in the task?

Why is the task being done?

Where will the system be used?

What other systems will this one interact with?

The comments from the stakeholder and documents that are explored as part of the problem definition are helpful in identifying the right questions to ask and point in the right direction for the answers.

Considering the models for requirements generation from Chapter II, it is important to note the process is rarely sequential; in the course of researching the problem context, it might become necessary to revisit and revise the problem statement. In turn, revising the problem statement may also refocus the mission of the system and the tasks it must perform or enable.

Some products from this phase may include a concept of operations (CONOP) statement and/or operational view diagram that defines how the system will be used. It is also helpful to provide some link from the CONOP to the questions and answers in the mission analysis back to the problem statement. Diagram that shows the decomposition of the problem based on the mission context using a dendritic tool, like a fishbone diagram that shows the decomposition in some logical way can be helpful. These types of diagrams help provide the required traceability when the system requirements begin to emerge.

3. Functional Analysis

Functional analysis begins to add a layer of actions that the system must do to operate in a way that is consistent with the CONOP from the mission analysis. There are several tools that will be used in this analysis. Scenarios describe a system in action as it executes task that it was designed to do. Vignettes are short, detailed narratives that describe specific actions or sets of actions that the system completes in the scenario. Engineers can describe the vignettes in diagrams like a functional flow block diagram. Once all of the tasks that a system needs to perform in the scenario are described functionally, engineers organize like functions into groupings that begin to form a hierarchy that forms the functional decomposition of the system.

A scenario provides additional context to the system that may not be apparent in the previous set of documents that are created as part of the mission analysis. The scenario provides information on the environment and begins to address the time scale in which that task must be performed. It also articulates interactions between operators and the system, the system and other systems and brings out information requirements that are transferred between each. Vignettes can not only fit into the overall scenario but also offer additional detail on critical tasks that the system must accomplish.

Functional flow block diagrams (FFBDs) are a pictorial method of showing a scenario. They depict each element participating in the scenario and show the tasks that each of those elements performs. Additionally, they show the interactions between the operational elements, specify which tasks are dependent on others and the order of executing task, and estimate how long the tasks should take.

Once the scenario and vignettes have been mapped out in a FFBD, engineers capture the functions that the system performs, along with any inputs, outputs, control mechanisms, and resource requirements.

4. Performance Requirements

Requirements for a system do not need to be captured only after functional analysis of the system. At each step in the process, requirements begin to emerge. In the problem definition phase, requirements may appear in regulatory or statutory documents. The mission analysis may articulate environmental constraints in which the system must operate or times when the system will or will not be operational. These are all valid requirements. There is no agreed upon time or place in the process where requirements should be developed, but going through the process completely ensures the greatest exposure to potential requirements for the system.

In relation to the functional analysis, every function can be mapped to a requirement, even if the requirement has a binary measure. In many cases, the additional information such as inputs and outputs, control mechanisms, resource requirements and timing will have more substantive requirements that can be measured in a quantitative way. There is a risk that more qualitative requirements may be interpreted in different ways causing confusion and conflict in later stages of development. Therefore, while it is not always possible to avoid them, it is advisable to make the effort to qualify the requirements with additional descriptions.

Since LAWST is specifically designed to support logisticians in wargames, this section shows the specific linkages of the requirements back to the FFBDs, and in turn the scenarios that describe a wargame. The requirements also provide information on timing and interactions that the system has as the logistician moves through the planning and wargame process.

5. Requirements Trade-off

The requirements trade-off phase is the point in the systems engineering process when it begins to transition to more tangible, solution-oriented tasks for engineers. At this point, physical components, blocks of code, schemes for training operators, adjustments to doctrine, and other Doctrine, Organization, Training, Materiel, Leadership/Education, Personnel, Facilities and Policy (DOTMLPF) considerations are fit together in different ways to explore the best combination of factors that meet the stakeholder's needs. The measures of effectiveness (MOEs) and measures of performance (MOPs) that are used to evaluate the different alternatives should reflect the priorities and interests of the stakeholder. While the MOEs and MOPs can be developed by the engineer, they should be well understood and accepted by the stakeholders before any comparison of alternatives is done.

This type of analysis is often called systems analysis (SA) and is often conducted by analysts who specialize in that discipline. Often a report is developed to inform a decision maker of the various feasible alternatives and explain which ones best address the problem for which the system is being developed.

In the case of this research, LAWST, as the materiel solution, will be the only alternative that is evaluated. Additionally, this research will not take other DOTMLPF considerations into account and MOPs will be those that are described in the systems requirements developed up through the performance requirements phase. For each requirement, LAWST will be evaluated on whether it meets the requirement and to what extent.

D. COMPARISON OF REQUIREMENTS

It is important to determine the difference between the requirement sets developed with and without a systems engineering process. This step should be focused on the requirements from one set or the other that do not match or address, in any way, a requirement from the other set. This allows insight into the potential shortfalls or oversights in current requirements generation processes. On the other hand, there may be evidence that there are other factors that were not captured by a systems engineering process that may be important to the customer.

1. LAWST Compared to Original Requirements

A majority of the work for this step has been completed by Dr. Steven Hall in 2016 as part of an assessment of the readiness of LAWST to undergo a VV&A. That information will be reviewed during this step of the methodology.

2. LAWST Compared to SE Developed Requirements

This portion of the methodology will assess LAWST against each of the requirements developed during the requirements generation process using a systems engineering approach. Each requirement will have an explanation of how LAWST does or does not fulfill that requirement. LAWST will demonstrate the function described in the requirement or it will not. If LAWST does perform the required function, it should explain to what extent it fulfills the requirement. For any requirement in which it is not readily apparent that LAWST addresses it, there should be some method by which the requirement can be tested or determined.

E. QUANTIFY DIFFERENT APPROACHES

There is a resource cost associated with every aspect of system development. The differences in the approaches used to develop LAWST will be quantified to evaluate those costs. For the purposes of this research, the percent difference between the requirements sets may be used to make an estimate of the additional cost, if one exists, required to incorporate the additional requirements. A work breakdown structure, which useful in determining system costs, is also used in the analysis.

F. DEVELOP FRAMEWORK FOR FUTURE DEVELOPMENT

As a final element in this methodology, summarize the process used to generate requirements using the systems engineering process. This framework can be used with any generic system or software. This framework will provide a way for future systems to be developed with the most complete set of requirements to reduce future costs and development time in making changes to the first iteration of the system.

This methodology will allow the research to answer the primary research questions. It will determine how the original requirements for LAWST were developed, what the requirements for the system would be (had a systems engineering approach been used), and then determine if LAWST meets those requirements using an SE approach.

IV. COMPARATIVE ANALYSIS OF REQUIREMENTS GENERATION PROCESSES

A. PRESUMED ORIGINAL LAWST REQUIREMENTS

The assessment of LAWST's readiness to undergo a V&V process reveals that the requirements were neither included in the documentation describing the system, nor was there evidence of the process used to generate the requirements for the current version of LAWST (Hall 2016). However, in separate documents information on the "Expeditionary Force 21 (EF-21) Energy Study and Wargame," which was conducted in early 2015 to examine the ability of the Marine Corps to support operations from an energy perspective, shows a modeling effort to determine if the anticipated fuel supply meets the demand of the units. The wargame document includes notes from the E2O director that indicate priorities for the effort (E2O, unpublished document). A diagram from the document shown in Figure 6 indicates the origin of LAWST.

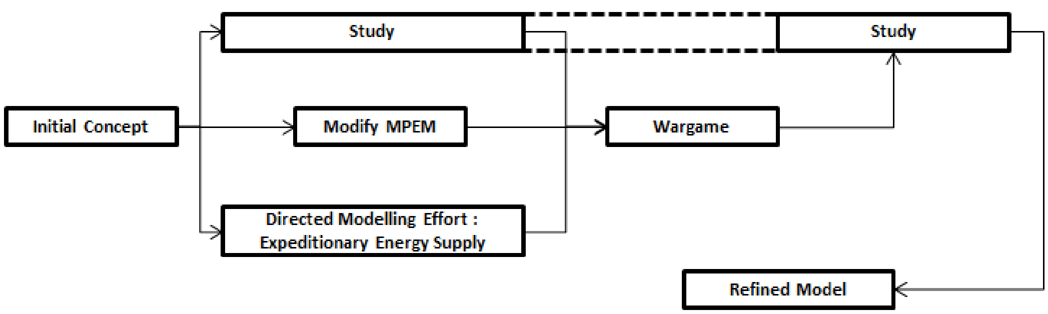


Figure 6. EF-21 Energy Study and Wargame Concept. Source: EF-21 Energy Study and Wargame document (E2O, unpublished document)

The block labeled "Directed Modelling Effort: Expeditionary Energy Supply," in Figure 6 is what eventually becomes LAWST. Documentation that is provided with LAWST indicates that the Marine Air-Ground Task Force (MAGTF) Power and Energy Model (MPEM) is a basis for the demand and LAWST fills in the gaps with respect to the demand created by the logistics network itself. In addition, the document contains a set of questions found in Table 1.

Table 1. Study Questions from the EF-21 Energy Study and Wargame. Source: EF-21 Energy Study and Wargame document (E2O, unpublished document).

1	What do the supply and demand curves look like from Sea-Echelon Area (SEA) to the FLOT?
2	Where are the CVs in the energy system?
3	How much fuel is required by type in each of the five zones? What is the capability to support in each zone? What are the risks by zone?
4	What is the demand of the various fuel types at various points in the operation?
5	What are the capacities to deliver and store fuel in each zone? Do they meet requirements?
6	What kind of USN/USMC C2 arrangements are necessary to assure fuel supplies?
7	How much fuel does it cost to deliver fuel at various points on the battlefield and as you alter battlefield conditions?

The questions posed in the study and wargame concept are found in a later presentation in which they are mapped to a set of proposed requirements. Those requirements are listed in Table 2.

Table 2. List of Requirements from the EF-21 Energy Study and Wargame Support Proposals. Source: Group W (unpublished document).

The solution must:
Calculate supply/demand by zone, echelon, or level
Define throughput, storage, and delivery capability at each node or arc
Calculate fuel consumed to deliver fuel
Accommodate (two) fuel types and multiple types of delivery assets
Accommodate other classes of supply
5.1 Compete for delivery assets
5.2 Deliver of other classes of supply consumes fuel
Account for geographic separation of units/assets
Allow for dynamic changes to the network (i.e., new nodes to support advancing forces, units changing location/fuel-resupply points, etc.)

The presentation goes further and links the proposed requirements to the study question in Figure 7.

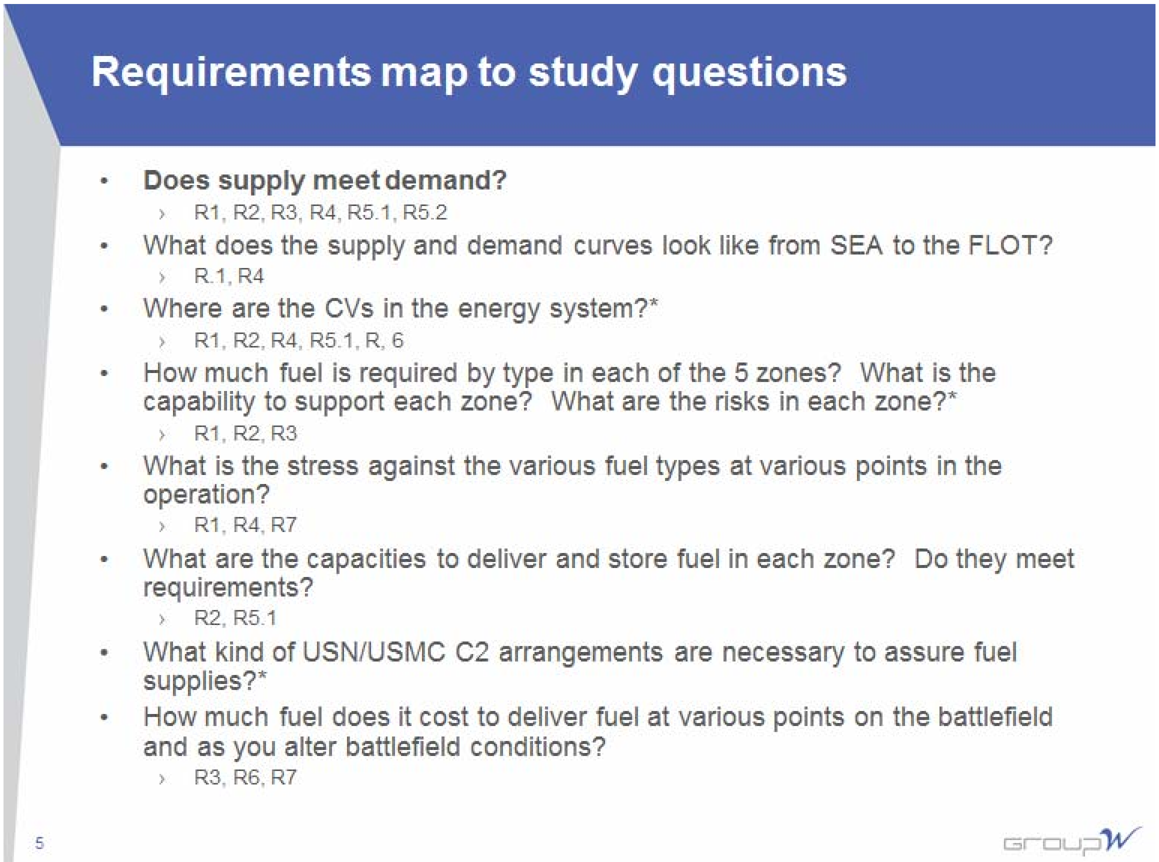


Figure 7. Linkage of Proposed Requirements to Study Questions. Source: EF-21 Energy Study and Wargame Support Proposals (Group W, unpublished document).

This indicates that the system requirements that led to the development of LAWST originated primarily to support EF-21 Energy Study and Operational Reach Wargame. There is no description of the process used to decompose the study questions into any functions that a system must perform during its operation that provides the logic used to develop the requirements that the developer suggests.

Additional information in the support proposal presentation indicates an initial feasibility analysis had different potential solutions (STORM Lite, Excel, ExtendSim, and Instantaneous Supply Calculator) (Group W, unpublished document). All were evaluated against the requirements to evaluate suitability and cost. The results of the analysis were not apparent in the presentation and there are no additional documents that indicate the further analysis exists.

B. REQUIREMENTS GENERATION FOR LAWST USING A SYSTEMS ENGINEERING APPROACH

1. LAWST Problem Definition

The problem definition is a mechanism by which the purpose for a system is established in order to begin the systems engineering process.

E2O is the primary and priority stakeholder or customer for LAWST. E2O indicated that it would like LAWST to be distributed as an aid in planning and wargaming at the tactical level. Since wargaming is an integral part of planning and evaluating courses of action (COAs), wargaming is always assumed part of the planning process. The E2O director, at the time of the development, also made hand-written comments on the EF-21 Energy Study and Operational Reach Wargame documents, which serve as an indication for the priorities of development. Group W points out an important element, with respect to tactical units, that logistics assets are shared among all classes of supply and any tool that is developed needs to include all of those classes. Additional comments add to the context of the problem: The Vision Statement says "efficient use of vital resources" (E2O 2017, 1) and the Intent Statement further clarifies that the system should: "to change the way the Marine Corps employs energy and resources." (E2O 2017, 1). These statements and pieces of information went into crafting the problem definition: The U.S. Marine Corps does not have a robust tool to plan, analyze, and optimize logistics networks in support of Combined, Joint, and Interagency operations in a non-contiguous JOA against a range of non-hostile to hostile threats.

