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Development of system architecture to investigate the impact of integrated air and missile defense in a distributed lethality environment

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THESIS

DEVELOPMENT OF SYSTEM ARCHITECTURE TO INVESTIGATE THE IMPACT OF INTEGRATED AIR AND MISSILE DEFENSE IN A DISTRIBUTED LETHALITY ENVIRONMENT

by

Justin K. Davis

December 2017

Thesis Advisor:	Paul Beery
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The proliferation of enemy threat capabilities necessitates increased innovation and a shift in tactical paradigm. The latest strategy pursued by the U.S. Navy is the concept of distributed lethality (DL), an offensive concept that utilizes small groups of ships incorporating deception techniques and distributed weapon systems in order to gain a tactical advantage. This thesis applies a standardized systems engineering approach to investigate the impact of conducting existing integrated air and missile defense (IAMD) operations in the context of this DL concept. An analysis is conducted through the development of an integrated systems architecture and the evaluation of the defined architecture using discrete event simulation. The analysis identifies key performance drivers and operational decisions that balance conflicting requirements for IAMD and DL. The results indicate an average of 11 percent increase in the number of enemy forces killed when conducting a combined mission. This improved lethality required increased vulnerability, resulting in an average increase of half of a hit on defended assets. While the core concepts of DL and IAMD are vastly different, a combined architecture will result in efficient execution of both missions and increased effectiveness of naval forces.

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DEVELOPMENT OF SYSTEM ARCHITECTURE TO INVESTIGATE THE IMPACT OF INTEGRATED AIR AND MISSILE DEFENSE IN A DISTRIBUTED LETHALITY ENVIRONMENT

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ABSTRACT

The proliferation of enemy threat capabilities necessitates increased innovation and a shift in tactical paradigm. The latest strategy pursued by the U.S. Navy is the concept of distributed lethality (DL), an offensive concept that utilizes small groups of ships incorporating deception techniques and distributed weapon systems in order to gain a tactical advantage. This thesis applies a standardized systems engineering approach to investigate the impact of conducting existing integrated air and missile defense (IAMD) operations in the context of this DL concept. An analysis is conducted through the development of an integrated systems architecture and the evaluation of the defined architecture using discrete event simulation. The analysis identifies key performance drivers and operational decisions that balance conflicting requirements for IAMD and DL. The results indicate an average of 11 percent increase in the number of enemy forces killed when conducting a combined mission. This improved lethality required increased vulnerability, resulting in an average increase of half of a hit on defended assets. While the core concepts of DL and IAMD are vastly different, a combined architecture will result in efficient execution of both missions and increased effectiveness of naval forces.

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LIST OF ACRONYMS AND ABBREVIATIONS

ABMD	AEGIS ballistic missile defense
AFP	adaptive force package
AO	area of operations
ASBM	anti-ship ballistic missile
AW	air warfare
AWS	AEGIS weapon system
BA	battlespace awareness
BMD	ballistic missile defense
CEC	cooperative engagement capability
CG	guided missile cruiser
CNO	Chief of Naval Operations
CJCS	Chairman of the Joint Chiefs of Staff
CNSF	Commander Naval Surface Forces
CV	capability viewpoint
DOD	Department of Defense
DOE	design of experiments
DON	Department of the Navy
DDG	guided missile destroyer
DL	distributed lethality
DTE	detect-to-engage
EMCON	emissions control
IAMD	integrated air and missile defense
ICBM	intercontinental ballistic missile
JCA	Joint Capabilities Area
JCIDS	Joint Capabilities Integration and Development System
JFC	Joint Force Commander
MMSP	multi-mission signal processor
MBSE	model based systems engineering
MEASA	methodology for employing architecture in systems analysis
NOB	nearly orthogonal and balanced design

NTT	Navy Tactical Tasks
OASUW	offensive Anti-Surface Warfare
OV	operational viewpoint
SRBM	short range ballistic missile
SSDS	ship self-defense system
UNTL	Unified Naval Task List

EXECUTIVE SUMMARY

Early 2015 marked the introduction of a new offensive concept. This emerging concept has resulted in the buildup of offensive capability for U.S. naval forces. Defined as the concept of distributed lethality (DL), Admirals Peter Fanta, Peter Gumataotao, and Thomas Rowden described a naval force that would be composed of small adaptive force packages (AFPs) that could operate in a dispersed and deceptive manner (Fanta, Gumataotao, and Rowden 2015). The development of these new offensive capabilities has spurred increased attention to the pursuit of key technologies as well as the pursuit of refined doctrine and tactics that will allow maritime forces to project offensive power in forward deployed and contested environments.

This thesis investigates the impacts of a current mission set, namely integrated air and missile defense (IAMD), on the newly proposed DL concept. The combined mission of IAMD is a result of conducting ballistic missile defense (BMD) operations in concert with an air defense (AD) mission. In stark contrast to the concept of distributed lethality, IAMD relies heavily on robust communication paths as well as emission of high-powered shipboard radars to detect and engage missile threats, whereas DL missions seek to minimize detectable emissions and rely on the element of stealth and low probability of detection techniques.

An architecture proposed by Johnson (2016) to analyze the DL concept describes a distributed force. Additionally, Harlow (2016) applied a model-based systems engineering (MBSE) approach to investigate the logistical component of DL. To add to the body of work, the author developed a combined DL and IAMD architecture that will provide a framework for a combat system design that can satisfy the complex requirements of the two diverse warfare areas. An investigation of the impacts of IAMD on DL was conducted using MBSE and discrete event simulation.

The architecture for this thesis was developed using a schema, which ensured full traceability of the architectural elements. The schema defined an architecture creation process that began with the identification of requirements to fulfill combined DL/IAMD missions. It then ensured that requirements were traced to mission capabilities, as defined by the joint capabilities areas (JCAs). The defined mission capabilities were achieved by operational activities adapted from the Unified Naval Task List (UNTL) and enabled by unique operational tasks. The functional and physical architecture was created in Innoslate, an architecture development software created by SPEC industries.

By adopting the architecture developed in Innoslate, discrete event simulation was conducted using ExtendSim 9 software and a robust design of experiments (DOE). Statistical analysis of the simulation results was used to investigate the level of significance that selected input factors have on the outputs selected as measure of effectiveness (MOEs) of the systems. The input factors consider 150 distinct factors that include blue force composition and capabilities, red force composition and capabilities, sensor capabilities, mission type, emissions control (EMCON) condition. Each of the input factors was evaluated using regression analysis against two different MOEs, percent of targets destroyed and blue force vulnerability. Results indicated an average of 11 percent increase in the number of enemy forces killed when conducting a combined mission versus conducting just an IAMD mission. The cost of this improved lethality was increased vulnerability, resulting in an average increase of half of a hit on defended assets.

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I. INTRODUCTION

A. BACKGROUND

Modern naval warfare has evolved dramatically in the past century. U.S. naval forces have focused primarily on defensive weapon system development. This is evident through an examination of the recent U.S. Navy major ship system developments, specifically the AEGIS weapon system (AWS), Ships Self Defense System (SSDS), and even AEGIS Ballistic Missile Defense (ABMD) System. All these systems have one key theme in their development: defense of assets.

Recently, there has been a shift in the warfighting mentality of some key Navy leaders; specifically, the Commander of Naval Surface Forces (CNSF) is showing a renewed interest in developing offensive capabilities. Development of these offensive capabilities has spurred increased attention to the pursuit of key technologies as well as the pursuit of refined doctrine and tactics that will allow maritime forces to project offensive power in forward deployed and contested environments. An emerging concept in this buildup of offensive capability is the concept of distributed lethality (DL) (Fanta, Gumataotao, and Rowden 2015).

1. Distributed Lethality

The key tenet of DL is to keep the enemy at risk, at range—that is, their asset commanders must feel a sense of danger while being forced to maintain safe distances from perceived adversarial forces. A key enabler of this tenet is maintaining battlespace awareness (BA), which is defined by the U.S. Navy Information Dominance Roadmap 2013–2028 as “the ability to understand the disposition and intentions of potential adversaries as well as the characteristics and conditions of the operations environment” (Department of the Navy [DON] 2013). The situational awareness gained through comprehensive BA allows commanders to understand their environment and further disrupt adversarial forces intended tactics using DL. Incorporating the DL concept involves geographically distributing naval forces. This helps to create an increased level of uncertainty in the mission planning of opposing forces. This uncertainty creates a perceived risk for the enemy commanders and therefore may result in delayed troop movements or in the abandonment of a preconceived mission set.

When executed properly a distributed force will have the ability to keep enemy forces at greater ranges. The ability to keep forces at range is dependent upon the capabilities of the naval forces to project power. When friendly forces have systems that allow for the projection of power at greater ranges than the enemy forces, then the opposing force commanders will have to consider this increased risk, which will keep their forces distributed and at increased range from the objective. Therefore, by properly executing the DL concept, friendly forces experience an increased level of security, which enables increased sea control in a given maritime domain.

2. Integrated Air and Missile Defense

This emphasis on power projection is vitally important to increasing the offensive capability of a naval force; naval warfare is not restricted to a single domain or concept such as DL. The evolution of warfighting has led to the requirement to fight in a multi-domain warfare environment. To this end, it is important to consider the emergence of maritime integrated air and missile defense (IAMD), which results from an evolution of warfighting. No longer is a naval surface unit able to only perform local air defense, a unit must now perform air defense and missile defense missions in concert with one another. Joint Publication 3–01 defines Integrated Air and Missile Defense as "The integration of capabilities and overlapping operations to defend the homeland and United States national interests, protect the joint force, and enable freedom of action by negating an adversary's ability to create adverse effects from their air and missile capabilities" (Chairman of the Joint Chiefs of Staff 2017, I-10). Simply stated IAMD is a mission set that includes both air defense and ballistic missile defense (BMD).