2. System Mission Analysis

The mission analysis is a critical step in the exploring the context of the problem. This system mission analysis is different from the mission analysis, or problem framing, that is described in later paragraphs. The system mission analysis, that is the focus of this section, is analyzing the mission and tasks that LAWST would perform as part of its operations in the environment in which it will operate.

The Marine Corps Planning Process (MCPP) is articulated in MCWP 5–1 (US Marine Corps 2010). There are six basic steps in the process: Problem Framing, Course of Action (COA) Development, COA Wargaming, COA Comparison and Decision, Orders Development, and Transition. Problem Framing is a methodical analysis of a given mission; the specified and implied tasks that a unit must do, limitations, information requirements and other considerations that planners need to take into account when developing their own plans to accomplish their given mission. During COA development, the planning staff develops a number of distinct courses of action to address the given mission. COA Wargaming refers to evaluating each COA based on enemy action, branches and sequels at decision points and potential shortcomings. After each COA is evaluated, the staff weights each COA based on evaluation criteria developed prior to the wargame and based on the score of each COA, recommends a course of action to the commander during the COA Comparison and Decision. This step is followed by Orders development that entails the production of the orders for subordinate units. Orders include a detailed description of the course of action, coordinating instructions, logistics instructions, and command and control instructions. Transition generally goes through the dissemination of orders, back briefs, rehearsals, and other pre-mission tasks. This is a concise view of the planning process but provides an overview for reference.

In the Problem Framing, there are a number of important pieces of information that a logistician must gather in preparation for the course of action development. The location of the mission is a critical starting point for gaining additional information about the situation. The logistician can determine existing infrastructure that could be used to support forward elements, initial estimates of throughput for major supply routes, initial distances and time required from sea bases, location of major logistics nodes, and current disposition of units and supplies.

During the COA development phase the operations officer usually develops the scheme of maneuver for a specific COA and the logistician develops a complimentary logistics concept in support of that COA. The logistics concept should be as detailed as possible to support the COA Wargaming, Comparison and Decision.

During the COA Wargaming, the logistician may be asked to provide his or her evaluation of a specific aspect of a COA with respect to the logistics concept, immediate feedback is preferred based on short timelines for planning so, any information that logistician has needs to be readily accessible and interpreted. Information, as articulated in MCWP 5–1 should be granular to two levels down (i.e., if this is a battalion level plan, wargaming is typically conducted down to the platoon level). In addition, the logistician must be able to adapt to the wargaming method that the facilitator (usually the operations officer or executive officer) chooses: belt, avenue in depth, critical task or box method. The belt method refers to wargaming a COA within a specific set of times or phase lines. The avenue in depth method allows the facilitator to wargame a specific unit or task over the entire duration of an operation. The critical task or box method refers to examining specific times or places within each COA (US Marine Corps 2010).

In the COA Comparison and Decision, the logistician needs to articulate the feasibility, strengths, and weaknesses of each COA with respect to the logistics concept. When evaluating a system, based on the tasks it needs to complete, the analysis should include an indication of how well the system should do any specific task. In the case of the MCPP, the best measures are based on extreme cases. For instance, the Rapid Response Planning Process dictates six hours to complete the planning process, allocating 90 minutes total to complete Problem Framing, COA Development, COA Wargaming, and COA Comparison and Decision. This timing information is critical in articulating requirements that can support the MCPP.

Systems Engineers use scenarios and vignettes in the mission analysis phase. The scenario is an overarching narrative that describes how the system will be used. In this case, the scenario is the MCPP. Vignettes describe, in more detail, specific tasks within the scenario. Two vignettes that are helpful in this case are the Problem Framing and the COA Wargaming that offer vital information on the type of tasks that a system must support.

Designers sometimes use a mind-map to link the different aspects of the mission analysis for a better understanding of the logistics tasks as part of the MCPP. Mind-mapping allows designers to expand on topics, examine linkages between items, and group ideas together to organize their work. Figure 8 was created in an application hosted on mindmapmaker.org called “Mindmaps” and shows one specific branch of a mind-map related to wargaming a COA.

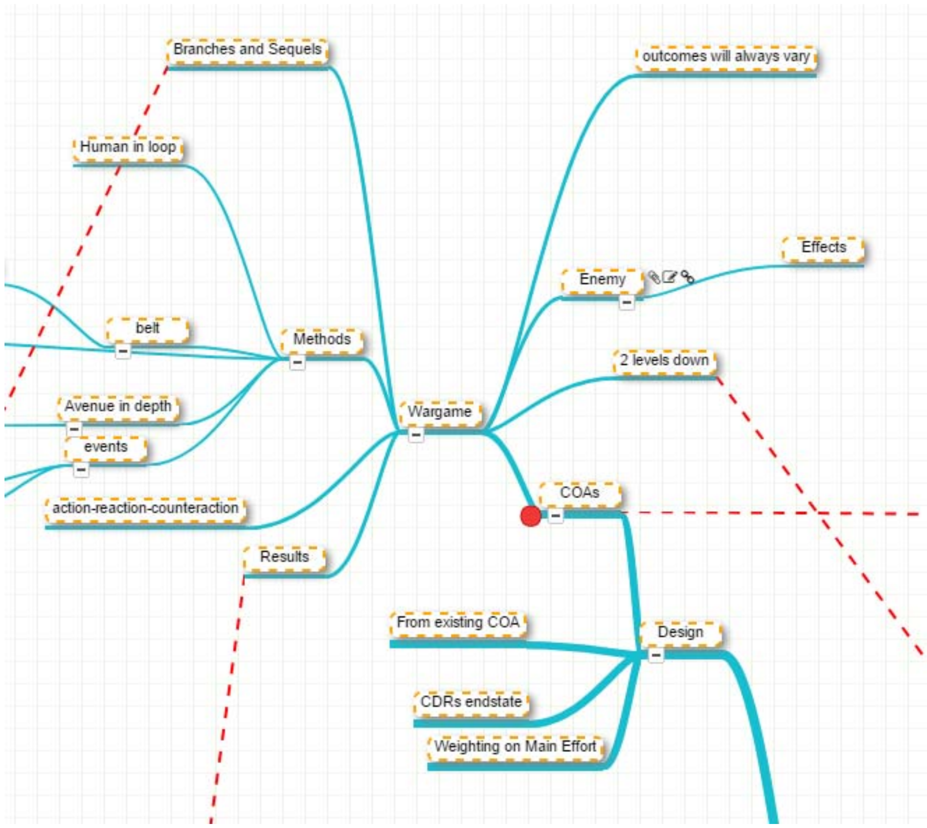


Figure 8. Mind-map Related to Conducting Wargame on a COA.

This portion of the mind-map examines COA wargaming. It organizes the methods of wargaming and the different considerations that need to be taken into account when a wargame is conducted. For instance, Figure 8 shows the wargame and branches describing different aspects and considerations of a wargame: the method, the enemy, evaluating two levels down, action-reaction-counteraction. This type of tool allows a large number of related or unrelated tasks to be quickly captured and organized for better visualization of the tasks involved with this system. A full mind-map for this mission analysis can be found in Appendix A.

This mission analysis provides a structure leading into the functional analysis. It provides some top-level functions that the system must do in performing the tasks during the mission and provides additional detail to an otherwise arbitrary selection of functions that the system will perform.

3. Functional Analysis

The functional analysis step in the SE process is really the beginning of looking at the system that will address the problem defined in the problem definition, but within the context of the tasks outlined in the mission analysis. The system, at this point, should be defined by the functions that it needs to do. Those functions should complement and assist the planners, from the scenarios in the mission analysis step, in accomplishing the tasks that are described in the scenarios.

At a top-level view, the system can be bounded by the tasks that describe its use. In this case, logisticians need to begin analysis by creating concepts or plans to support COAs developed during the COA development phase of the MCPP. Once an analysis of the COAs is complete, the system has completed its tasks. The comparison and decision of which COA to use is based on criteria that the logistician may not have any control over; however, the commander deciding which COA to execute will take the logistician's recommendations into consideration when making the decision. Figure 9 shows the high-level functional decomposition of a system that supports a logistician in analyzing a COA.

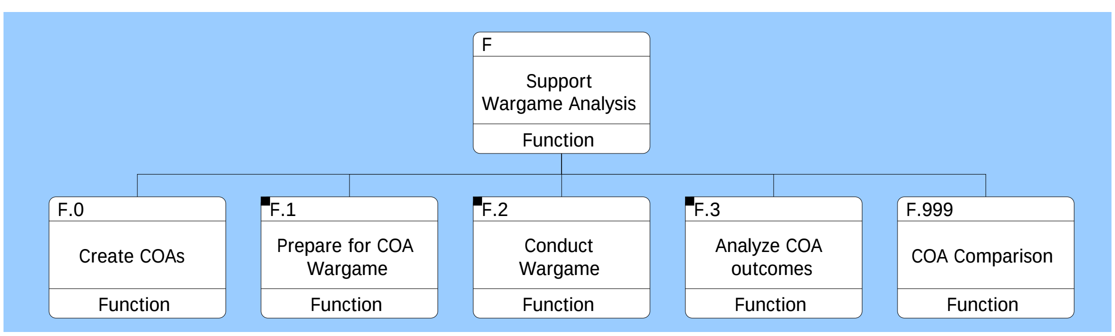


Figure 9. Top Level Functional Decomposition of an Analysis Tool.

Additionally, Figure 10 shows those functions in the sequence they need to occur, usually called a functional flow block diagram (FFBD), in order to support COA Wargaming.

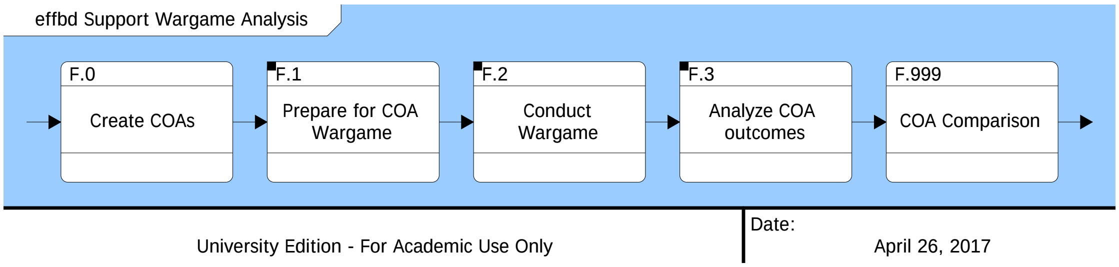
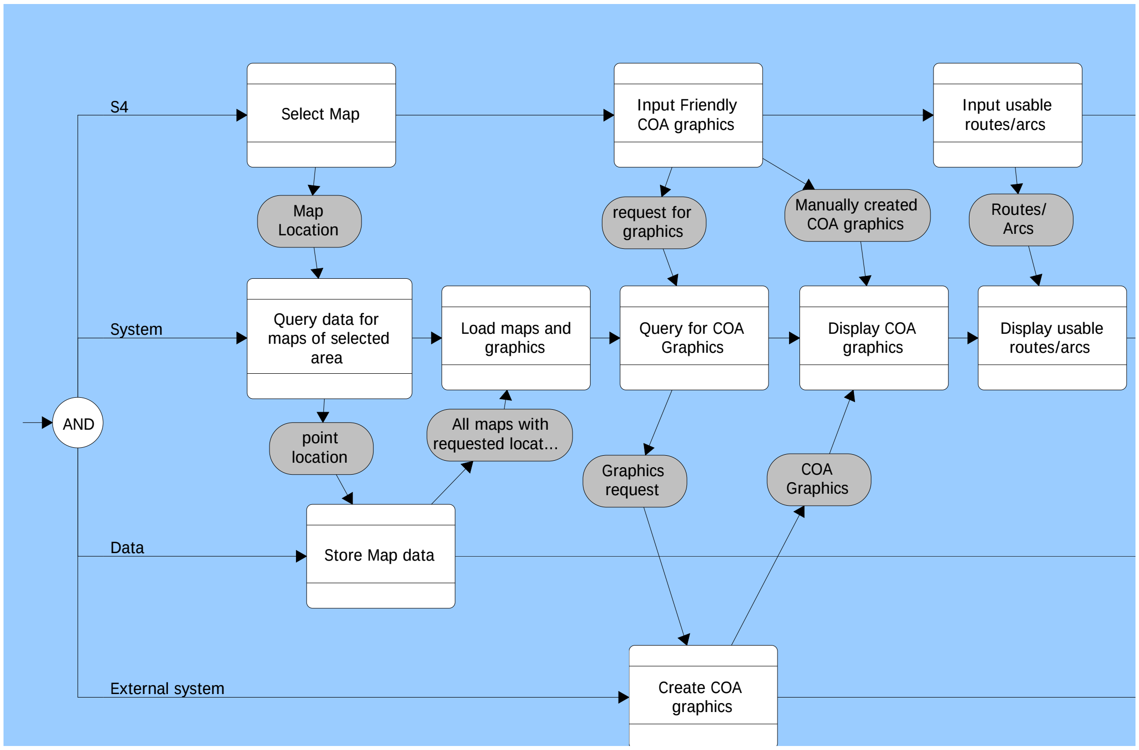


Figure 10. Functional Flow Block Diagram of a Wargame Analysis Tool.

In Figure 9 and Figure 10, the F.0 function, Create COAs, and the F.999, COA Comparison are the starting and ending points for the system. F.1, F.2, and F.3 are the primary focus points for this tool, and presumably LAWST.

Each function can be further broken down to look at more specific aspects of the system as it relates to lesser tasks. These tasks, at a detailed level, are one source of system requirements that are recorded during the requirements generation phase. For example, F.1, Prepare for COA Wargame can be broken down by looking at all the tasks that different entities have to perform while preparing for a COA wargame. Figure 11 shows an FFBD in which the S4, the logistician, is using the tool/system to accomplish the tasks necessary to prepare for a wargame.



This is the beginning of the FFBD describing the logistician preparing for a COA wargame; the entire diagram can be found in Appendix A.

Figure 11. FFBD of a Logistician Using a Support Aid/Tool While Preparing for a COA Wargame.