The advent of IAMD highlighted the vital importance that anytime a new concept is derived, time and research must be devoted to consider the implication of this new concept. Specifically, the combination of AW and BMD to evolve to what is now known as IAMD came with some complications. In a 2016 paper, Morton (2016) points out that it was not until the development of the multi-mission signal processor (MMSP) for the

Spy-1D radar that this capability (IAMD) could be realized. The earlier BMD computer suites utilized separated signal processers and that resulted in a degradation of AW capability while operating in BMD mode (Morton 2016, 111). The new MMSP reduced the burden on the crew while increasing the effectiveness of the SPY-1D radar suite and provided enhanced engagement capability in littoral environments as well as engagements against sea skimming anti-ship cruise missiles in high-clutter environments. To this end, one must evaluate the DL mission for potential architectural elements that may be saturated or overtasked.

B. SCOPE AND METHODOLOGY

Defined research methods govern thesis research. The goal of this thesis is (1) to define architectures for IAMD and associated DL forces, and (2) to analyze the performance of those DL forces in an IAMD mission. Accordingly, this thesis utilizes the analysis research method (Giachetti 2016), which focuses the research on assessment of IAMD performance in a DL environment using in-depth quantitative and computational analysis.

The selection of the analysis research method informs the structure of the finalized thesis. The first two chapters present an introduction as well as literature relevant to both the IAMD and DL concepts. Chapter III defines the requirements, functions, and components required for the development of executable architectures. Chapter IV presents and analyzes a discrete event simulation that models the effectiveness of various force compositions, as well as the resource constraints that affect operational effectiveness, in both a DL and IAMD mission. Analysis of results identifies key performance drivers and operational decisions that balance conflicting requirements for both mission sets.

This method takes advantage of the waterfall model used in Systems Engineering (SE), introduced by Royce in 1970. An examination of Figure 1 depicts this waterfall process. The process starts with the analysis of requirements and finishes with the testing of the candidate designs. The power of this process is in the feedback loops, which can take place at any step of the process and allow for continued improvement of the product.

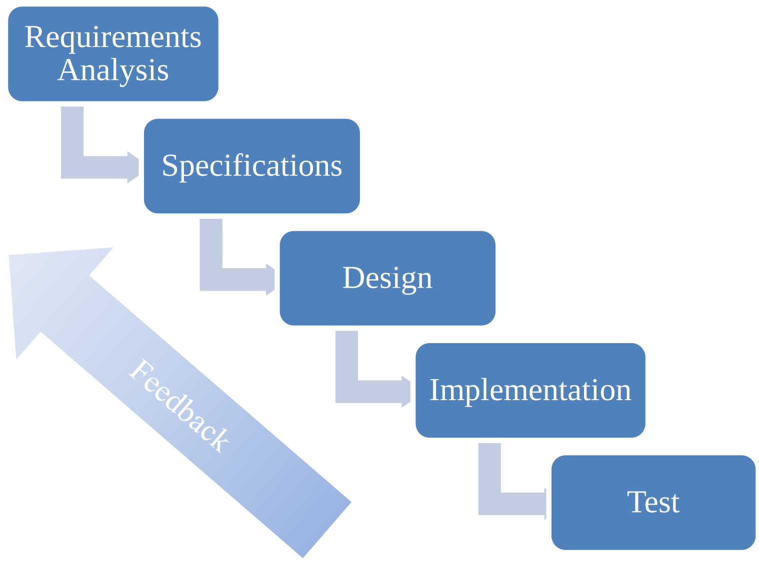


Figure 1. Waterfall Process Model. Adapted from Royce (1970).

C. PURPOSE AND RESEARCH OBJECTIVES

The value of this study is identification of architectures that can satisfy IAMD performance standards in the context of a DL mission. By identifying the shared resources and modeling their interactions, one can identify potential constraints in design are isolated and high performing force compositions (in both DL and IAMD missions) are identified.

The content of this thesis presents the following research objectives.

- It utilizes standardized systems architecture tools and techniques to integrate architectures for IAMD and DL.
- It develops and analyzes a discrete event simulation consistent with the systems architecture that identifies key performance drivers and operational decisions that balance conflicting requirements for IAMD and DL.

II. RESEARCH METHODOLOGY

A. SYSTEMS ARCHITECTURE

Architecting supports decisions. The 1995 Department of Defense integrated architecture panel defined an architecture as "the structure of components, their inter-relationships, and the principles and guidelines governing their design and evolution over time" (Van Haren 2011, 9). This implies that there must be a way to organize, capture, and display information. By presenting large amounts of data into concise and tailored views, decision makers can develop informed decisions regarding complex issues. Architecture provides a means of constructing a mental picture of the system. It also allows for the design of a system using non-verbal methods such as diagrams and illustrations, which facilitates the conversion of tacit knowledge to explicit knowledge and informs meaningful conversations.

This thesis leverages the Tier 1 Integrated Air and Missile Defense architecture created for the Joint Chiefs of Staff by the J6 directorate (see Appendix A) as many of these systems have been placed in production. By examining the existing IAMD architecture an understanding of the system can be developed, which facilitates the creation of an advanced architecture to include DL.

The development of a combined DL and IAMD architecture provides a framework for developing a complete combat system design that can satisfy the complex requirements of the two diverse warfare areas. Architecture development must be done in a methodical and deliberate fashion ensuring that all elements of the systems are considered and that relevant missions are addressed. To this end, careful mapping of the systems will take place to ensure complete traceability of system functions, components, tasks, capabilities as well as providing clearly defined requirements.

B. LITERATURE REVIEW

1. Distributed Lethality Review

Work to define DL has been advancing at a rapid pace as demonstrated by some recent thesis work. Johnson (2016) described a potential architecture for a distributed force. Johnson took a structured approach to defining the core requirements for DL as well as describing the capabilities needed to achieve those requirements. His paper goes on to define a potential systems architecture for operational DL and began the process of developing connections and relationships between various elements of his DL model.

Harlow (2016) described the logistical component of DL by utilizing a model-based systems engineering (MBSE) approach. His work looked at the stakeholder requirements for the system and identified the necessary operational architecture to support a distributed force. Harlow developed an architecture that provides a traceable, flexible and scalable architecture, which aids in codifying the DL concept, but he also stated that there is an opportunity for follow-on research that would focus on identifying specific measures of performance and conducting detailed modeling and simulation.

A 2017 report published by the Office of the Commander, Naval Surface Forces (CNSF) titled *Surface Force Strategy: Return to Sea Control* describes the United States' return to sea control.

> Sea control is the precondition for everything else we must do as a navy. Distributed Lethality reinforces fleet initiatives that drive collaboration and integration across warfighting domains. Distributed Lethality requires increasing the offensive and defensive capability of surface forces, and guides deliberate resource investment for modernization and for the future force. (CNSF 2017, 2)

Furthermore, the concept of DL is broken down into three key tenets: increase the offensive lethality of all warships, distribute offensive capability geographically, and give the right mix of resources to persist in a fight. Clearly, the DL mission is progressing at a rapid pace; however, the right mix of resources to conduct a DL mission must be considered in the context of a naval force's ability to continue to conduct defensive missions such as IAMD.

2. Integrated Air and Missile Defense Review

Senior military officials view IAMD as a joint capability to be employed at the tactical, operational and strategic levels of war (Morton 2016, 111). However, this document will consider only the surface warfare or maritime view of IAMD. Figure 2 provides an operational context to the operation of a joint IAMD mission.

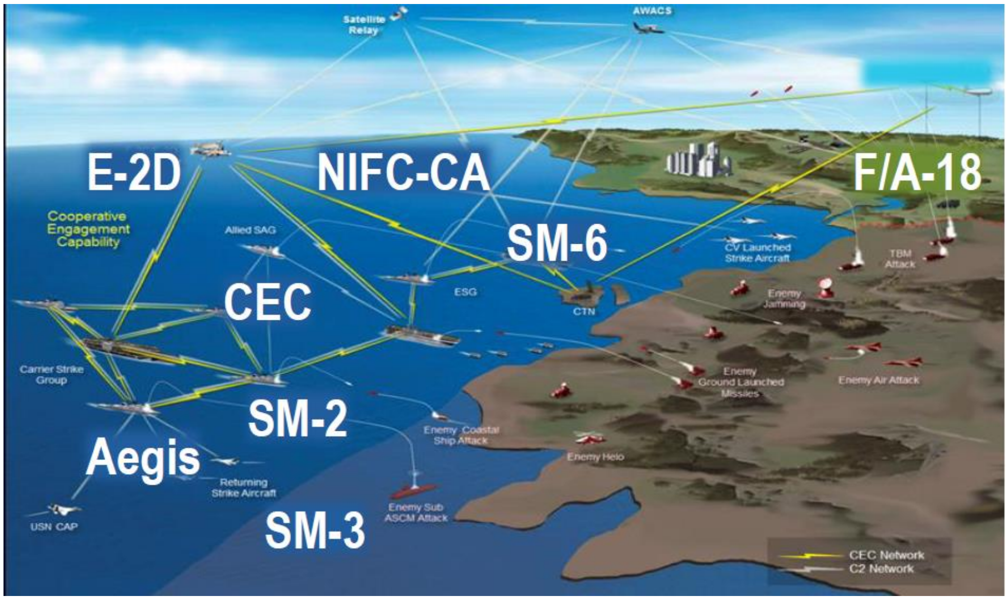


Figure 2. Surface Warfare View of IAMD in the Joint Environment. Source: Kilby (2013).

When conducted in a maritime environment, joint forces require wide variety of assets to complete a successful IAMD operation. The assets required include guided missile cruisers (CG) and guided missile destroyers (DDG) equipped with BMD capable AEGIS weapon systems with robust command and control systems, including link-11, link-16, and cooperative engagement capability (CEC). CEC provides a sensor network that allows for the exchange of fire control quality data between participating units. This fire control quality data can enable extended range engagement opportunities. The military accomplishes engagement of air threats with standard missile variants SM-2 and SM-6. They engage ballistic threats using SM-3 and SM-6 for space based engagement and terminal engagement of ballistic targets, respectively. Airborne assets such the F/A-

18, E-2D and F-35 aid in providing increased situational awareness, defense in depth as well as offensive capabilities. Finally, the inclusion of navy integrated fire control-counter air (NIFC-CA) allows for a capability that dramatically increases the sensor's ability and allows for missile engagement past ship's organic radar horizon.

In stark contrast to the concept of distributed lethality, the operational view presented in Figure 2 relies heavily on robust communication paths as well as on emission of high-powered shipboard radars to detect and engage missile threats, while DL missions seek to minimize all detectable emissions and rely on the element of stealth and low probability of detection techniques.

In the Joint IAMD Vision 2020, the Chairman of the Joint Chiefs of Staff (CJCS) outlined imperatives that must be considered in future IAMD development. The final imperative laid out is to "create an awareness of the IAMD mission and the benefits of its proper utilization across the Department of Defense to include the development of the enabling framework of concepts, doctrine, acquisition and war plans that support full integration of the IAMD into combat operations" (CJCS 2013, 5). Ensuring that IAMD is fully integrated in the DL concept is consistent with the imperative set forth by the CJCS.

C. MODEL DEVELOPMENT

Model Based Systems Engineering is a powerful tool in which ideas can be organized, displayed, explained, and evaluated. Through the use of established DOD Architecture Framework (DODAF), which is implemented in Innoslate, the software tool developed by Systems and Proposal Engineering Company (SPEC Innovations); this thesis defined boundaries, needs requirements, goals and functions of both DL and IAMD architectures. Additionally, the complete architecture informed the creation of a complex engagement model using ExtendSim9, a discrete event-simulation software program developed by Imagine That Inc. Creation of that model allows for detailed analysis of system behaviors and interactions. Figure 3 depicts how this defined architecture allowed for the analysis and evaluation of the system, which feeds the decision-making process and allows for courses of action to influence decisions and define an evaluated architecture which supports both mission areas.

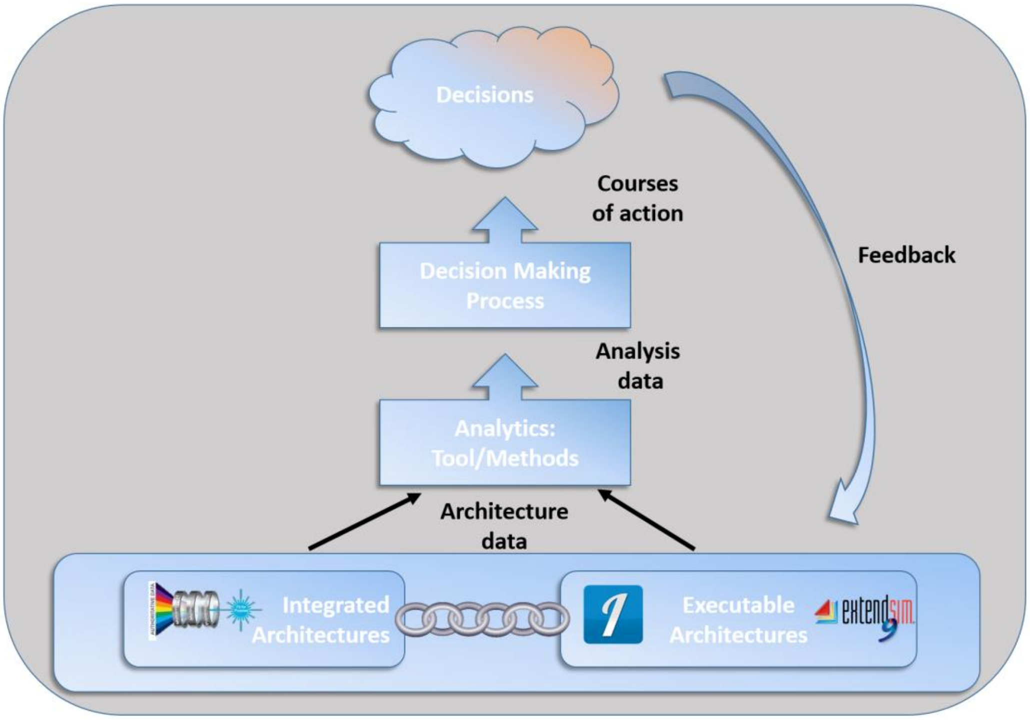


Figure 3. Architectures Influence in the Decision Making Process. Adapted from Department of Defense Chief Information Officer (2017).

1. DOD Architecture Framework

The Department of Defense (DOD) follows a six-step process in the high-level development of architecture products, as shown in Figure 4 (Department of Defense Chief Information Officer 2017). Step one involves determining the use of the architecture. This step is accomplished through the evaluation of the objectives, purpose, tradeoffs and requirements of the architecture. Early consideration of analysis methods also occurs during this phase but may be revised at later stages as the project matures. These tradeoff considerations are vital to the core of the ability of the thesis evaluate further the interactions that may occur when IAMD missions are accomplished in a DL environment. By considering the tradeoffs that must be made, design changes can be incorporated at lower cost when compared to implementation at later stages.

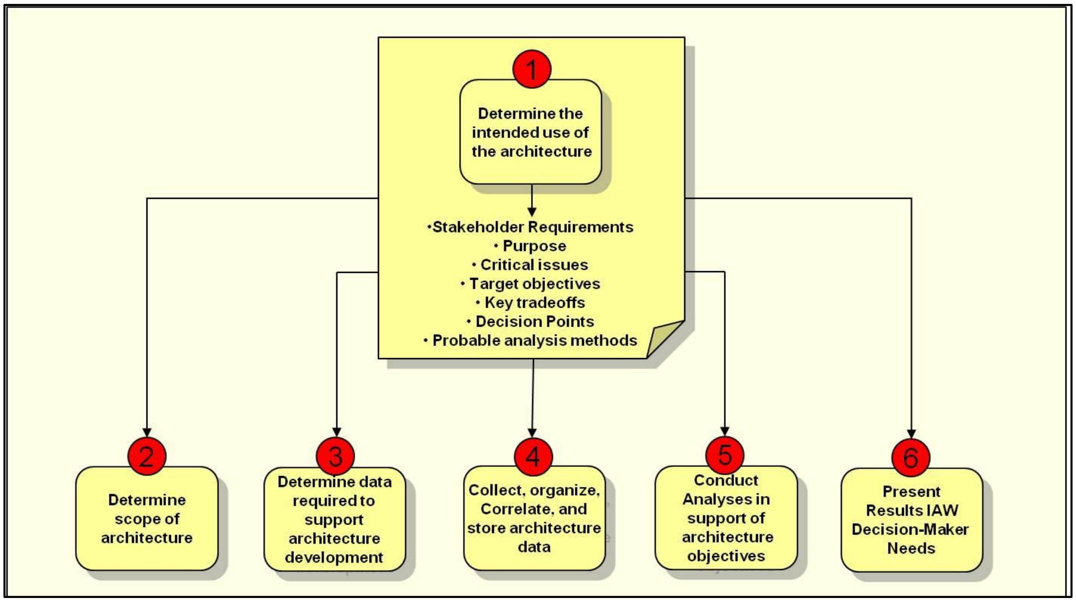


Figure 4. Architecture Development Six-Step Process. Source: Department of Defense Chief Information Officer (2017).

The second step of the DODAF process is determination of the scope of the architecture, which involves defining the boundaries and establishing the depth and breadth of the architectural description effort. Clear definition of the scope, operational boundaries, as well as physical boundaries, ensures that one places the correct focus is placed on the area of concern and avoids broad scoping which could lead to insufficient detailed process definitions. To this end, the author has chosen to scope this thesis in a restricted maritime IAMD scenario with scenarios that depict DL, IAMD and combined operations against a near peer adversary in a contested environment.

The third step in the process is determining the data required to support the architecture development and is directly supportive of completing step four, the collection, organization, correlation and storage of data. The DODAF goes on to state that data collection and organization is typically done through the use of architecture techniques designed to use views. These viewpoints can represent different perspectives in which the system can be examined; some example views are activity, process, organization, and data models. This report examines these viewpoints in the Innoslate discussion herein regarding MBSE.

Step five involves the analysis of the architecture objectives. This can be in the form of shortfall analysis, capacity analysis or interoperability analysis. An important facet of this step is that it contains a feedback loop to step three in which the architecture’s completeness is tested for both accuracy and sufficiency. If found inadequate, then the architecture support data is revised and required architectural characteristics updated.

The final step is presenting the data to a decision maker or stakeholder. The use of standards, such as DODAF, insures the decision maker is able to quickly evaluate the content of the architecture and not waste excess time trying to understand new data presentation methods for each product. This key element is a major reason for selecting the DODAF standards for the development and evaluation of the DL and IAMD architectures.