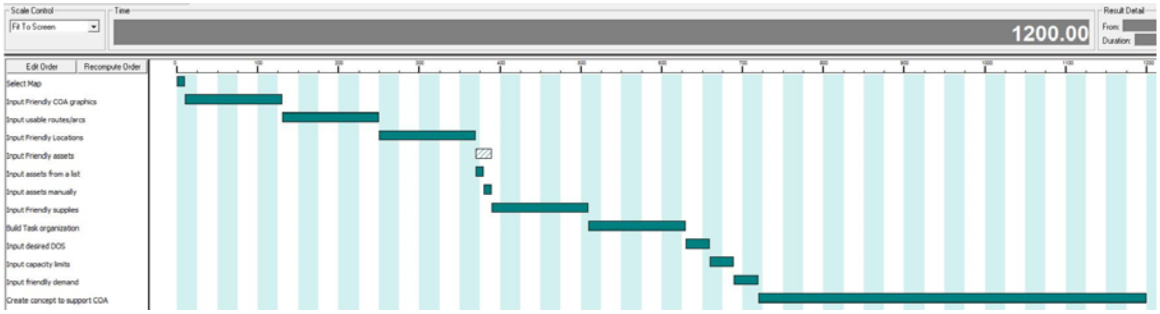
The FFBD in Figure 11 includes the players or nodes in the task, the information that is transferred between nodes, and the sequence of events that each node must complete to accomplish the task. For this FFBD, there is an S4, the system on which he or she is working, data that the system needs to contain, and external systems that interact. This FFBD describes the following vignette from the System Mission Analysis:

> The S4 selects the map sets needed for the operations area where the mission will take place by entering an eight or ten-digit grid location. The system loads a set of maps, including digital terrain elevation data (DTED), hydrology, imagery, and standard MGRS map sets. The S4 either imports COA graphics from an external system or creates the COA graphics on the tool. The S4 then determines the usable routes or arcs that a logistics network could use to support the COA. The S4 also inputs friendly unit information, logistics asset information, supply locations. The S4 sets parameters for each one, including desired days of supply (DOS), supply capacity limits, and demand. The S4 then creates a logistics concept to support the COA and task organizes logistics assets to support the COA.

Another factor to consider is the timing of the functions. The MCPP allocates about 20 minutes during a planning cycle, in support of operations, to developing COAs. Assuming three COAs are developed, a hypothetical allocation of time for each task is as follows:

- Select Map, 10 seconds
- Input COA graphics, 40 seconds per COA
- Input usable routes, 40 seconds per COA
- Input friendly unit locations, 40 seconds per COA
- Input friendly asset information, 40 seconds per COA
- Input friendly supply information, 40 seconds per COA
- Build task organization, 40 seconds per COA
- Input desired DOS, 10 seconds per COA
- Input capacity limits, 10 seconds per COA
- Input friendly demand, 10 seconds per COA
- Create Concept for logistics support, 180 seconds per COA

These times can be allocated in other ways based on how the customer wants to trade-off different capabilities of the tool. This initial allocation can be adjusted in subsequent iterations of a requirements generation process. Figure 12 shows a snapshot of this set of tasks associated with preparing for a wargame and their timing.



CORE has a simulation mechanism that allows the timing to be shown pictorially for greater understanding of the functions over time.

Figure 12. Simulated Times for Each Task in an FFBD Created in CORE.

In this figure, the times combine to 1200 seconds, or 20 minutes, which is the time allocated by the MCPP to generate COAs in a rapid response planning timeline.

A complete set of FFBDs and functional hierarchy is found in the Appendix A.

4. System Requirements

System requirements come from a variety of sources. However, all requirements should have the same general properties. Karl Wiegers (1999), writing on software requirements states they should be:

> Correct; a robust process with feedback loops will ensure correct requirements
>
> Feasible; requirements should be attainable with the resources provided by the customer.
>
> Necessary; they should be traceable back to the original problem statement.
>
> Prioritized; developers should understand the requirements that are the most important for success.
>
> Unambiguous; wording should be clearly understood by different designers in the same way.
>
> Verifiable; there should be a way to measure or confirm that a requirement has been met.

Other aspects of requirements described by Buede (2009) include: complete, consistent, correct. He also stresses the need for requirements to focus on defining the problem to be solved rather than the solution.

The primary source of requirements is from the functional analysis. An initial set of requirements is taken directly from the functions on a one-for-one basis. Care is taken to eliminate redundant requirements and correct inconsistent requirements.

The first function that will lead to a requirement is “Query data for maps of selected area.” An operator should be able to enter a grid coordinate somewhere in the area of operations and find all the associated maps with that location. Because the operator may be operating on a ship and a potentially secure network, the maps should be readily accessible. There are other command and control, intelligence, and fires systems that also use maps. Using a standard mapping engine that already accepts those types of maps reduces the need to keep all map sets resident on the system. The requirement could then be written as:

“The system shall use a mapping engine that accepts CADRG (MIL-C-89038), CIB (MIL-STD-2411) and DTED map data.”

This requirement is correct: logistics networks are visualized on a map, as are COA graphics and both are determined during the mission analysis phase. The requirement is feasible: there are several open source map engines that are compatible with standard maps sets used by the military. The requirement is necessary: it traces back to specific functions and tasks in the mission analysis phase. The requirement should be prioritized as high priority: maps are a basis for many types of planning and wargaming. The requirement is clearly-worded. The requirement is verifiable; a demonstration could determine whether the requirement has been met. This is an acceptable requirement.

A related requirement is:

“The system shall allow operators to select the map, and display it at a scale necessary for planning, and location within 10 seconds.”

While the time limitation seems arbitrary, it is necessary in maintaining the timeline required by a rapid response planning process as described in Figure 12. If other times during the COA development phase of the MCPP could be reduced, then longer times to locate the appropriate maps may be acceptable. This is a good example of a requirement that can be negotiated with the customer. For many of the same reasons as the previous requirement, this requirement is also acceptable.

As related to wargaming specifically:

"The system shall allow operators to input branches and sequels identified at each decision point during the wargame."

Almost every version of wargaming involves decision points and branches. The tool needs to be able to accommodate this common mechanism in order to be useful to logisticians participating in a wargame.

Other requirements may come directly from the customer. For example, E2O is an organization that is focused on energy efficiency so a required element is the total amount of fuel used and the rate at which it used for any given COA. That required element manifests itself in the following requirement:

"The system shall determine the overall fuel used, over time, for each COA."

By examining the customer needs, mission tasks, and required functions designers can determine the requirements for a system. However, other sources of requirements are often overlooked such as regulatory requirements and requirements that are derived from best business practices.

Regulatory requirements are often roadblocks to successfully operating a system in its intended environment. For example, the logistics tool will operate on the Navy Marine Corps Intranet (NMCI). In order to operate on the NMCI, the tool must comply with all the applicable rules, guidance, and certifications that govern the network as per the DON CIO Memo 02–10, 26 April 2010: "The system shall be compliant with all DoN regulations for authority to operate (ATO) on NMCI networks."

A complete set of requirements developed during this research is found in Appendix B.

5. The Extent That LAWST Fulfills the Presumed Original Requirements

Section A in this chapter introduces the potential origins of requirements for LAWST. Half of these assumed requirements are met by LAWST and can be verified by inspection. For Requirement 1, LAWST can calculate supply and demand by echelon and level. However, the term zone is not defined and there does not seem to be a clear way to calculate supply and demand within a specified portion of the supply network using LAWST.

Requirements 2 and 6 seem straightforward and can be readily demonstrated using LAWST but the word “define” seems targeted to LAWST. Since LAWST is described in the LAWST documentation as a data driven model, it is actually the operator that defines the throughput, storage and delivery capability so the requirements are unclear.

Requirement 3 is closely related to requirement 5.2 in that it specifies the need to determine the fuel consumption for a specific commodity. The difficulty is that LAWST does not specifically break out the fuel cost of any given commodity type. While the commodity fuel cost for any given commodity type could be determined artificially by only including the demand of that commodity in the model, LAWST does not break out fuel cost of any given commodity.

LAWST does not show any feature that accounts for different types of fuel as specified in requirement 4. While artificialities could be incorporated such as defining a commodity as a second fuel type with a specific demand for a unit, LAWST does not inherently accommodate two fuel types.

The final requirement is supported by LAWST. Concepts that the LAWST documentation puts forward such as Scripted sorties can be included to change the baseline logistics network at certain times and places.

An overall assessment of LAWST against these articulated requirements is shown in Table 3.

Table 3. Summary of LAWST Assessed Against Articulated Requirements

Requirement	Degree that LAWST meets requirement
Requirement 1	Partially
Requirement 2	Yes
Requirement 3	Partially
Requirement 4	No
Requirement 5.1	Yes
Requirement 5.2	Partially
Requirement 6	Yes
Requirement 7	Yes

In summary, LAWST fulfills 4/8 of these requirements, partially addresses 3/8 requirements, and does not address one requirement.

If these requirements were the correct requirements to which LAWST was developed, then LAWST failed to meet all the requirements and may not be suitable for its intended purpose. It may be that these are only an initial set of requirements and additional trade-offs were made prior to developing the system. However, without a record of those negotiations and the outcomes, there is no conclusive answer to whether LAWST is valid for the purpose that these requirements stem from.

6. The Extent That LAWST Fulfills Requirements Generated by a Systems Engineering Approach

There are 45 potential requirements developed using a systems engineering approach. Appendix B contains an assessment of how well the current version of LAWST meets the requirements that were developed using a systems engineering approach. In the interest of brevity, this section will examine a sample of the full set of requirements. It presents a summary for how the current version of LAWST fares with the requirements that were developed using a systems engineering approach. The following, selected randomly, are examples of the assessments:

Requirement two states “The system shall allow operators to select the appropriate map and location within 10 seconds.” LAWST requires operators to upload a picture of a map and size it correctly to the grid system in the user interface by matching the corners of the picture to a latitude/longitude point. This process takes a few minutes to accomplish and is far from the 10 seconds described in the requirement.

Requirement eight states “The system shall allow operators to set objective DOS for friendly units.” LAWST has a function that allows operators to adjust the required DOS for units and logistics nodes.

Requirement 16 states, “The system shall allow the creation of arcs/routes for the supply network within 40 seconds.” LAWST allows nodes and arcs to be created and placed on the map. There are two ways to do this, first by manually creating the node or arc. Nodes are can be placed on the map by clicking on the point on the map or entering a latitude or longitude. Arcs are defined between two different nodes. The second way to produce the nodes and arcs is to define them all in a Microsoft Excel spreadsheet and adjust the configuration file to call that spreadsheet. This requirement can be met depending on the situation. If the nodes and arcs are pre-defined and readily available in an Excel file, in the proper format, LAWST can meet this requirement. If the nodes and arcs must be manually entered, this can take on the order of minutes to hours depending on the complexity of the network. In this case, LAWST would not meet the requirement.

Requirement 23 states “The system shall allow operators to evaluate the state of the logistics networks at each branch and sequel of an operation.” LAWST allows one network at a time to be evaluated. Additional branches and sequels would need to be evaluated as separate networks. This could be accomplished by adjusting the nodes, arcs, unit locations, and other relevant portions of the network and re-evaluating. Re-adjusting elements in the network may take several minutes and not be useful within the time constraints of a fast-paced wargame. In the case of a rapid response planning process, the wargame of a single COA may only take about five minutes. While LAWST can evaluate different networks, comparing a network with several branches and sequels is infeasible for the software: LAWST would not meet this requirement.

Requirement 31 states, “The system shall determine the number of excess transportation assets within the logistics network over time.” LAWST can determine the utilization rate of transportation assets at a logistics node. This is a derivative piece of information based on the number of assets being used over a period of time. With relatively little effort, a logistician can determine where in the network there are available transportation assets; therefore, LAWST fulfills this requirement.

Overall, the current version of LAWST meets 24/45 requirements that were developed using a systems engineering approach. The remaining requirements would not be achieved by LAWST without substantial investment of additional time, money, and effort.

C. COMPARE THE REQUIREMENTS SETS

There are several differences between the requirements sets, namely the number and detail of requirements, the traceability of the requirements, and the type of requirements. The larger number of requirements is typically due to a clearer understanding of the functions that the system must perform. Traceability means that the requirement has a reason that supports the analysis in a previous step of the design process. The different types of requirements usually stem from different viewpoints being evaluated as part of a design process.

The original seven LAWST requirements stemmed from the need to analyze a specific event, the EF-21 Energy Study and Operational Reach Wargame. The requirements are focused on answering the questions that the study aimed to answer, which is reasonable, if the tool is meant only to be valid for the specific wargame. On the other hand, if the tool was meant to address EF-21 Energy studies beyond the wargame, additional information should have been considered during development. With a systems engineering approach, the problem is analyzed with a more rigorous stakeholder analysis that uncovers additional uses for the system beyond the short-term problem. The expanded problem set uncovers additional uses and required functions that need to be accounted. Thus, the SE-developed requirements are more thorough in addressing the aspects of the system that the customer desires.

The traceability of the requirements is an important aspect of any system requirement. It ensures that system specifications will produce a capability that can address the problem for which it was designed. The assumed original requirements provided by Group W included a linkage between each of the requirements and a specific question asked in the EF-21 Energy Study and Operational Reach Wargame concept. This indicates that a system developed to this requirement set would be valid for participating in Operational Reach or any other application with the same limited scope. The requirements developed through a systems engineering approach have traceability that is examined through operational planning and wargaming procedures, as well as a wider scope of questions that would specify a system that is useful for a larger range of applications and uses.

The types of requirements that are developed using these two approaches are significantly different. With the original requirements set, the focus of the requirements is mainly on construction of the logistics network, what factors an operator needs to control, and how to analyze the data. These requirements were tailored to support a single seminar wargame that did not require immediate results. The systems engineering approach developed additional types of requirements. Usability requirements, not addressed with the original system requirements, addressed the time constraints that operators had to work in when they are participating in a planning process. The systems engineering approach also uncovered interoperability requirements based on the environment within which the system would be operating. Additionally, the stakeholder analysis produced the need for a system to help operators identify ways to adjust the logistics network to overcome problems that arise during the construction of the network or the wargame.

The systems engineering approach produces requirements that not only address the customers immediate issues but also get to the root of the problem that the customer has. It produces requirements that address a larger range of capabilities that a system needs to have, and by more thoroughly analyzing the problem, produces a more robust system than would otherwise be realized.

An additional insight here is that there are no requirements oriented to operations at a tactical or operational level in the presumed original requirements so therefore, the problem that drove the original requirements is not the one stated in the problem definition (from the SE approach). In other words, the problem that E2O wants LAWST to address is not the problem that it was developed to address.

D. QUANTIFYING DIFFERENCES IN APPROACHES

We use two methods to quantify the approaches: work breakdown structure and value tree. A work break down structure shows the resource requirements for individual parts of a system as they are related to the total development of the system. An objectives tree reflects the interests that a stakeholder has in developing a system.

There are some difficulties for quantifying the differences in the processes that produced the two requirement sets. To begin with, the problem statements that produced the two sets of requirements are potentially different since there is no documented version of the problem statement for the original version of LAWST. The only viable process available to us for this analysis is the systems engineering approach. There is no one-for-one mapping between requirements from the two sets. Additionally, each requirement has a different level of effort associated, with respect to the resources required to realize it in a system. The following analysis recognizes these issues and for the sake of discussion makes the following assumptions:

- There are five types of requirements that can be discerned; usability, model/simulation, analysis, interoperability, and optimization.
- Each requirement, within a set of requirements, needs the same level of effort to incorporate into a system. No weighting is applied to any one type of requirement.
- The requirements lists are complete. That is, the list is agreed upon by both the customer and developer.
- The model/simulation level of effort between the two requirements sets will be the same level of effort in order to compare the sets.
- A work breakdown structure (WBS) will be used to compare the requirements sets

Consider the level of effort for the first set of requirements to be 100 hours of work to realize System A using the eight requirements listed in Section C of this chapter. Half of the work is done on model/simulation requirements and the other half is on analysis requirements so a WBS for this system would look as shown in Figure 13.