2. Model Based Systems Engineering in INNOSLATE

Innoslate was utilized to create DODAF 2.02 viewpoints (see Figure 5), which take a top down approach to maintain consistency with the Joint Capabilities Integration and Development System (JCIDS) process (SPEC Innovations 2017).

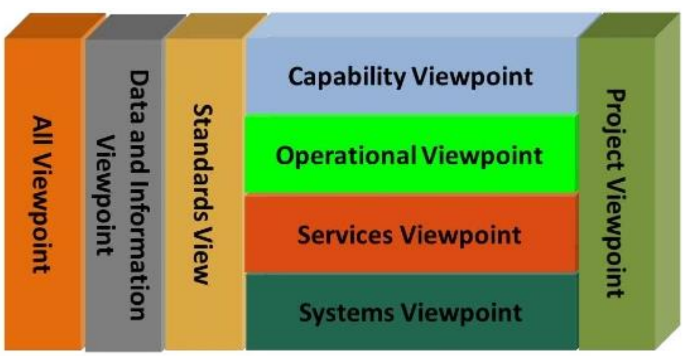


Figure 5. DODAF Viewpoints. Source: Department of Defense Chief Information Officer (2017).

Tenets of Innoslate methodology follow that of the Lifecycle Modeling Language (LML) specification 1.1. We define Innoslate as something that can exist by itself and is uniquely identifiable. The schema makes use of 22 different and unique entities, which they define as classes.

We further define each entity in Innoslate by attributes. An attribute is an inherent characteristic or quality of an entity. It further describes the entity, enhancing its uniqueness (Innoslate 2017). Each entity in Innoslate can be further defined through the use of attributes. An attribute is an inherent characteristic or quality of an entity. It further describes the entity, enhancing its uniqueness (Innoslate 2017). Some examples are text, numbers, or percent assigned to entities.

Finally, Innoslate allows the definition of clearly defined relationships between the discrete entities created. Some example relationships as defined by LML specification 1.1 are “decomposed by,” “specified by,” and “referenced by.” The architecture developed in this thesis will abide by these conventions and seeks to comply with DODAF framework when possible.

III. OPERATIONAL / FUNCTIONAL ARCHITECTURE

A. DISTRIBUTED LETHALITY / IAMD ARCHITECTURE

The first step in evaluating the interactions of IAMD and DL to define a combined architecture to be modeled and analyzed. This chapter adapts the Model-Based Systems Engineering Methodology for Employing Architecture in Systems Analysis (MBSE MEASA) put forth by Beery (2016), which describes a methodology for employing architecture in system analysis. The MBSE MEASA is composed of the five steps displayed in Figure 6.

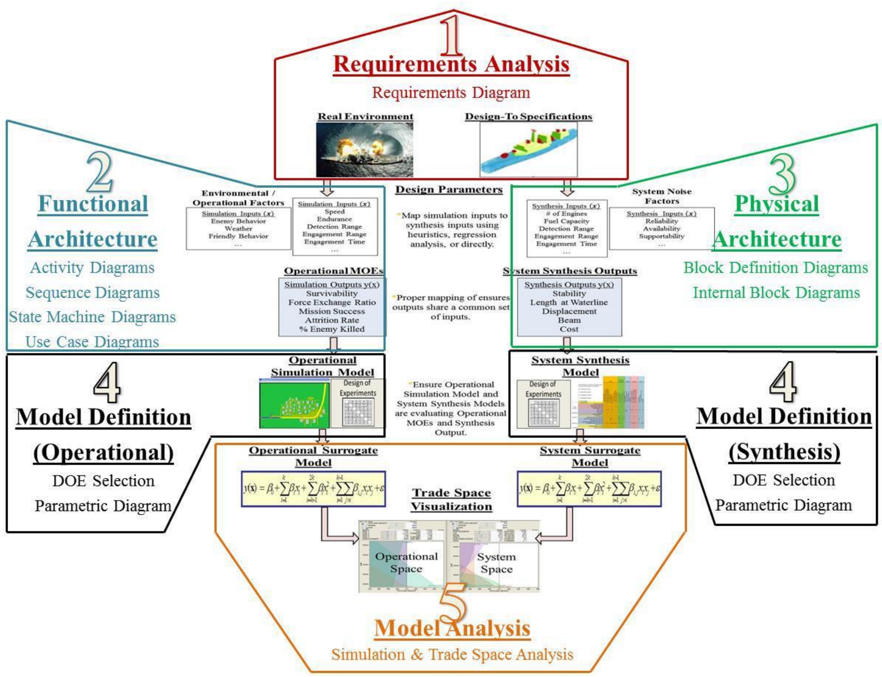


Figure 6. MBSE MEASA Process. Source: Beery (2016).

The remaining chapters are organized around this process. This chapter will first define clear requirements for combined DL/IAMD missions, and then develop functional and physical architecture in Innoslate as shown in steps two and three of the MBSE MEASA process. Step four of the MBSE MEASA process, presented in Chapter IV, is executed using ExtendSim software and a robust design of experiments (DOE). Chapter four will conclude by using standard statistical methods to conduct the analysis shown in step five.

1. Requirements

The first step in creating the systems architecture is the development of concise requirements. System requirements provide the basis for any quality systems engineering process and good requirements are vital to the success of any systems engineering endeavor. Bahill and Dean (2005) describe the process of developing requirements in five steps.

1. Elicit, analyze, validate and communicate stakeholder needs.
2. Transform customer requirements into a derived requirement.
3. Allocate requirements to hardware, software, test, and interface elements.
4. Verify requirements.
5. Validate the set of requirements.

Traceability is also a key factor in the development of any systems engineering effort. In order to structure the analysis of DL and IAMD requirements a schema, was developed that organizes existing guidance from joint capability areas (JCAs) and the Unified Naval Task List (UNTL), in a consistent fashion with the terminology used in this thesis. Starting at the top of Figure 7, the requirements are traced to the mission capabilities as defined by the JCAs see (Appendix C). Next, mission capabilities are achieved by utilizing operational activities, which are derived through the use of the Unified Naval Task List (UNTL).

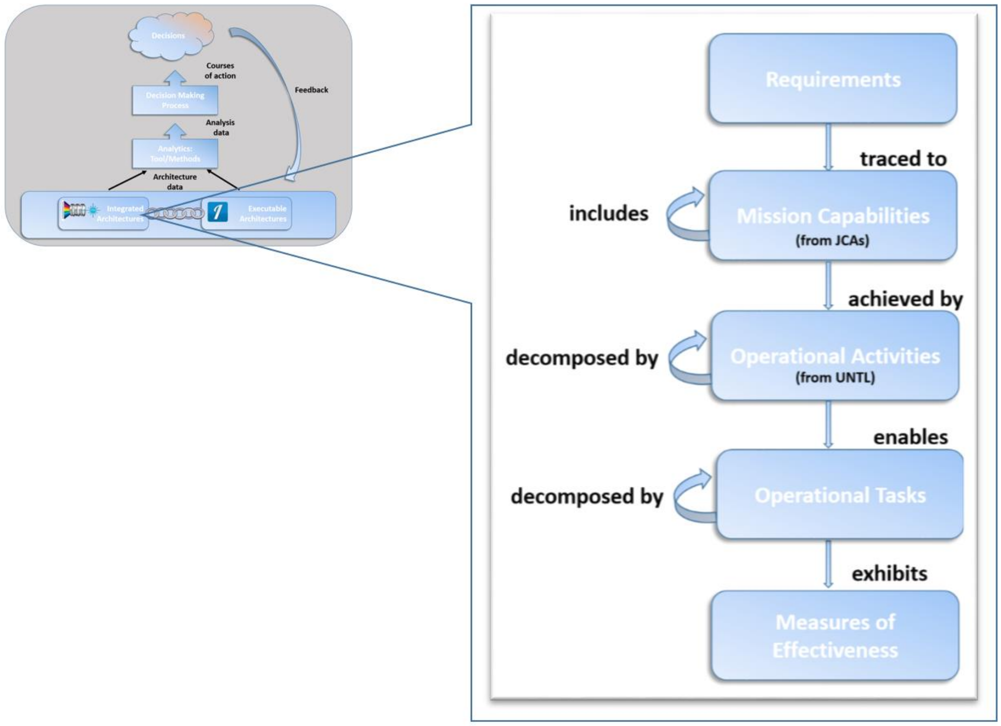


Figure 7. Architecture Schema (cf. Figure 3).

The requirements, for a combined IAMD and DL mission consider the relevant elements of both architectures and incorporate some overlap of needs. Johnson (2016) captured 11 high level requirements for the DL mission. Johnson (2016) argued that distributed lethality must provide targeting, allow for rapid AFP turnaround, and be self-sustaining. Additionally, there are requirements to utilize current/near future resources, be deceptive, operate dispersed, force the adversary to react, have limited carrier strike group (CSG) support, execute localized sea control, integrate Marine Corps, and lastly DL must be offensive in nature.

The requirements for IAMD are to be defensive; provide joint interoperability and integration; sense, track and discriminate contacts; provide air control; and provide protection against air threats, all while being mobile (CJCS 2012). Figure 8 shows an adaptation of Johnson's initial requirements for DL. On the left, items highlighted in green are deemed to be redundant functions for DL and IAMD, items in red are readdressed in the combined architecture presented on the right of Figure 8, and lastly items in white are identified as exclusively DL requirements.