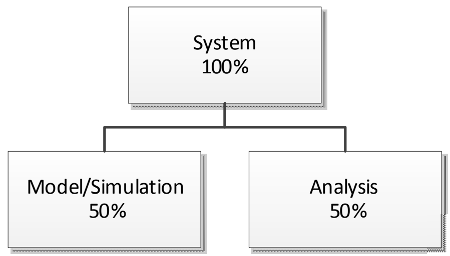


Figure 13. Notional WBS for System A.

Now consider a system, System B, developed against the set of requirements generated using a system engineering process and as seen in Figure 14. Here the 45 requirements are organized into five categories: six requirements are usability requirements, three are interoperability, 18 are related to model/simulation, 16 are analysis, and two are optimization.

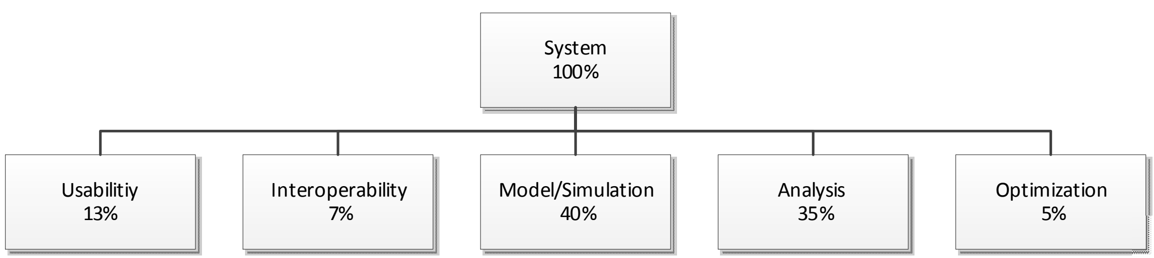


Figure 14. Notional WBS for System B Developed Using a Systems Engineering Approach.

Recall the assumption that the model/simulation level of effort between the two systems would be proportional. Then with System B, keeping the model/simulation effort proportional to that in System A, then takes 125 hours to complete. The general insight is that a system developed using a systems engineering approach will take more time to develop when compared to an undirected requirements development process.

Now, recall the extent to which LAWST meets the requirements developed using a systems engineering approach. If partially met requirements only count as one-half of a met requirement, then LAWST achieved 28.5 requirements of 45 requirements or 63%, leaving 37% of requirements unmet. If LAWST was developed in 100 hours as in System A and only fulfills 63% of the requirements, then the rework required to meet the rest of the 37% of the requirements is about 58 more hours. This brings the total number of hours for System A to meet the requirements for System B to about 158 hours.

The point here is that a system developed against a set of SE requirements may appear to be more expensive to produce. However, if a system is not produced using a systems engineering approach and requires rework to meet that set of requirements, it will be more expensive, in terms of level of effort, in the end.

The numbers presented here provide anecdotal evidence of the increased cost when not using a systems engineering process that reflects a 58% increase in recourse requirements. GAO reports that actual program cost increases due to changing requirements have been anywhere between 23%–114% of initial cost baselines (GAO 2015). The result from this analysis is within the range of the GAO reports.

Another way to look at the different approaches to requirements generation is by looking at an objectives tree for the customer, E2O, and compare it to the requirements sets and determine to what extent the different approaches support E2O's objectives. In the Problem Definition phase of the systems engineering process, the research explored high-level interests of E2O, specifically around the efficient use of resources and influencing the way the Marine Corps employs its energy and resources during operations. When it comes to efficient use of resources, analysis and optimization are key aspects of addressing that objective. Likewise, interoperability and usability are key aspects of getting tools to Marines at the lowest level where they can be easily employed and affect change in the way they think about and use energy and other resources. Another broader category of objectives would be to provide general information and tools to the Marine Corps in managing the complex issues around managing energy and resources. E2O concurred with the following weights in Table 4.

Table 4. Weighting for the Categories of Requirements and Factors Related to E2O Objectives.

Factor	Weight
Analysis	0.25
Optimization	0.15
Interoperability	0.1
Usability	0.2
Model/Simulation	0.3
Total	1

A reasonable objectives tree with weighting for this organization is in Figure 15:

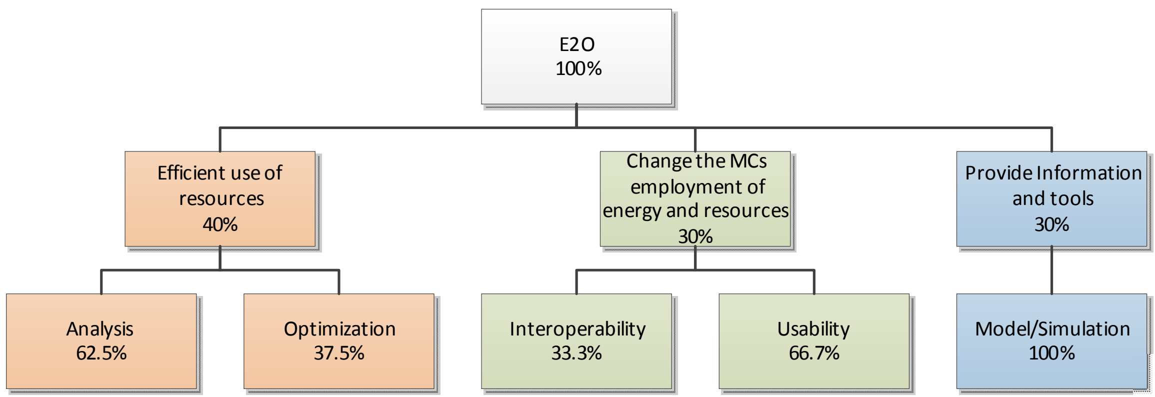


Figure 15. Objectives Tree for E2O.

The factors organized under the organization's objectives add to 100%, for example, the objective "Efficient use of resources" has two factors: Analysis and Optimization. While the weights of the factors are 0.25 and 0.15 respectively, their relative weights, 0.625 and 0.375 add to 1 or make up 100% of the factors for "Efficient use of resources." Now, if the different approaches to requirements generation are compared in this way, the requirements developed using a systems engineering approach address all the objectives of the organization where the assumed original requirements only address 55% of the organizations objectives. The shortfalls of the assumed original requirements being a tool that is interoperable and usable at the lowest levels and the ability to optimize the use of resources.

THIS PAGE INTENTIONALLY LEFT BLANK

V. CONCLUSIONS AND RECOMMENDATIONS

A. SUMMARY OF RESULTS AND INSIGHTS

The methodology described in chapter III outlines a process by which the process that was used to develop systems requirements for LAWST is compared to a systems engineering process for developing system requirements. Since LAWST is a system that has already been developed and used by E2O in evaluating energy distribution, the evaluation of the current requirements and the process by which they were developed is primarily an investigation of current documentation regarding the system.

LAWST is a useful tool for seminar wargames such as the EF-21 Energy Study and Operational Reach Wargame. It was designed to complement MPEM's operational unit energy demand with the demand produced by the logistics network used to deliver those energy resources. The results provide an estimate of risk and give some indication as to where problems in the logistics network may be. Outside the scope of this specific seminar wargame, the system has limited utility since it is not designed with a larger scope.

LAWST is insufficient at the tactical level, battalion and brigade, for planning and evaluating logistics networks. The primary reason for this is its inability to support the timelines required to build COAs, wargame, and evaluate those COAs. In cases such as a rapid response planning process, there are only 4 hours between the receipt of a mission and the distribution of orders. LAWST is designed for overnight analysis of a logistics network and cannot support such planning.

System requirements developed using a systems engineering method start with a problem definition based on E2O comments and documentation. The problem is further refined by including the context of the mission in, which the system will be involved. This additional specification differs from the original process that drove the current version of LAWST in that it includes the system's use at the tactical and operational level. A functional analysis breaks down the functions of the system which leads to system requirements. Those system requirements developed using a systems engineering approach show a distinct difference to the original requirements in that they have additional emphasis on interoperability, usability and optimization type requirements. A brief analysis of LAWST indicates that the system meets 24 of the 45 requirements.

The research shows, using LAWST as an example, which the costs for changing the system after it has been developed are greater than if the system were developed *correctly* in the first place. Additionally, supporting data from GAO indicates program costs increasing over 100% of initial costs because of changes to requirements (GAO 2015). This supports the need for a systems engineering approach to developing systems, especially earlier in the process prior in examining the problem and developing requirements.

B. CONCLUSIONS

There are a number of questions that this research answers:

1. How Were the Design Requirements Established for the Development of LAWST?

There is evidence in Chapter IV, Section A, which was provided by E2O and Group W, which shows a directed modeling effort, in parallel with MPEM that will support a wargame and study. Additionally, Group W provided a presentation that outlines the proposed support for the EF-21 Energy Study and Operational Reach Wargame (Group W, unpublished document). In that presentation, the questions posed in Operational Reach are directly linked to proposed solution requirements that are evaluated in Chapter IV, Section C. It follows that this is how the design requirements were established for the development of LAWST. If this is indeed the case, an assertion can be made that LAWST could be valid as a tool to assist analysts, during a deliberate seminar type wargame, in evaluating the energy consumption of the logistics network, while delivering supplies to maneuver units whose energy demand is modeled through MPEM. This assumes that the model can be verified to be correct within some defined tolerance against empirical data. Outside of that scope, there is little evidence that LAWST would be valid.

2. What Would the System Requirements for LAWST Be if a Systems Engineering Approach Had Been Used?

This research begins by defining the problem. Information from E2O indicates that the organization is interested in improving the way the Marine Corps supports operations from a perspective of energy efficiency. This is partly accomplished by equipping Marines with tools geared towards operating in a more expeditionary manner. It seems that the original requirements did not capture the need to use LAWST in a tactical or operational environment and, therefore, did not accommodate the type of functions and usability features that are necessary at that level.

The systems engineering method for requirements generation stresses starting with the proper question and understanding the environment in which the system will operate. In the case of LAWST, wargaming in the context of planning for a mission in a time constrained environment is significantly different from a wargame conducted as part of a study conducted over several weeks Blanchard and Fabrycky (2011) state that the application of systems engineering can " help promote greater design maturity earlier." (p 64) The systems engineering method for requirements generation produces a larger variety of requirements because of the greater scope of viewpoints that are examined. Adding further support: "Without sufficient systems engineering input to better define requirements and examine trade-offs early on, there is no assurance that acquisition programs going forward have a sound basis to start system development." (GAO 2015, 20) The requirements developed for this research along with a brief explanation of each is found in Appendix B.

3. Does the Current Version of LAWST Address the System Requirements That Would Have Been Developed through a Systems Engineering Approach?

The Logistics Analysis and Wargame Support Tool, if evaluated, would most likely meet a majority of the requirements in Appendix B. There are two primary shortfalls with the current version of LAWST, as it relates to requirements developed using a systems engineering approach: usability and interoperability.

Usability is generally a function of how easy the system is to use. The drivers for usability can come from two places: the mission that the system must participate in and other factors like amount of training. In this case, the amount of training was not taken into account with this specific iteration of the systems engineering method; however, a majority of the usability requirements are produced specifically because of the mission that the system will be used for. If LAWST is to be used to evaluate a logistics network as part of a planning process, the ease of use and the speed at which operators can use the tool is critical.

Interoperability is important because of the environment within which the system operates and the tasks that it must perform. From the mission analysis, LAWST would operate in a tactical environment and need to interact with other systems used for planning operations. It would be required to operate on the same network where other planning tools are being used and need to both share and provide data to those systems. LAWST was designed as a stand-alone system so these aspects have not been addressed.

The requirements that supposedly drove the design of LAWST are not specifically traced to any problem or gap that the system is addressing. Documentation from E2O shows linkage between requirements and questions from Operational Reach; however, there is no other evidence of verbal or written linkage to any problem. Establishing validity of the model is impossible without linking it back to the problem that LAWST was designed to address.

LAWST does not meet E2O system objectives. LAWST is not postured to meet the demands of VV&A because there is little documentation on the process used in designing the system. Furthermore, the E2O requirements development provides an inadequate foundation for valid improvements to LAWST or as a means to assess the degree LAWST meets E2O needs.

C. RECOMMENDATIONS

1. Framework for Future Development

E2O should adopt a method to guide future development, in order to reduce time necessary to deliver capabilities to the field, reduce resources necessary for development, and produce more positive outcomes in early deliverables. We recommend that the systems engineering process guide those future developments. Incorporating such a process increases the likelihood of delivering products that are more immediately useful to the goals of E2O.

A simple process, similar to that used in this research, that E2O can use in generating requirements can be found in Figure 16 and explained in the following narrative:

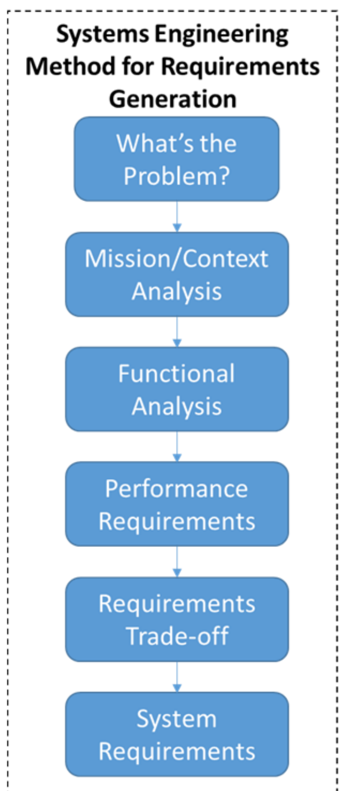


Figure 16. Model for Requirements Generation Using a Systems Engineering Approach.

This model is a simple graphic that describes how to develop system requirements using a systems engineering approach.

- Step 1, Problem Definition: Determine what the problem or gap that the system is addressing. Get to the root of why the system is being developed by talking to relevant stakeholders and examining related topics.

- Step 2, Mission Analysis: Determine where the system will be used, how it will interact with operators, other systems, and its environment. Determine the tasks that the system will be used for, what information is needed to conduct the task, what information the system must provide or action that the system must complete as part of its operation in completing the task. Describe the timing of the task, is it time dependent; near real time, is timing prescribed, or does time not matter. Determine the system operator, level of training, knowledge of the task being conducted, or physical limitations.

- Step 3, Functional Analysis: Determine the functions of the system; what actions the system must complete as part of its operation. Use information from the mission analysis to support the functional analysis to ensure proper traceability.

- Step 4, Performance Requirements: Determine a set of requirements that can be communicated to a developer to design the system. The requirements should be focused on the functions that the system must perform as part of its operation. Capture both functional requirements as related to the functional analysis and non-functional requirements that are related to other aspects as described in the mission analysis.

- Step 5, Requirements Trade-off: Determine the time and resources available to develop the system and make necessary trade-offs to system capability. This may require re-examining the problem definition, mission analysis, and functional analysis to get the right balance of capability for resources available.