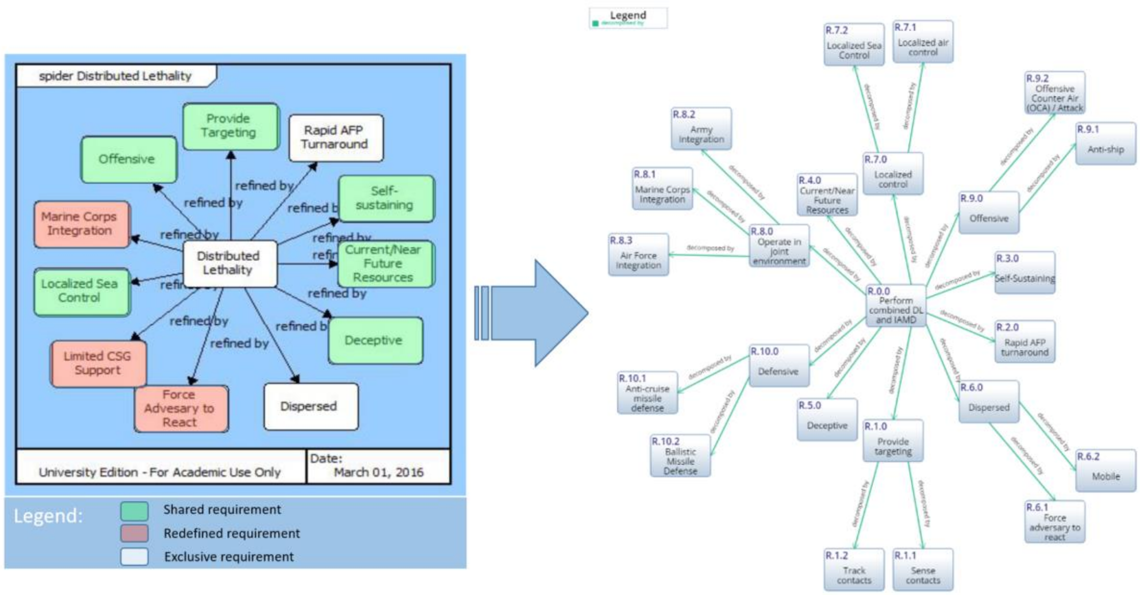


Figure 8. Combined Requirements. Adapted from Johnson (2016).

Development of a combined DL and IAMD requirements architecture results in a set of hierarchical requirements. Each requirement incorporates unambiguous, concise statement, which provides a consistent description of the system requirements and provides the traceability required in the further development of complete systems architecture. The combined IAMD and DL assessment yields ten distinct high-level requirements seen in Figures 9–11.

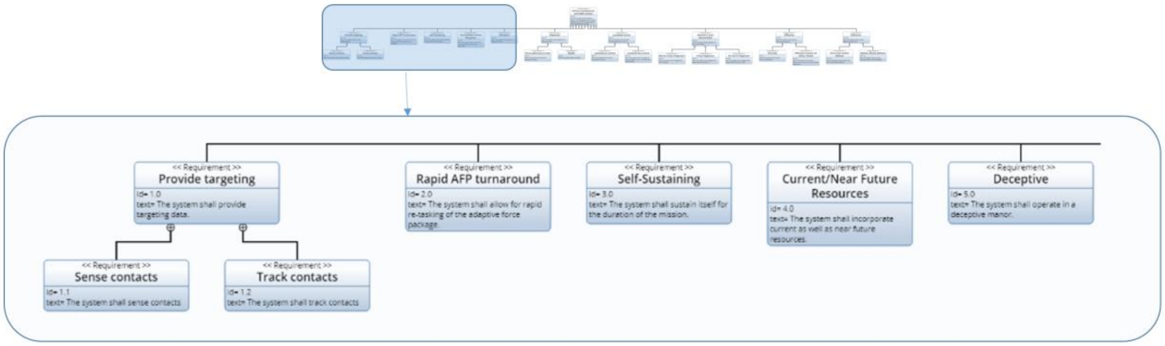


Figure 9. Combined IAMD/DL Requirements.

1.0 **Provide targeting:** The system shall provide targeting data. This requirement is further refined by requirements R.1.1, sense contacts, and R.1.2, track targets. These are fundamental requirements for both DL and IAMD systems, which must engage hostile enemy combatants. If the combatants cannot be targeted, then further engagements are not possible.

2.0 **Rapid AFP turnaround:** The system shall allow for rapid re-tasking of the adaptive force package. The 2017 Surface Force Strategy: Return to Sea Control asserts, "adaptive force packages allow operational commanders to scale force capabilities depending on the level of threat" (Commander Naval Surface Forces 2017, 9). To this end, the AFP composition must be agile enough to conduct a DL mission while not incurring significant reduction in mission capability through emergent tasking from higher headquarters, such as IAMD mission tasking.

3.0 **Self-sustaining:** The system shall sustain itself for the duration of the mission. While considering advanced logistic solutions are being considered, the ability to sustain forward presence and remain on station is a key capability that allows U.S. naval forces to maintain a competitive advantage over adversarial nations. Harlow (2016) defined a systems architecture for logistics of a distributed naval force stating that "sustain[ing] a distributed force requires a dynamic infrastructure that can respond to a demand signal swiftly." He concluded that further work is needed to explore new capabilities, such as VLS Re-Arm at Sea (Harlow 2016). The implementation of new logical techniques is required to enable self-sustainment.

4.0 **Current/Near Future Resources:** The system shall incorporate current as well as near future resources. Advances in the development and fielding of new technologies are crucial for the sustainment of technical advantage. One of the three tenets identified for distributed lethality is to increase the offensive lethality of all warships (Commander Naval Surface Forces 2017). Commander Naval Surface Forces (CNSF) states that "our ships must be equipped with the tools necessary to fight and defeat highly capable adversaries" (Commander Naval Surface Forces 2017, 11). Achieving this requirement means the incorporation of advanced technologies. These technologies will include not just advanced kinetic weapons but also use of unmanned systems, as well as highly adaptive command-and-control systems with the ability to reconfigure rapidly and utilize low probability of detection methods of transmission.

5.0 **Deceptive:** The system shall operate in a deceptive manner. The requirement to operate in a deceptive manner presents a number of challenges to conducting combined DL/IAMD missions. While the DL concept is inherently reliant on its ability to execute in a stealthy manner and remain undetected, IAMD conflict with the execution of deception.

Deception can occur in a number of different ways. One such way is to reduce the electromagnetic signature of a vessel by the incorporating emission control (EMCON). By reducing or eliminating the electromagnetic signals broadcast from a vessel, the vessel then becomes more difficult to detect and therefore more deceptive. Integrated air and missile defense missions typically require an organic or local to the ship, high-powered volume search radar to scan the sky and space for missile like objects. This requires the emission of large amounts of RF energy, which is easily detectable by enemy forces. One aspect this thesis examines is the effects of placing a ship in EMCON and relying on cued sensors to conduct BMD engagements in support of IAMD missions.

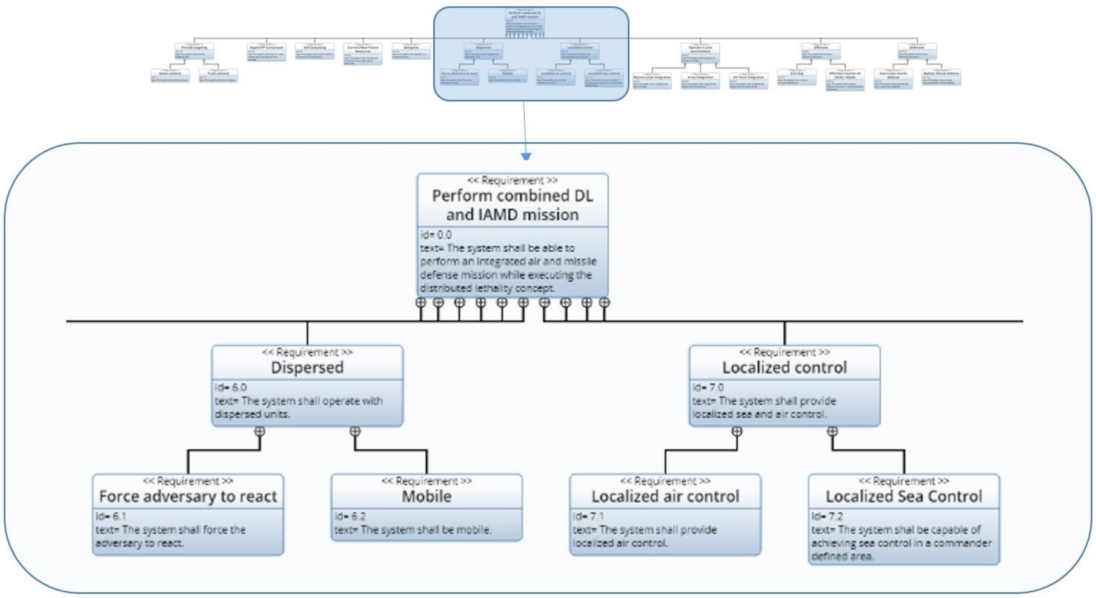


Figure 10. Combined IAMD/DL Requirements.

6.0 **Dispersed:** The system shall operate with dispersed units. Unlike the previous requirement, this is supportable for both IAMD and DL missions. This requirement is further refined by requirements R.6.1, Force the adversary to react, and R.6.2, Mobile. Simply stated, a mobile AFP configuration can easily be dispersed and force the adversary to react.