2. Future Work

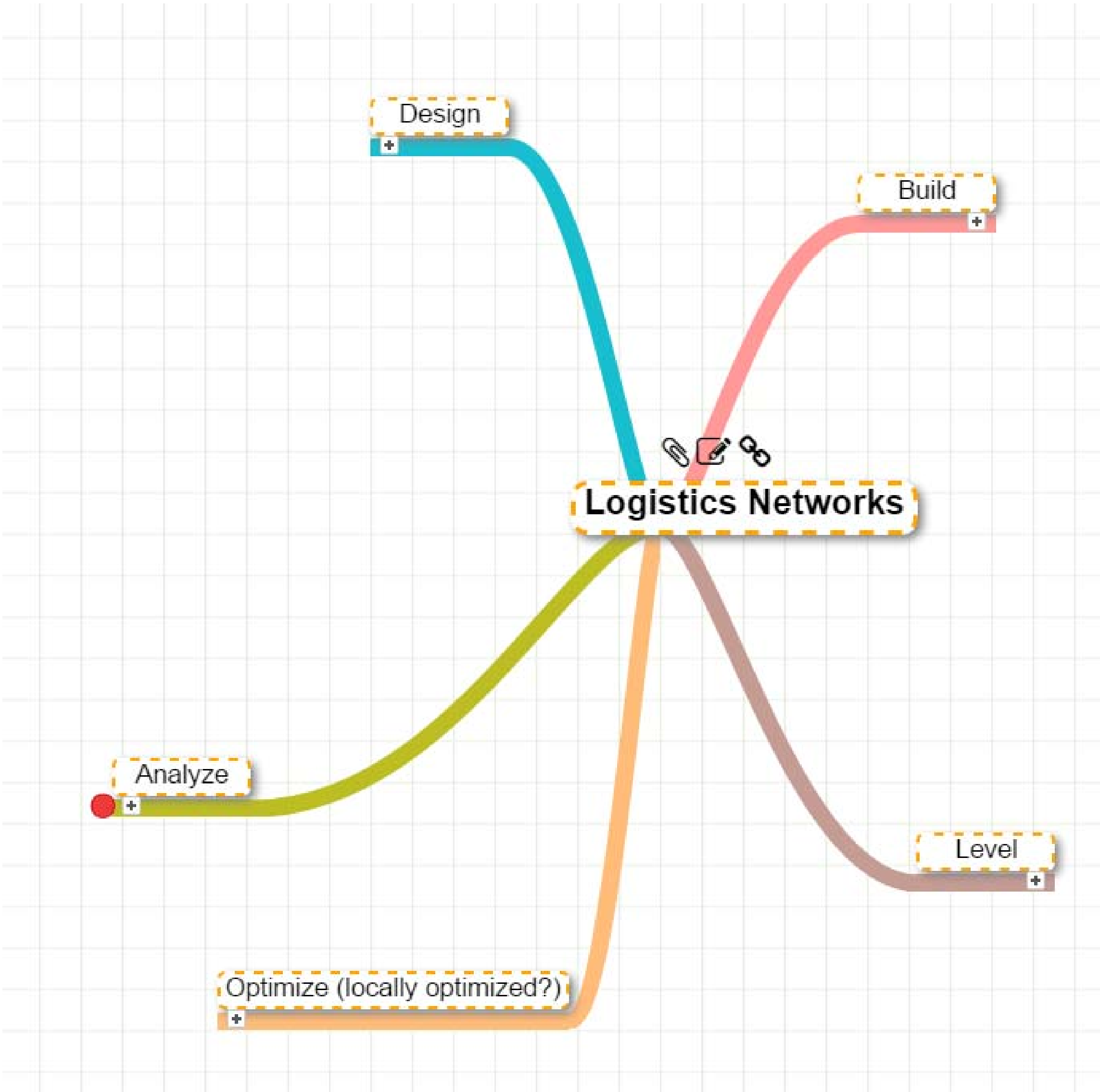
E2O has expressed interest in validating LAWST for use by the Marine Corps. The scope for what uses LAWST could be valid is somewhat limited by how it was designed, as well as the actual tasks that it can perform. If the desire is to use the tool as an aid in planning and analyzing logistics networks at the tactical level, additional considerations such as interoperability and usability should be taken into account for further development. The additional capabilities that LAWST may require should be carefully considered when determining if the system should be significantly changed (i.e., new development) to address the capability or the system should be moderately changed (i.e., new interface or built in tools) to rectify the shortcomings. A deliberate analysis should be conducted to determine the best way to address this, in many cases it may seem easier to adjust existing systems rather than starting from the beginning but this may turn out to have a much larger resource impact than anticipated (Blanchard 2011).

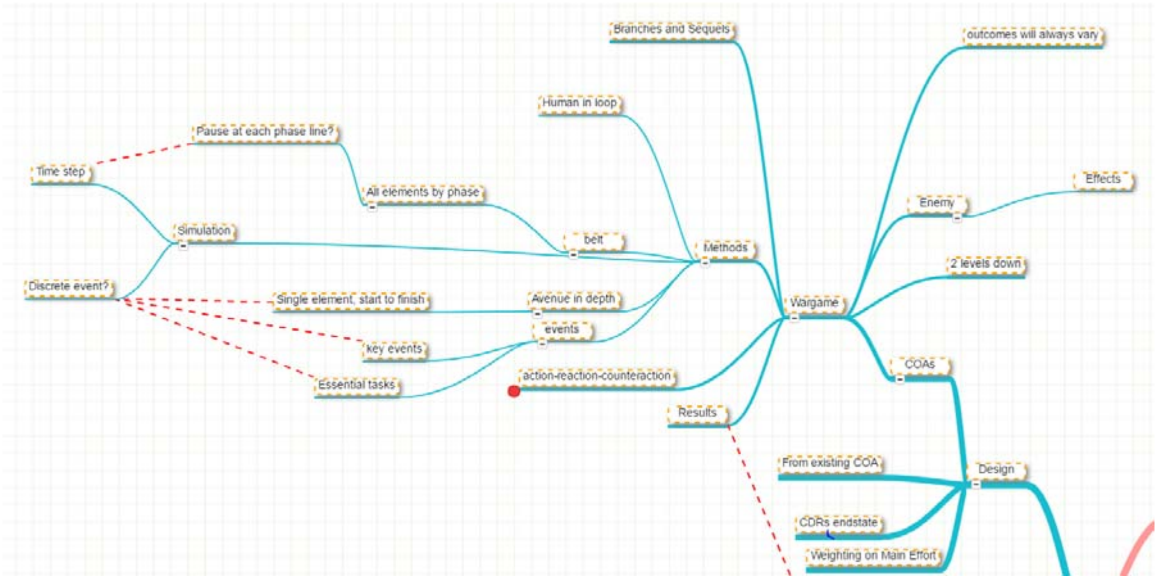
There are also additional areas to explore in relation to LAWST. LAWST relies on energy usage data from MPEM. Perhaps other areas where LAWST makes assumptions to simplify the analysis such as resupply scheduling could also be incorporated. For instance, in an in-process review to E2O in April 2017, one project introduced the concept of "Scheduling Ship to Shore Fuel Deliveries"; this area is one that LAWST assumes certain information which may or may not be there. LAWST assumes that, at a logistics node, there is a pool of available vehicles with an available amount of time and capacity. As long as the availability is met, LAWST does not explicitly define which assets deliver which supplies. E2O should use this type of tool to evaluate the assumptions made in the development of LAWST.

THIS PAGE INTENTIONALLY LEFT BLANK

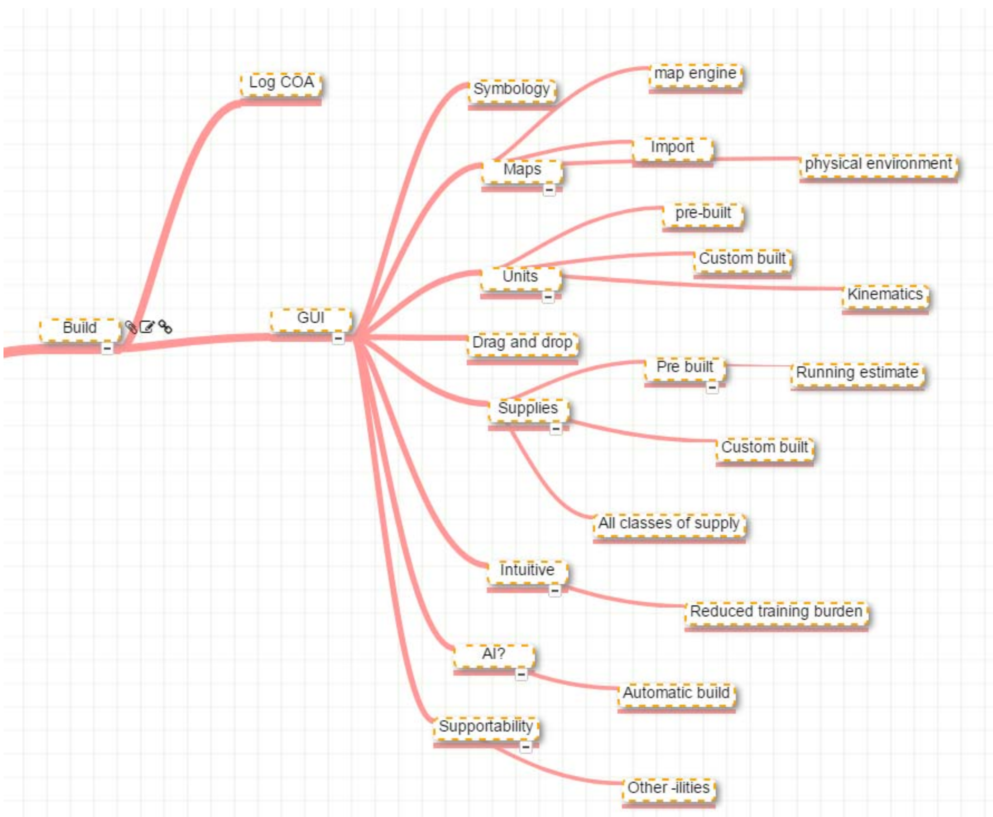
APPENDIX A. SYSTEM ENGINEERING ARTIFACTS

A. MIND-MAP FOR TOPICS RELATED TO LOGISTICS NETWORKS

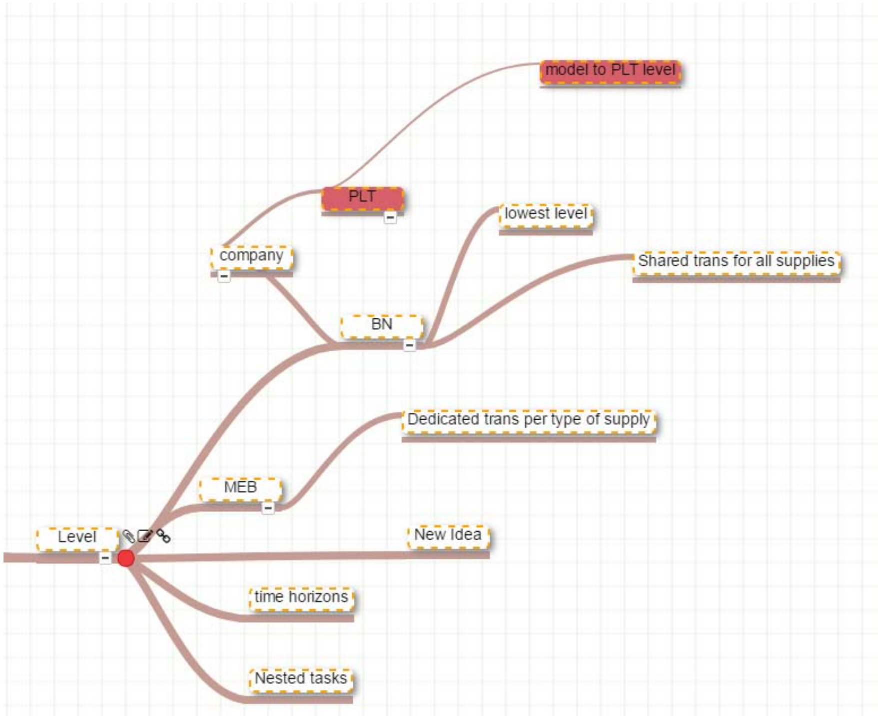


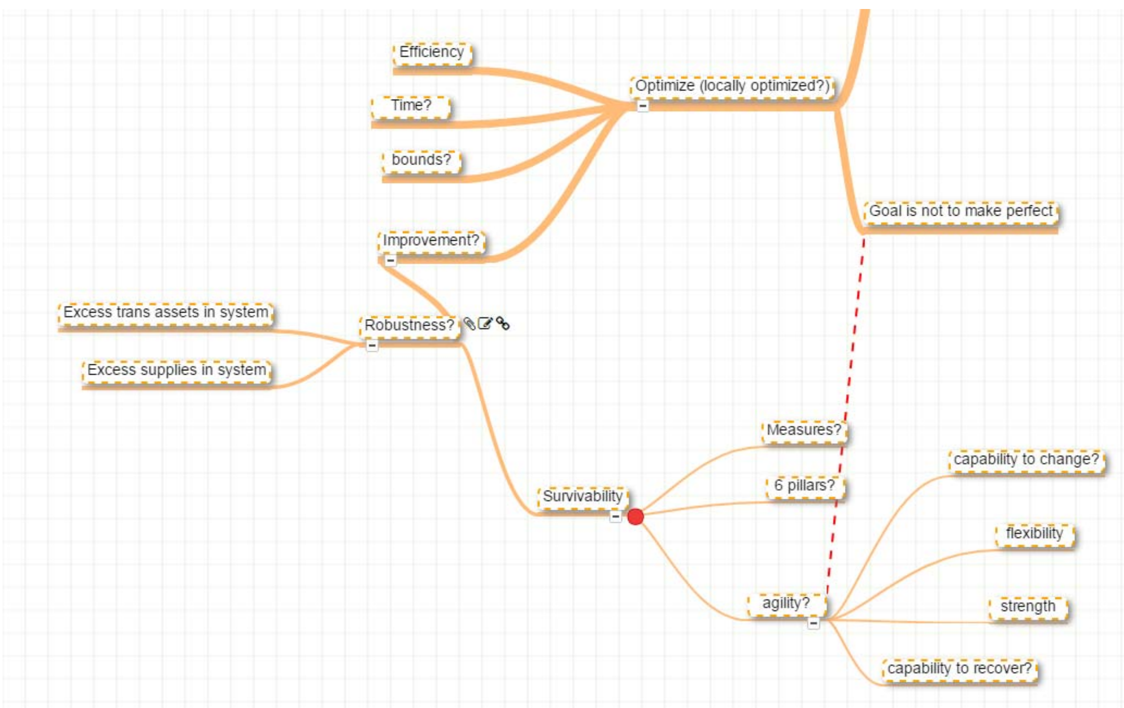


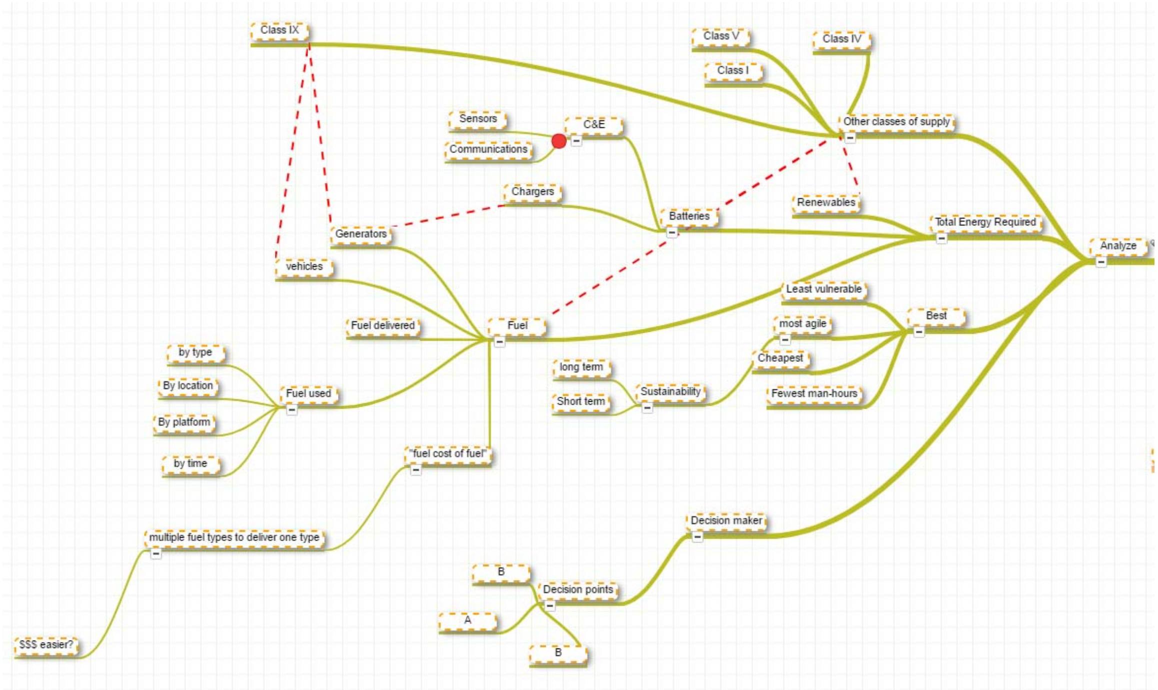
Branches and Sequels
outcomes will always vary
Human in loop
Pause at each phase line?
Time step
All elements by phase
Effects
Enemy
Simulation
belt
Methods
2 levels down
Discrete event?
Single element, start to finish
Avenue in depth
Wargame
events
key events
COAs
action-reaction-counteraction
Essential tasks
Results
From existing COA
Design
CDRs endstate
Weighting on Main Effort



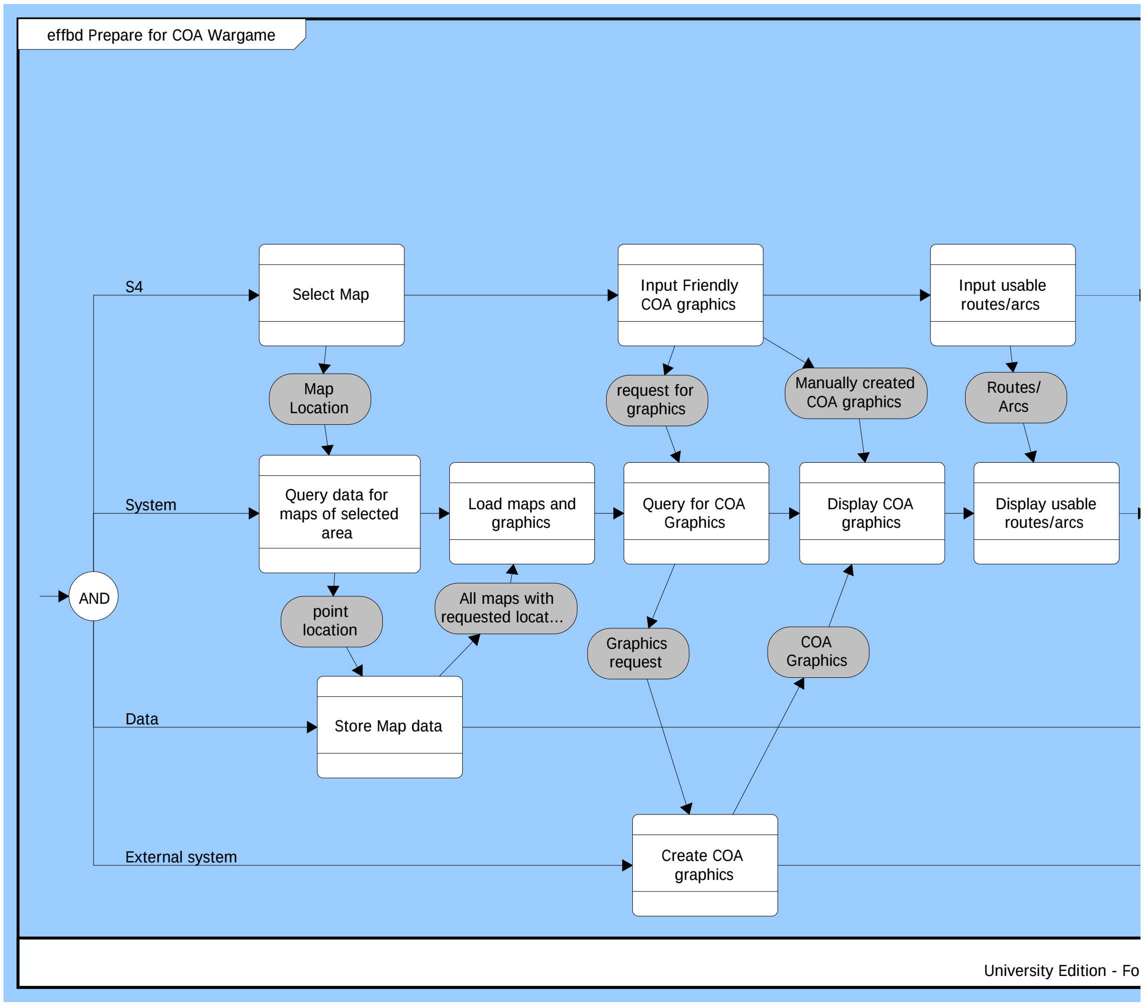
Log COA
Symbology
map engine
Import
physical environment
Maps
pre-built
Custom built
Units
Kinematics
Build
GUI
Drag and drop
Pre built
Running estimate
Supplies
Custom built
All classes of supply
Intuitive
Reduced training burden
AI?
Automatic build
Supportability
Other -ilities


model to PLT level
PLT
lowest level
company
Shared trans for all supplies
BN
Dedicated trans per type of supply
MEB
Level
New Idea
time horizons
Nested tasks

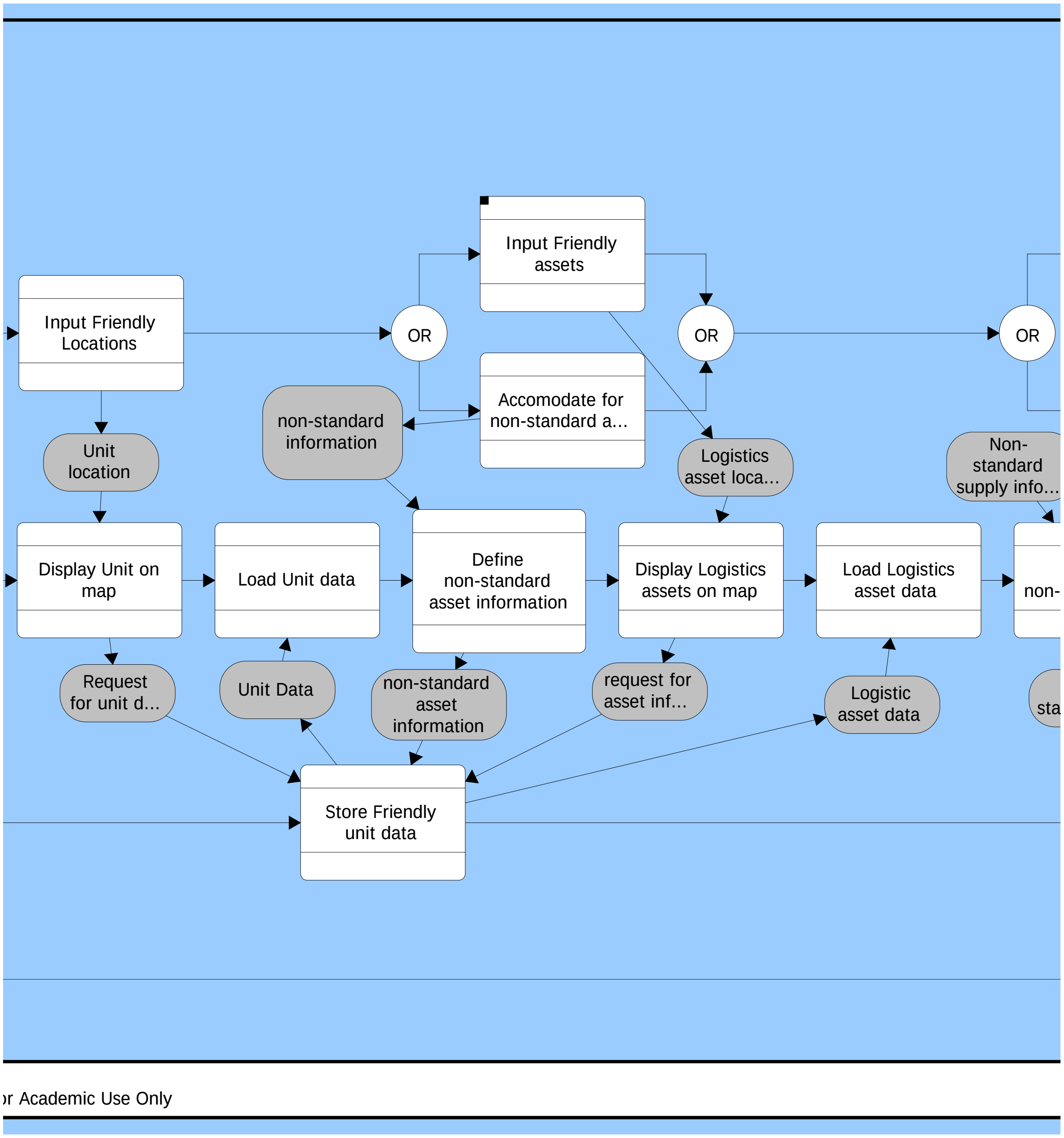

Efficiency
Optimize (locally optimized?)
Time?
bounds?
Goal is not to make perfect
Improvement?
Excess trans assets in system
Robustness?
Excess supplies in system
Measures?
capability to change?
6 pillars?
Survivability
flexibility
agility?
strength
capability to recover?


Class IX
Class V
Class IV
Class I
Sensors
C&E
Communications
Other classes of supply
Chargers
Batteries
Renewables
Total Energy Required
Generators
vehicles
Analyze
Least vulnerable
Fuel delivered
Fuel
most agile
Best
by type
Cheapest
long term
By location
Fuel used
Sustainability
Fewest man-hours
Short term
By platform
by time
"fuel cost of fuel"
Decision maker
multiple fuel types to deliver one type
B
Decision points
A
B
$$$ easier?