7.0 **Localized control:** The system shall provide localized sea and air control. This requirement is further refined by R.7.1, Localized air control, and R.7.2, Localized sea control. This requirement directly supports the CNO's first line of effort, "strengthen Naval Power at and from Sea" (CNO 2016).

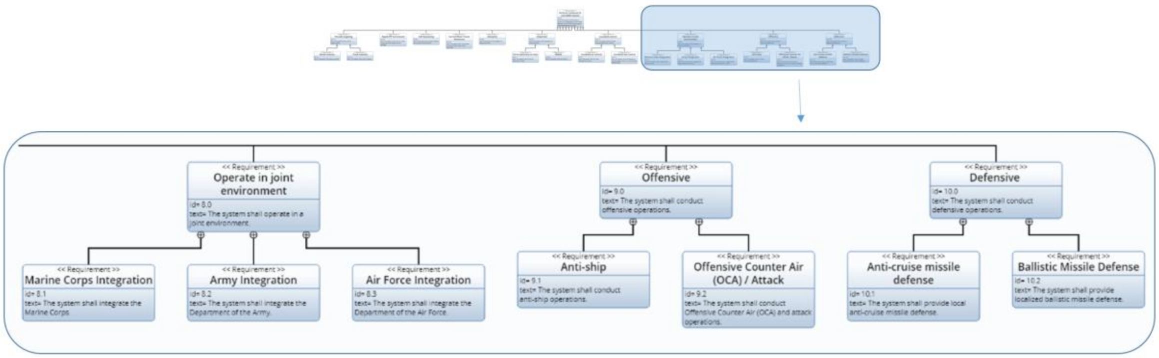


Figure 11. Combined IAMD/DL Requirements.

8.0 **Operate in joint environment:** The system shall operate in a joint environment. This requirement is supported by the Marine Corps, Army, and Air Force as R.8.1, R.8.2 and R.8.3 respectively. Both IAMD and DL can benefit from this distinct advantages through the incorporation of joint capabilities from all services. Advantages come in the form of increased battlespace awareness through the use of shared sensors, as well as the increased lethality offered by joint weapon systems when combined with naval maritime forces.

9.0 **Offensive:** The system shall conduct offensive operations. Supported directly by requirements R.9.1, Anti-ship and R.9.2, Offensive Counter Air (OCA)/Attack. This requirement is the key element from which the concept of DL is formed. The following quote presented in a January 2015 issue of *Proceeding Magazine*, captures the strong message presented by U.S. naval leadership:

> A shift is now under way within the surface force. It is not subtle, and it is not accidental. The surface force is taking the offensive, to give the operational commander options to employ naval combat power in any antiaccess/area-denial (A2/AD) environment…Increasing surface-force lethality—particularly in our offensive weapons and the concept of operations for surface action groups (SAGs)—will provide more strike options to joint-force commanders, provide another method to seize the initiative, and add battlespace complexity to an adversary's calculus (Fanta, Gumataotao, and Rowden 2015, 1).

This sends a clear and distinct message that the system requirement to conduct offensive operations is not negotiable and that DL missions must achieve this requirement.

10.0 **Defensive:** The system shall conduct defensive operations. This requirement is supported by requirements R.10.1 anti-cruise missile defense and R.10.2 ballistic missile defense. To maintain control of the battlespace the local units must be capable of providing defense not only to themselves but also to other units or locations as tasked by higher headquarters.

2. Mission Capabilities

With clearly defined requirements created, the next step in the architecture development process is to define the required mission capabilities. The Department of Defense Directive 7045.20 defines a "capability as the ability to achieve a desired effect under specified standards and conditions through a combination of means and ways across doctrine, organization, training, materiel, leadership and education, personnel, and facilities (DOTMLPF) to perform a set of tasks to execute a specified course of action" (DOD 2017, 10).

Table 1 contains a tailored listing of the mission capabilities and sub-capabilities identified for both DL and IAMD mission.

Table 1. Mission Capabilities and Sub-Capabilities

Mission Capabilities	**Mission Sub-Capabilities**
Surface Warfare	Provide Self-Defense Against Surface Threats
	Conduct Offensive Operations Against Surface Threats
Maritime Interdiction	Sea Lines of Communication (SLOC) Disruption
	Maritime Interception Operations
Maneuver	Forward Presence
	Marine Force Configurations
	Informational Operations
Offensive Counterair Operations	Suppression of Enemy Air Defensed (SEAD)
	Offensive Counterair Sweep
	Escort
	Offensive Counterair Attack Operations
Integrated Air and Missile Defense	Defensive Counterair Operations
	Theater Ballistic Missile Defense
Theater Air and Missile Defense	Provide Self-Defense Against Air and Missile Threats
	Provide Maritime Air and Missile Defense
	Provide Overland Air and Missile Defense
	Conduct Sea-Based Missile Defense
Command and Control	Communications
	Situational Awareness
	Information Processing & Storage
	Decision Making
	Collaborative Planning
	Interoperability
	New Capabilities
Battlespace Awareness	Planning and Direction for Collection and ISR
	Observation and Collection
	Processing and Exploitation
	Analysis and Production
	Discrimination and Integration
	Develop and Maintain Shared Situational Awareness
	Evaluation and Feedback

Each of the developed capabilities is carefully mapped to a requirement and a full matrix of the mapping can be found in Figure 47 of Appendix D.

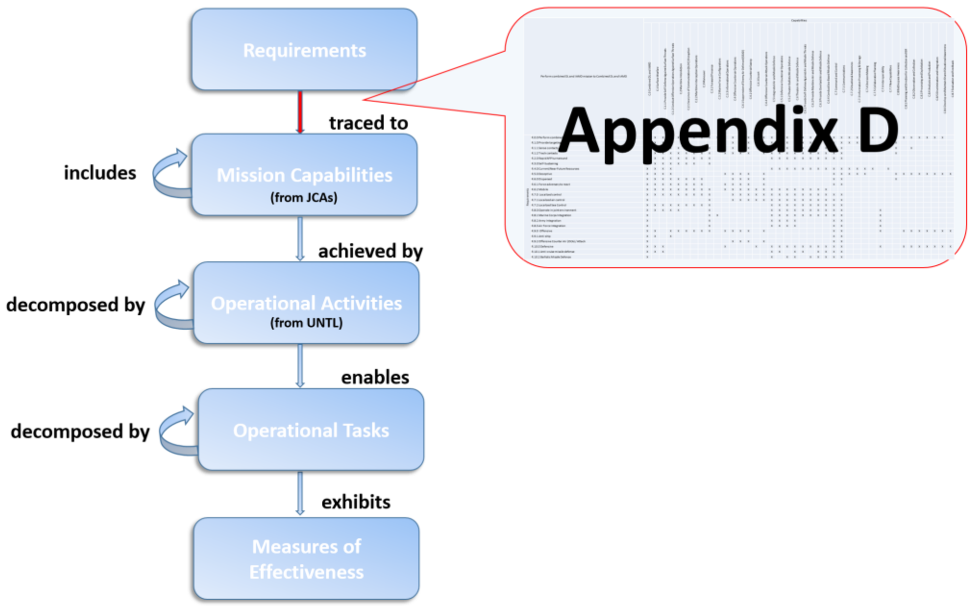


Figure 12. Mapping of Requirements to Mission Capabilities. (Compare to Figure 7).

3. Operational Activities

Operational Activities are defined as what work is required, and is specified independently of how it is to be carried out (DODCIO 2017). For the purposes of this thesis, the author has chosen to leverage the existing Universal Naval Task List (UNTL) specifically, the Navy Tactical Tasks (NTAs). Table 2 contains a tailored listing of the NTAs used. The NTAs identified were converted directly into operational activities used in the architecture development.

Table 2. Tailored Universal Naval Tactical List.

Universal Naval Task List (operational activities)	Sub-NTA
NTA 1: Deploy / Conduct Maneuver	Move Naval Tactical Forces
	Navigate and Close Forces
	Maintain Mobility
	Conduct Countermobility
	Dominate Operational Area
NTA 2: Develop Intelligence	
NTA 3: Employ Firepower	Process Targets
	Attack Targets
	Conduct Special Weapons Attack
NTA 4: Perform Logistics and Combat Service Support	Arm
	Fuel
	Repair/Maintain Equipment
NTA 5: Exercise Command and Control	Acquire, Process and Communicate Information and Maintain Status
	Analyze and Assess Situation
	Determine and Plan Actions and Operations
	Direct, Lead and Coordinate Forces
	Conduct Information Warfare (IW)
NTA 6: Protect the Force	Enhance Survivability
	Provide Security for Operational Forces

The conversion of NTAs to operational activities can be seen in the list displaying OA.1 through OA.6.

OA.1 **Deploy/Conduct Maneuver**: This activity includes OA.1.1 Move Naval Tactical Forces, OA.1.2 Navigate and Close Forces, OA.1.3 Maintain Mobility, OA.1.4 Conduct Countermobility, OA.1.5 Dominate Operational area

OA.2 **Develop Intelligence**

OA.3 **Employ Firepower**: Activities for this operation include OA.3.1 Process Targets, OA.3.2 Attack Targets, and OA.3.3 Conduct Special Weapons Attack.

OA.4 **Perform Logistics and Combat Service Support**: This activity is performed with the sub-tasks, OA.4.1 Arm, OA.4.2 Fuel, OA.4.3 Repair/Maintain Equipment,

OA.5 **Exercise Command and Control**: OA.5.1 Acquire, Process and Communicate Information and Maintain Status, OA.5.2 Analyze and Assess Situation, OA.5.3 Determine and Plan Actions and Operations, OA.5.4 Direct, Lead and Coordinate Forces, OA.5.5 Conduct information Warfare (IW)

OA.6 **Protect the Force**: OA.6.1 Enhance Survivability, OA.6.2 Provide Security for Operational Forces.

Figure 13 shows how the defined schema incorporates the mapping of the mission capabilities to the operational activities. The matrix used for this mapping can be found in Figure 48 of Appendix D.

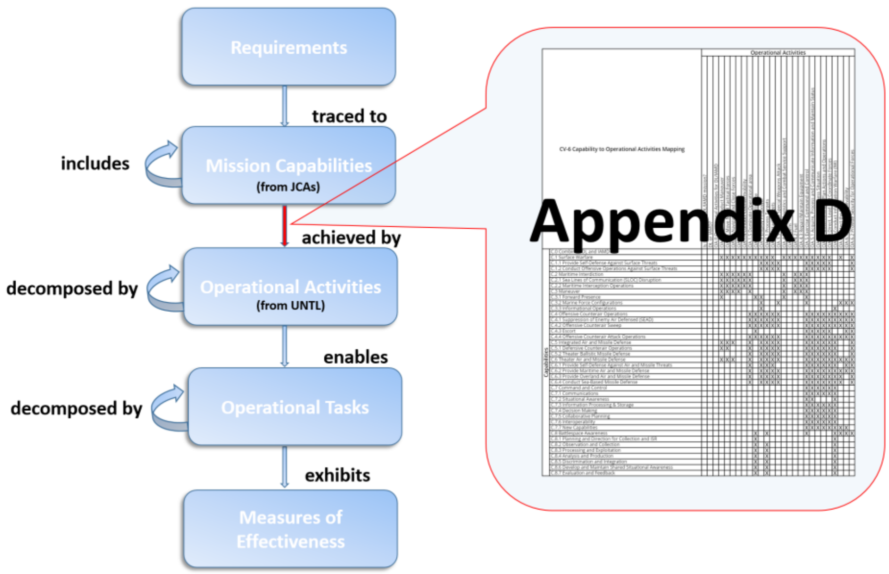


Figure 13. Mapping Mission Capabilities to Operational Activities.

4. Operational Tasks

The realization of an executable model requires that the generic operational activities developed above, which have no real method of execution, now must be further decomposed into operational tasks. Careful study of existing architectures and the processes of distributed lethality as well as integrated air and missile defense led to the creation of three major tasks associated with both DL and IAMD, which are plan, execute and recover. Figure 14 displays how these operational tasks are implemented in the Innoslate software (grey block in center) and how each can be further broken down into subtasks.

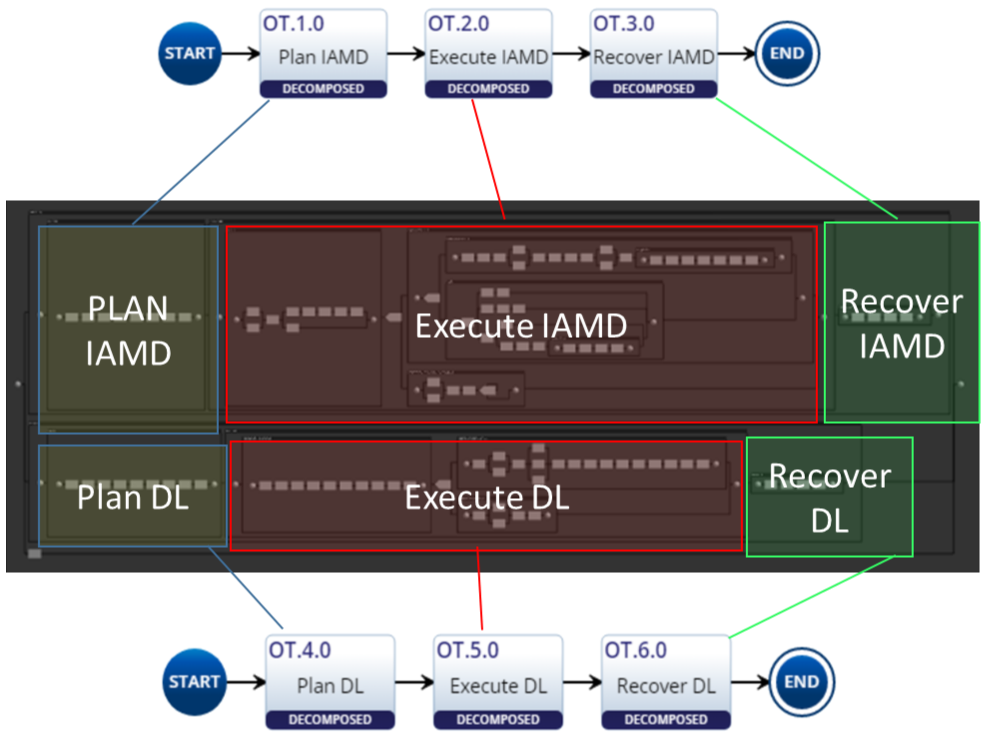


Figure 14. Innoslate IAMD/DL Overall Process.

In Innoslate, one implements the operational tasks created by using action diagrams. While action diagrams more closely align with LML architecting methods than DODAF, they work well to provide the structure necessary to create an executable architecture. The three primary tasks of IAMD depicted using action diagrams as shown in Figure 15.

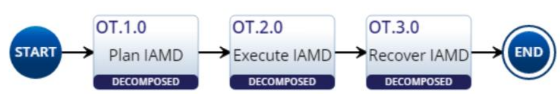


Figure 15. Innoslate IAMD Overall Process.

The planning phase of IAMD involves eight major steps as indicated in Figure 16. Every IAMD mission begins with the receipt of strategic guidance from a higher headquarters (OT.1.1). This guidance is evaluated by the operational chain of command consisting of the unified commanders, naval component commander, numbered fleet commanders, and varies task forces, task groups and task units. In the event of joint operations, a Joint Force Commander (JFC) is assigned. The JFC staff will conduct an operational analysis (OT.1.2) in which the primary purpose is to understand the problem and purpose of the operation. The JFC will then issue guidance as appropriate to enable the remaining planning process.

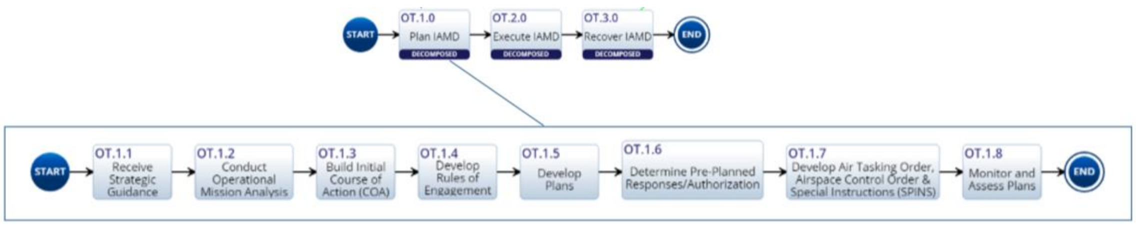


Figure 16. Innoslate Plan IAMD Process.

Execution of IAMD is broken into three major areas and conducted with both operational elements as well as tactical assets. The first task is OT.2.1 Observe. This task is decomposed in detail in Figure 39 of Appendix B. The primary tasks completed in OT.2.1 are monitoring the operational and strategic environments. This involves locating, assessing, or estimating the adversary’s capabilities as well as their limitations and understanding the environment in which they will be operating. Enablers for this task are intelligence collection, organic sensors as well as remote linked systems.

Once a contact is detected and sufficient information has been gathered, the engagement process can move through a decision point as indicated by the OR gate in Figure 17. This allows a decision maker to choose a defensive counter air mission or an offensive counter air mission. Modeling the engagement process of these tasks is further elaborated in 40–42 of Appendix B.

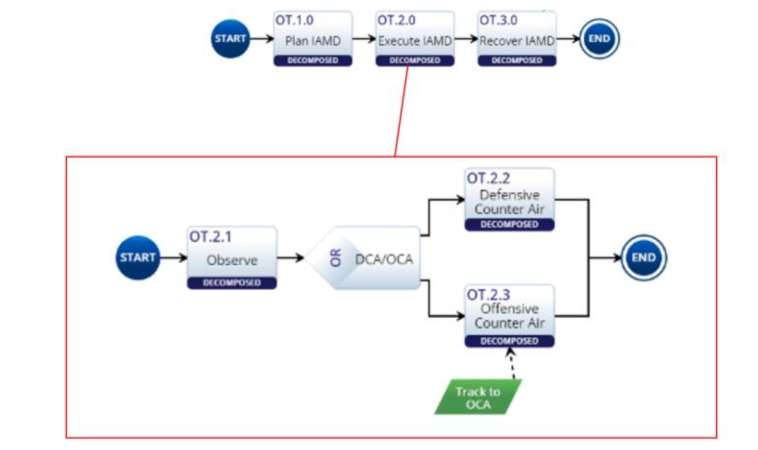


Figure 17. Innoslate Execute IAMD Process.

The final stage of the IAMD process is OT.3 recovery. This is largely an administrative as well as consequence and resource management process. Figure 18 depicts the decomposition of OT.3.0 and displays the four stages of the recovery process.