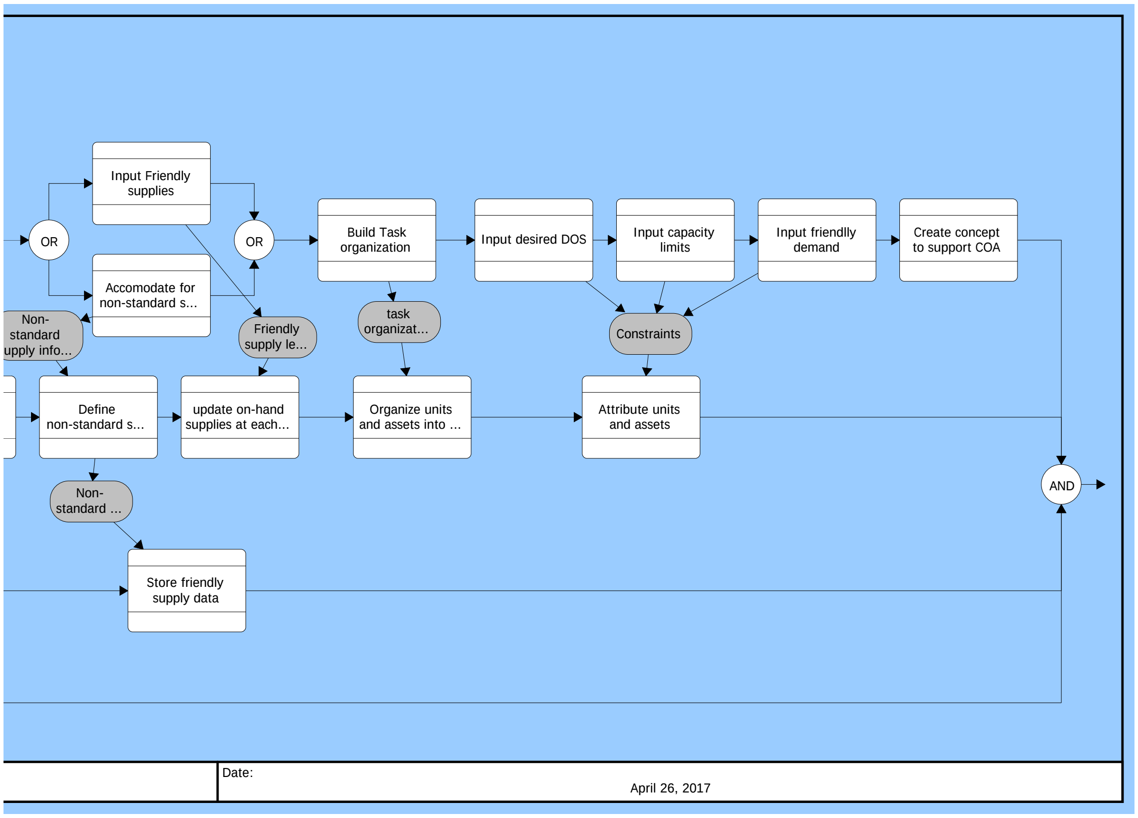
B. ENLARGED VIEW OF FIGURE 11



1/3 Prepare for COA Wargame

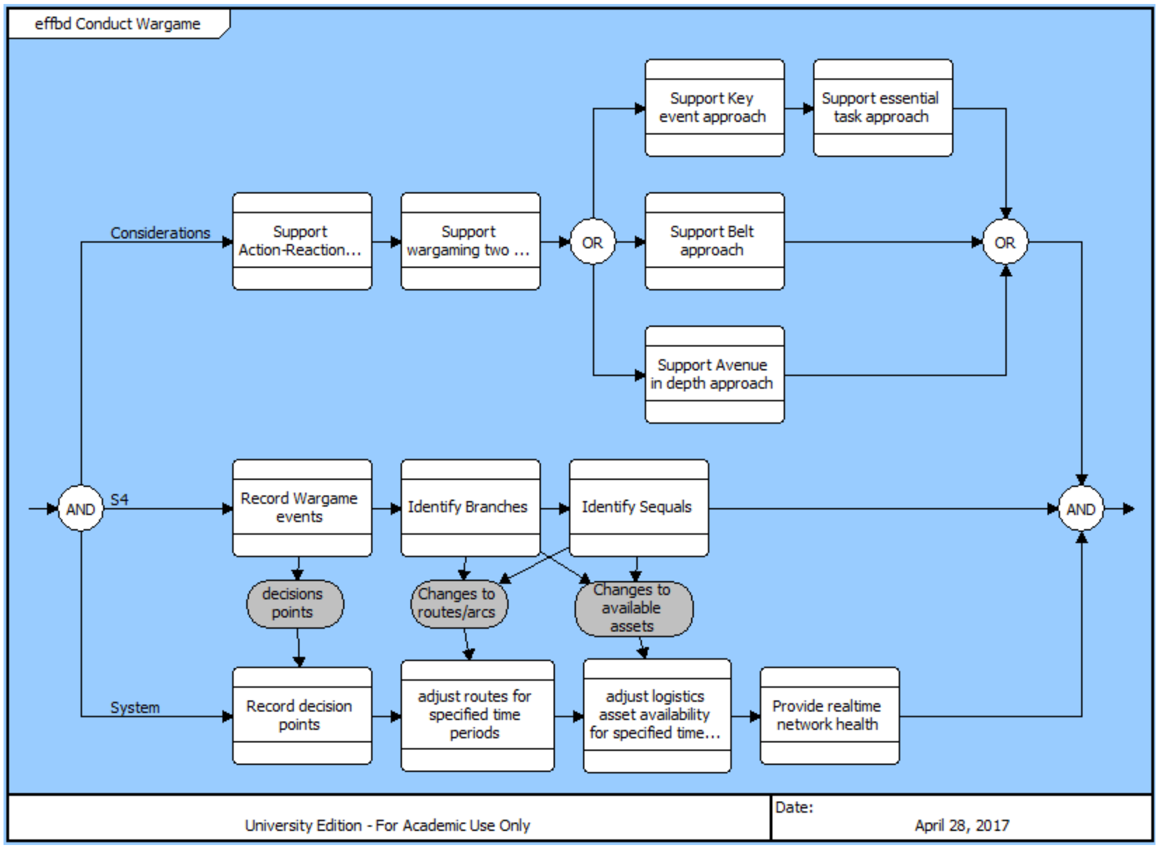


2/3 Prepare for COA Wargame

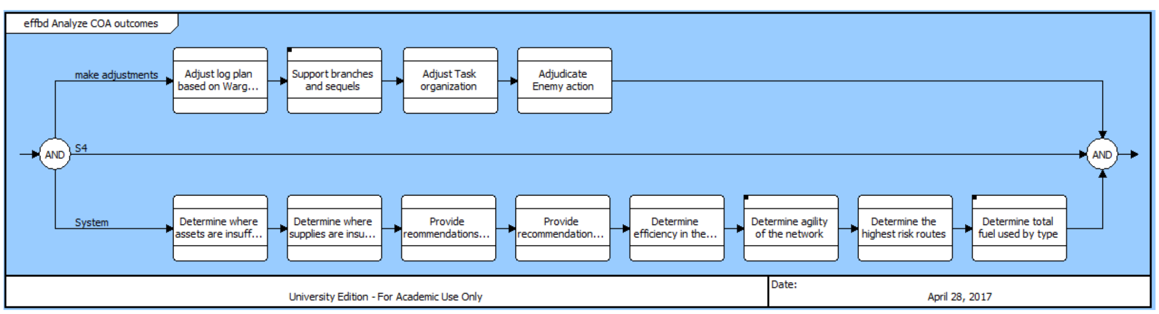


3/3 Prepare for COA Wargame

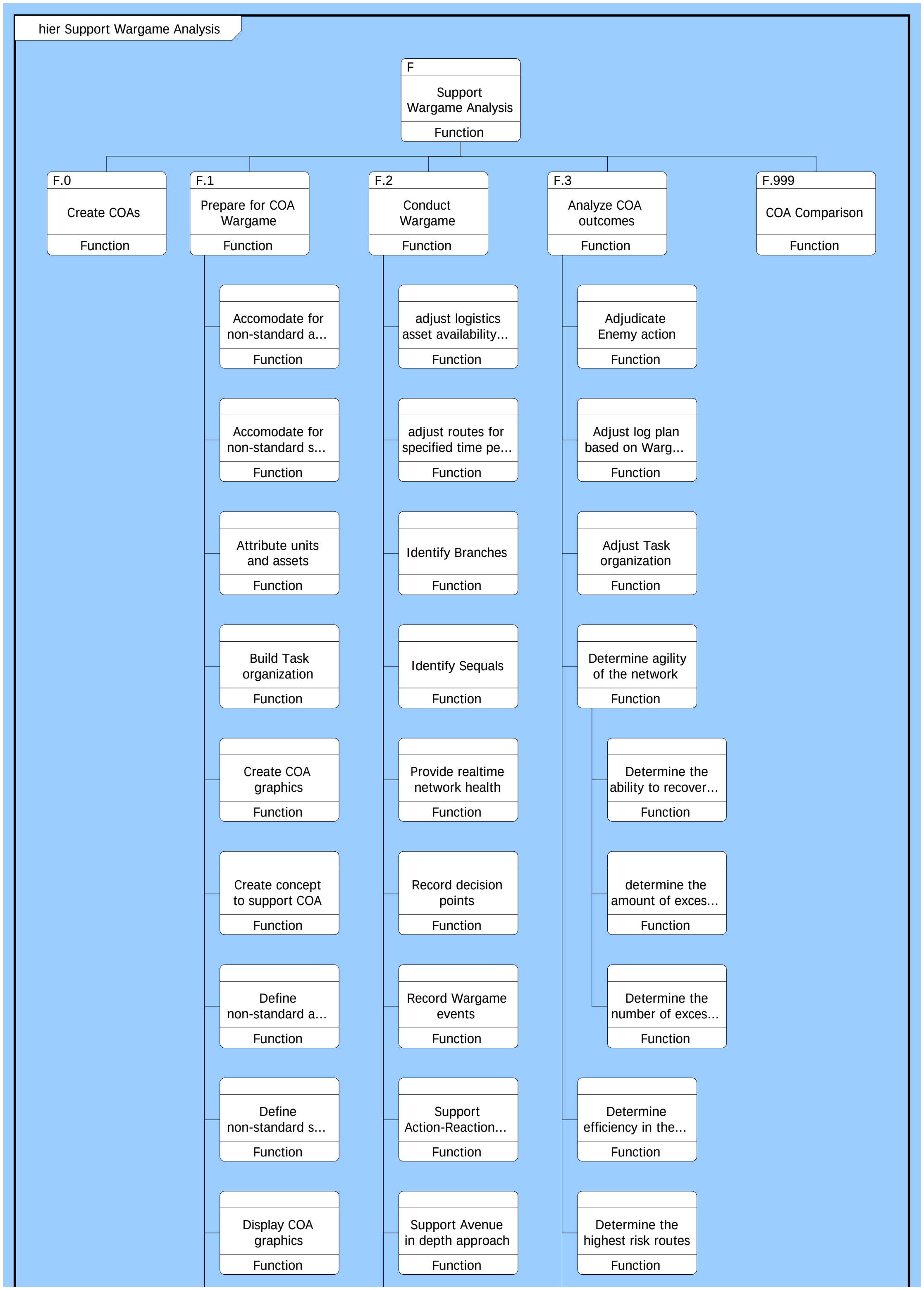
C. WARGAME FFBD



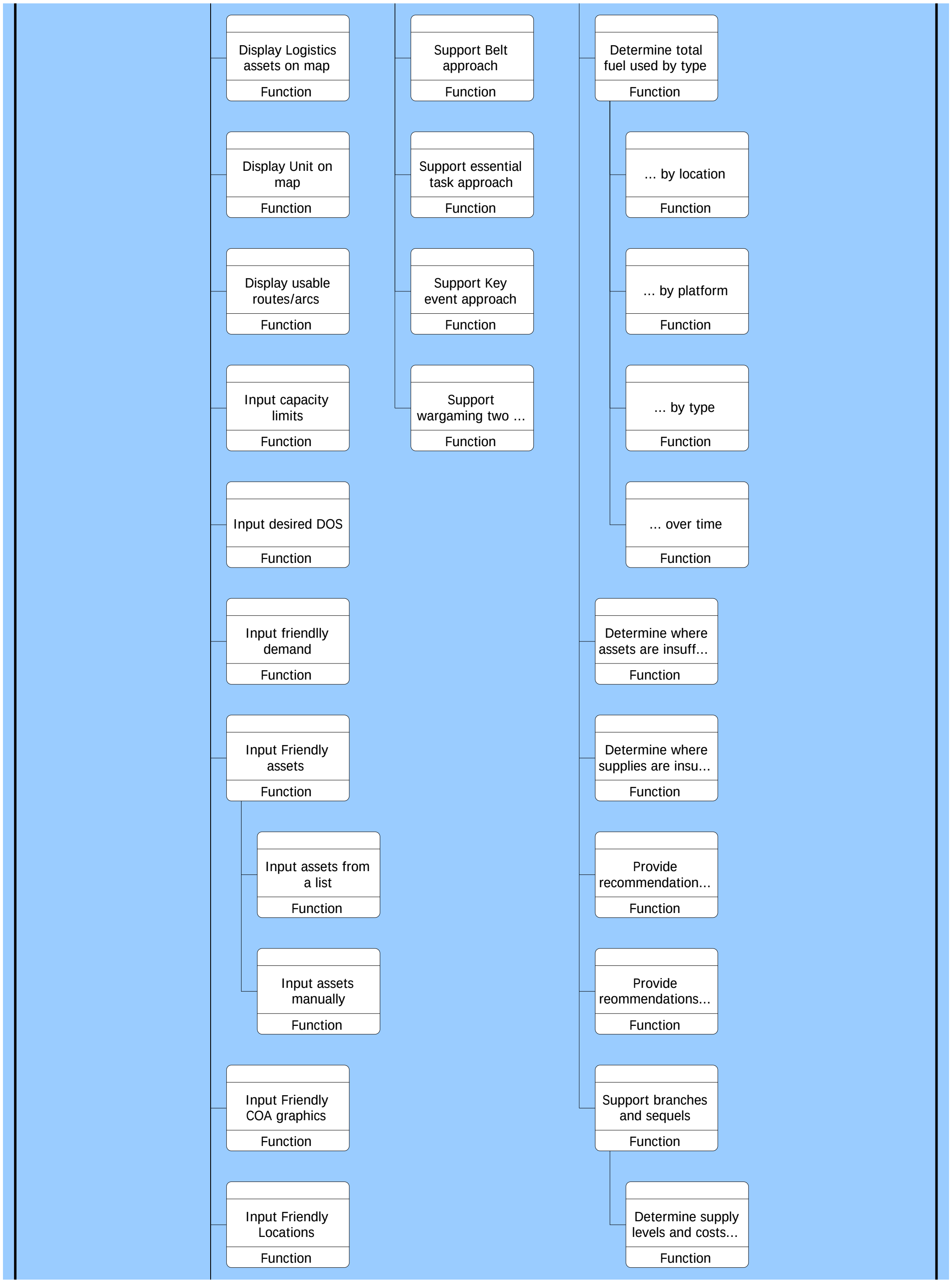
D. ANALYZE COA FFBD



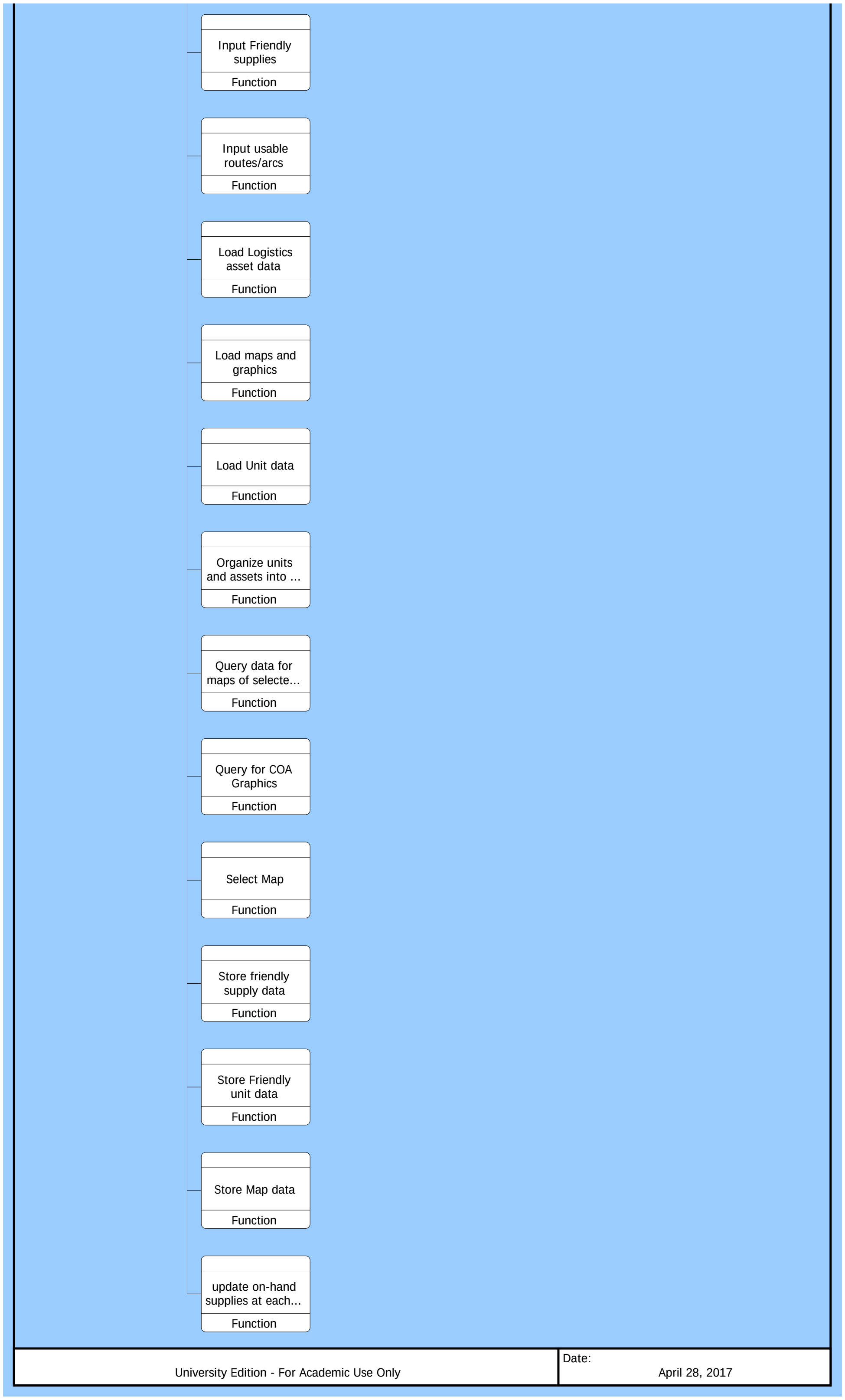
E. FUNCTIONAL HIERARCHY



1/3 Functional Hierarchy



2/3 Functional Hierarchy



3/3 Functional Hierarchy

THIS PAGE INTENTIONALLY LEFT BLANK

APPENDIX B. REQUIREMENTS FROM A SYSTEMS ENGINEERING PROCESS

1. The system shall use a mapping engine that accepts CADRG (MIL-C-89038), CIB (MIL-STD-2411) and DTED map data.

This requirement is linked to the requirements analysis and is related to a planning scenario where the logistics tool may be located on a secure network with limited access to commercial maps. Standard mapping engines will accommodate readily available military maps and DTED.

LAWST does not meet this requirement.

2. The system shall allow operators to select the map, and display it at a scale necessary for planning, and location within 10 seconds.

This requirement is based on the time constraints related to creating the support concepts for three COAs in a 20-minute timeframe.

LAWST does not meet this requirement.

3. The system shall allow operators to define non-standard friendly assets.

Requirement based on mission analysis and potential task that an S4 must execute.

LAWST meets this requirement.

4. The system shall allow operators to define non-standard supply types.

Requirement based on mission analysis and potential task that an S4 must execute.

LAWST meets this requirement.

5. The system shall allow operators to create a task organization based on available friendly units and assets within 40 seconds.

This requirement is based on the time constraints related to creating the support concepts for three COAs in a 20-minute timeframe.

LAWST does not meet this requirement.

6. The system shall allow operators to create a scheme of maneuver for the logistics network.

Requirement based on mission analysis and potential task that an S4 must execute.

LAWST meets this requirement.

7. The system shall allow operators to set the maximum capacity for each friendly asset and unit.

Requirement based on mission analysis and potential task that an S4 must execute.

LAWST meets this requirement.

8. The system shall allow operators to set objective DOS (Days of Supply) for friendly units.

Requirement based on mission analysis for S4 to vary the DOS based on mission requirements and COA.

LAWST meets this requirement.

9. The system shall allow operators to input supply consumption, based on OPTEMPO, for each type of friendly asset.

This requirement is based on the mission analysis and the requirement to surge or maintain supply levels

LAWST meets this requirement.

10. The system shall allow the input or import of friendly unit information.

This is a requirement from the Mission analysis, during the planning process, the S4 needs to determine available forces to support a COA.

LAWST meets this requirement.

11. The system shall allow operators in upload friendly asset information from an external file.

Information should be available for operators to upload. Creating data bases for every unit is time intensive and infeasible during a planning process.

LAWST meets this requirement.

12. The system shall allow operators to input Friendly asset information manually.

This requirement is related to requirement 11.

LAWST meets this requirement.

13. The system shall provide a mechanism to input friendly maneuver graphics within 40 seconds.

Logisticians need a basic framework of a COA to build the network that supports his or her units.

LAWST does not meet this requirement.

14. The system shall provide a mechanism to input or import friendly unit's locations within 40 seconds.

Friendly unit locations during each phase of the operation are required by the logistician in order to determine the delivery of supplies to that unit. When the operations planners develop the COAs, the unit's locations are included.

LAWST partially meets this requirement. LAWST can input locations but will not meet time constraints. Even in a spreadsheet, a logistician needs to determine unit names, locations, and unit type during COA development.

15. The system shall provide a mechanism to input supply levels at every node in the network within 40 seconds.

Known quantity of supplies is necessary to prioritize logistics activities and understand urgency and risk in the logistics network.

LAWST partially meets this requirement. LAWST allows operators to specify supply levels at every node, however time constraints will not be met, similar to requirement 14.

16. The system shall allow the creation of arcs/routes for the supply network within 40 seconds.

Logisticians must define the routes that will be used during an operation but have limited time to build the structure of the supply network during the COA development.

LAWST partially meets this requirement. While the arcs and routes can be created quickly with pre-defined points, it is infeasible to create them all within 40 seconds.

17. The system shall be compliant with all DoN regulations for authority to operate (ATO) on NMCI networks.

This is a regulatory requirement that has little to do with the actual operation of a system. However, a system that cannot achieve an ATO is generally not used because of the difficulty associated with standalone machines.

LAWST can achieve this requirement by working through the ATO process.

During Wargame:
Assume 5 minutes per COA, 2 branches or sequels per COA

18. The system shall allow operators to input branches and sequels identified at each decision point during the wargame.

This is required during a wargame as per the MCPP.

LAWST does not meet this requirement. It requires a separate file per COA.

19. The system shall allow operators to record wargame events in order to modify logistics network.

Often, COAs are changed during a wargame to accommodate for reactions and counteractions that are identified during the wargame. These reactions and counteractions are generally global and require changes across all platforms

LAWST meets this requirement.

20. The system shall allow operators to see immediate results (less than 10 seconds) of modifying the logistics network based on enemy action.

The facilitator of a wargame may ask questions of functional area representatives such as logisticians that require a near immediate response in order to synchronize all functions and to understand the repercussions of any action or counteraction.

LAWST meets this requirement.

21. The system shall allow operators to evaluate the state of the logistics network for a specific unit over time.

During a wargame where the facilitator prescribes an avenue-in-depth method, a logistician needs to be able to follow a unit or number of units to from start to finish during an operation.

LAWST meets this requirement.

22. The system shall allow operators to evaluate the state of the logistics network at each phase of an operation.

Like avenue-in-depth, if a facilitator chooses to look at COAs by phase, a tool must be able to accommodate this method.

LAWST meets this requirement.

23. The system shall allow operators to evaluate the state of the logistics networks at each branch and sequel of an operation.

Every decision point identified by the facilitator of a wargame usually has a branch or sequel associated with it. A system supporting the logistician must be able to evaluate any branch, sequel or combination.

LAWST does not meet this requirement. As described in Chapter IV.

24. The system shall allow operators to evaluate the state of the logistics networks at specified times during an operation.

Another method for wargaming is key event method; this is where the facilitator looks at specific times and places in a COA during a wargame.

LAWST meets this requirement.

25. The system shall model units down to the platoon level (T), or the individual platform or Marine (O).

Wargaming at any given echelon usually explores units two levels down; for example, at battalion level, wargames examine platoon level tasks.

LAWST meets this requirement.

26. The system shall allow routes to be adjusted for certain time periods to support branches and sequels in 20 seconds or less.

The time constraints for answers during a wargame are generally tight. A logistician needs to be able to answer questions quickly so the wargame can progress.

LAWST meets this requirement.

27. The system shall allow logistics assets availability to be adjusted for certain time periods to support branches and sequels in 20 seconds or less.

In addition to the structure of the logistics network changing during the wargame, the location of assets that are used for transportation may need to be readjusted to support certain branches or sequels. Due to time constraints associated with the wargame, outcomes need to be realized quickly.

LAWST partially meets this requirement. Moving assets involves going into each logistics node and adjusting the number of assets in each. This could take a few seconds to several minutes depending on the number of adjustments that need to be made.

Analysis:
The system shall provide the following analysis within 10 seconds when any changes are made to the Logistics network:

Determine agility of the logistics network:

28. -The system shall determine the amount of time it takes for the network to recover to the objective DOS on-hand after the loss of transportation assets or closure of an arc.

Recovery of the logistics network after a major change is a good indicator of how robust the network is and how agile the response to issues in the network is.

LAWST does not meet this requirement. This can be done with LAWST, scripted sorties allow unscheduled assets to deliver supplies but there is no function to remove assets or routes at a given time during the simulation.

29. -The system shall determine the DOS at each friendly unit in excess of the objective over time.

Delivery of supplies is generally not exact, with respect to the amount. Sometimes units request additional supplies for certain times and places; other times like during movement, they only want the basic 3 DOS on hand. It is important to determine where the supply network can flex when supplies or transportation assets may be lacking.

LAWST does not meet this requirement. The algorithm in LAWST only fills units to the objective DOS as specified by the operator. Excess supplies are not delivered.

30. -The system shall determine the utilization rate of transportation assets within the logistics networks.

Flexibility requires that options can be determined. High utilization rates are important to identify, this signifies that there is little availability to surge additional supplies in a given area.

LAWST meets this requirement.

31. -The system shall determine the number of excess transportation assets within the logistics network over time.

This requirement is similar to 30.

LAWST meets this requirement. This requirement may be merged or rectified with requirement 30 after some trade-offs are made.

Determine efficiency of the logistics network:

32. The system shall determine the efficiency of the network with respect to number of transportation assets used.

Logisticians may want to use fewer assets if possible, to reduce costs.

LAWST does not meet this requirement.

33. The system shall determine the efficiency of the network with respect to fuel used to distribute supplies.

Logisticians may want to determine the most efficient network with respect to fuel used during operations. This is also a key question that E2O is interested in.

LAWST meets this requirement.

34. The system shall determine the efficiency of the logistics network with respect to an estimated cost of fuel used to deliver supplies.

It is important to look at the estimated cost of an operation with respect to the amount of fuel used. This is an important metric to determine savings for one COA vs. another.

LAWST does not meet this requirement.

Determine fuel used by each type: priority information for E2O

35. -The system shall determine the fuel used by each distribution node in the network.

36. -The system shall determine the fuel used by each platform, both maneuver and logistics platforms.

37. -The system shall determine the fuel used by each type of platform.

38. -The system shall determine the overall fuel used over time.

39. The system shall estimate the cost, in terms of estimated dollars and fuel costs to execute each COA.

For requirements 35–39, it is important to determine where the greatest impact is with respect to fuel usage.

LAWST partially meets (5) these requirements. Formatted reports are not built into LAWST, however the data is available after the simulation is complete.

Identify Issues:

40. The system shall determine where assets are insufficient to provide the objective DOS within the logistics network.

It is important to pinpoint where the logistics network is weakest.

LAWST meets this requirement.

41. The system shall determine where supplies are below the objective DOS within the logistics network.

Logisticians need to determine where and when to surge supplies to keep up with demand.

LAWST meets this requirement.

42. The system shall determine where supplies are insufficient to meet demand within the logistics network.

Similar to requirement 41, maybe combine during requirements trade-off.

LAWST meets this requirement.

43. The system shall assess and identify areas of critical vulnerability, what is most susceptible to interdiction.

It is important to examine high utilization arcs and nodes to determine which portions of the logistics network is most critical to the success of a mission. This allows a better understanding where additional redundancy or force protection is required.

LAWST does not meet this requirement. While a deeper analysis can be conducted using the data that LAWST produces. The risk scores help to determine where utilization, throughput, etc., is high but it does not show, for instance, where a high capacity arc with relatively little throughput could be lost and have severe impact to the logistics network.

Optimize:

44. The system shall provide recommendations, based on excess logistics assets and available supplies, how to improve the network efficiency.

With the complexity of any logistics networks, a logistician needs help identifying options to best improve a logistics network. With the number of factors and levels associated with these networks, there are thousands of options to improve the network.

LAWST does not meet this requirement.

45. The system shall provide recommendations, based on excess logistics assets and available supplies, how to improve the network effectiveness with respect to delivering objective DOS.

Similar to requirement 44, it is important to determine how the network should be optimized. Logisticians should be able to determine which factors are the most important to their commander when analyzing a COA. This requirement may be combined with requirement 44 in requirements trade-off.

LAWST does not meet this requirement.

THIS PAGE INTENTIONALLY LEFT BLANK

LIST OF REFERENCES

Blanchard, Benjamin, and Wolter Fabrycky. 2011. *Systems Engineering and Analysis*. 5th ed. Upper Saddle River, NJ. Pearson Education.

Buede, Dennis M. 2009. *The Engineering Design of Systems: Models and Methods.* 2nd ed. Hoboken, NJ. John Wiley & Sons.

Chief Information Officer. 2010. *Information Assurance Policy Update for Platform Information Technology*. (DON CIO Memo 02–10). Washington, DC. Department of the Navy. April 26.

Commandant of the Marine Corps. 2014. *Marine Corps Modeling and Simulation (M&S) Management.* (MCO 5200.28A). Washington, DC. Headquarters United States Marine Corps. July 15.

Cross, Nigel. 2011. *Design Thinking: Understanding How Designers Think and Work.* New York: Oxford University Press.

Defense Acquisition University. 2017. "Systems Engineering Process." Last modified March 1. https://dap.dau.mil/acquipedia/Pages/ArticleDetails.aspx?aid=9c591ad6-8f69-49dd-a61d-4096e7b3086c

Expeditionary Energy Office. 2017. "Mission & Vision" Accessed June 12, 2017. http://www.hqmc.marines.mil/e2o/Mission-Vision/

Government Accountability Office. 2015. *Defense Acquisition Process; Military Service Chiefs' Concerns Reflect Need to Better Define Requirements before Programs Start*. GAO-15-469. Washington, DC: U.S. Government Accountability Office. June.

Group W Energy M&S Team. 2015. "LAWST Energy Supply Sim Demo-Low." YouTube video. 5:49. Published March 31, 2015. https://www.youtube.com/watch?v=Wii8yn1vUpI

Hall, Steven. 2016. "Independent Verification and Validation Assessment of LAWST." Report for E2O, Monterey, CA: Naval Postgraduate School. September 21.

Liedtka, Jeanne and Tim Ogilvie. 2011. *Design for Growth: A Design Thinking Took Kit For Managers*. West Sussex, NY: Columbia University Press.

Modeling and Simulations Coordination Office. 2012. *Department of Defense Standard Practice; Documentation of Verification, validation, and Accreditation (VV&A) for Models and Simulations*. MIL-STD-3022. Alexandria, VA. Director, Modeling and Simulations Coordination Office. April 5.

Secretary of the Navy. 2002. *Department of the Navy Modeling and Simulation Management*. SECNAVINST 5200.38A. Washington, DC. February 28.

Sidky, Ahmed S., Rajat R. Sud, S. Bhatia, James D. Arthur. 2002. "Problem Identification and Decomposition within the Requirements Generation Process." Technical report, Virginia Polytechnic Institute and State University. https://vtechworks.lib.vt.edu/handle/10919/20104.

Space & Missile Systems Center, and United States Air Force. 2005. *SMC Systems Engineering Primer & Handbook*, 3rd Edition., El Segundo, CA: SMC.April 29.

Sud, Rajat. 2003. "A Synergistic Approach to Software Requirements Generation: The Synergistic Requirements Generation Model (SRGM), and An Interactive Tool for Modeling SRGM (itSRGM)." Master's thesis, Virginia Polytechnic Institute and State University.

Under Secretary of Defense (AT&L). 2007. *DOD Modeling and Simulation (M&S) Management*. DOD Directive 5000.59. Washington, DC: Under Secretary of Defense (AL&T), August 8.

———. 2009. *DOD Modeling and Simulation (M&S) Verification, Validation, and Accreditation (VV&A).* DOD Instruction 5000.61. Washington, DC: Under Secretary of Defense (AL&T), December 9.

———. 2014. *Management of DOD Modeling and Simulation (M&S) Activities*. DOD Directive 5000.70. Washington, DC: Under Secretary of Defense (AT&L), March 19.

United States Marine Corps. 2010. *Marine Corps Planning Process.* (MCWP 5–1). Washington, DC. Headquarters United States Marine Corps. August 24.

Wiegers, Karl. 1999. "Writing Quality Requirements." *Software Development* 24(5): 44–48.

INITIAL DISTRIBUTION LIST

1. Defense Technical Information Center
   Ft. Belvoir, Virginia

2. Dudley Knox Library
   Naval Postgraduate School
   Monterey, California