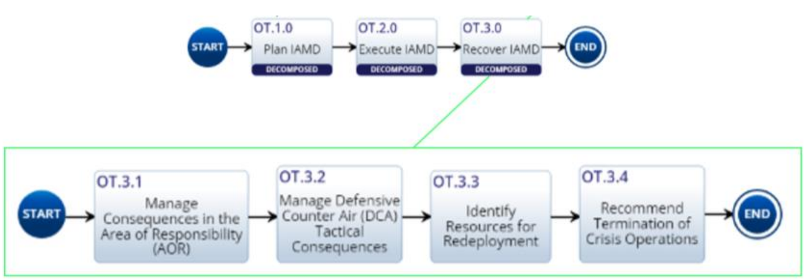


Figure 18. Innoslate Recover IAMD Process.

The architectural development of the distributed lethality process closely resembles that of the IAMD processes. The overall structure of the architecture is designed to take advantage of the same three basic processes of plan, execute, and recover.

Figure 19. Innoslate Overall DL Process.

The plan stages (Figure 20) of the DL process and policies are not yet formally developed therefore the architecture products created utilize the structure developed for the IAMD mission but adapted to include the required surface engagement elements such as developing an OPTASK SUW.

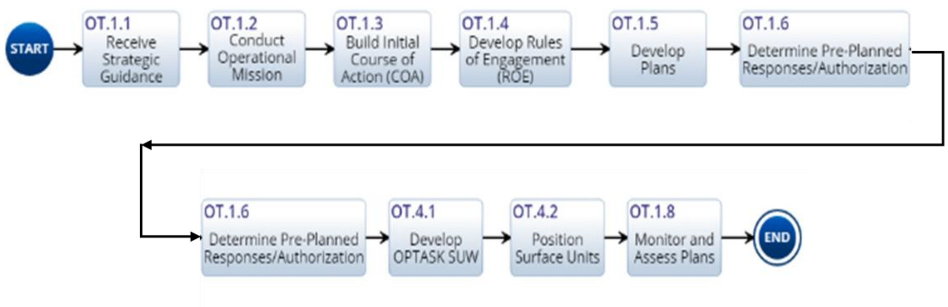


Figure 20. Innoslate DL Plan Process.

Execution of DL tasks, shown in Figure 21, is accomplished in operational tasks OT.5.1 Observe Surface, OT.5.2 Defensive Surface and OT5.3 Offensive Surface. Further decomposition of these operational tasks is contained in Appendix B.

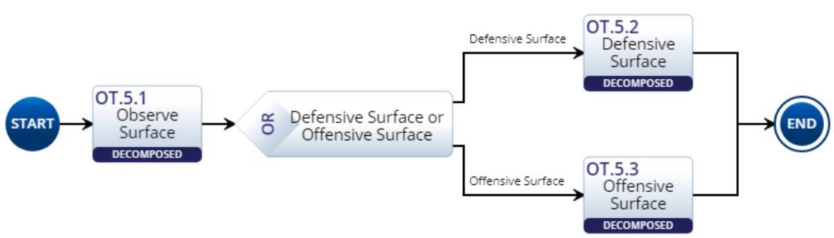


Figure 21. Innoslate DL Execute Process.

Finally, Figure 22 displays the last stage of the DL process, which is the recovery stage. This stage has four operational tasks associated with its operation. OT.6.1 and OT.6.2 are managing the offensive and defensive surface operations tactical consequences while OT.6.3 the operational and tactical leadership seek to identify the resources required for redeployment. Lastly, OT.6.4 is the recommendation to terminate surface operations and complete the DL mission.

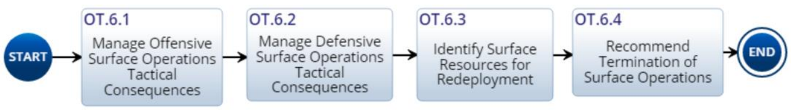


Figure 22. Innoslate DL Recover Process.

IV. SIMULATION AND ARCHITECTURE ANALYSIS

A. SCENARIO AND MODEL DEVELOPMENT

1. Description of Scenario

Discrete event modeling conducted for this thesis was done in ExtendSim governed by the following basic assumptions. The model developed considered a complex asymmetric environment with multiple threats engaging various AFP configurations. Figure 23 provides a general layout of the red force assets as well as the blue force engagement elements.

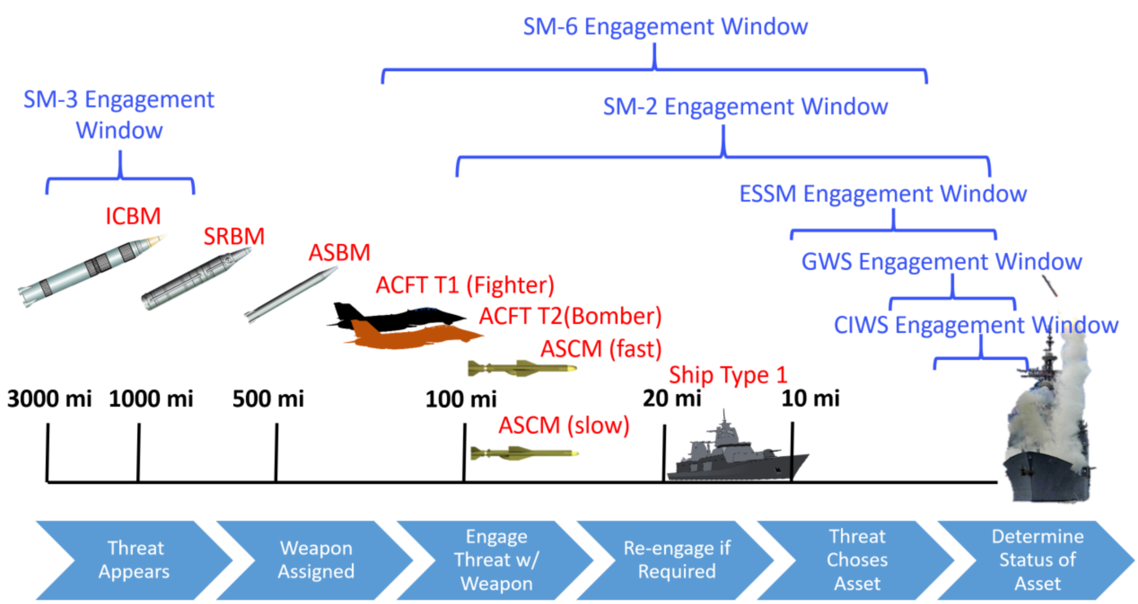


Figure 23. Threat Layout and Blue Force Capabilities.

Red force composition includes four broad categories of threats, which are ballistic missiles, cruise missiles, aircraft, and ships. The ballistic threats consider three primary threat types: long-range intercontinental ballistic missile (ICBM), short-range ballistic missile (SRBM), and anti-ship ballistic missile (ASBM). Engagement modeling is not conducted for the ICBM. One should only consider the ICBM based on the effects that it presents on the radar systems. This includes the reduction in the probability of detection resulting from increased loading on the radar processing elements and the resulting increase in radar resource allocation caused by tracking a complex ballistic target. The SRBM as well as the ASBM paths are modeled to represent a full detect-of-engage (DTE) process including the incorporation of layered defense against the ASBM.

The DTE process depicted on the lower portion of Figure 23 by the blue arrows begins with the detection of the threat by a given sensor, which is indicated by the arrow labeled "Threat Appears." The model then assigns a weapon based upon the kinematics of the target as well as the capabilities of the blue force engagement elements. When the target is within weapons release range of an engagement element, the engagement will begin. A kill evaluation will take place, and if the target has not been destroyed, it will be reengaged. If the threat is not destroyed by the first engagement element within the assigned engagement window, then additional engagement elements will be used as the range is to the threat is reduced. If no engagement elements kill the red force threat, it is counted as a potential hit against the blue force target and further analysis is conducted to evaluate as a kill.

The number of hits on the blue force targets and the percentage of red force targets are collected and utilized to evaluate the effectiveness of both the IAMD mission area as well as a combined DL and IAMD mission.

The scenario in Figure 23 includes threats from two different anti-ship cruise missiles. ASCM threats differ by the speed of the threat and labeled accordingly as ASCM fast for a supersonic missile and ASCM slow for a subsonic missile. Aircraft modeling is similar and considers an aircraft type 1 as a fighter type threat and aircraft type 2 as bomber type threat. Finally, a single ship class represents red force surface threats with varying numbers of ships deployed by the red forces. Input parameter values are contained Tables 3 and 4.

It is important to note, the values given for weapon capabilities and limitations are not actual values in order to avoid the unintentional compromise of classified materials. Users of this document can apply the correct values on a system at the desired level of classification to assess the results. It is the author's intent to use values that are within reasonable magnitude of the actual to produce valid and applicable results.

Table 3. ExtendSim Factor Value Assumptions

Blue Force Weapon Properties		
Factor	**Low Value**	**High Value**
SM3CycleTime (s)	1.5	2.5
SM3Speed (nm/s)	1.98	2.1
SM3PHit	0.85	0.95
SM3MaxRange (nm)	900	1100
SM3MinRange (nm)	50	150
SM6PHit	0.5	0.95
SM6PK	0.7	0.9
SM6MinRange (nm)	8	12
SM6CycleTime (s)	1.4	2.2
SM6Speed (nm/s)	0.6	0.7
SM6MaxRange (nm)	200	250
SM3Pk	0.7	0.95
SM2CycleTime (s)	0.9	1.2
SM2Speed (nm/s)	0.6	0.7
SM2Phit	0.5	0.8
SM2MaxRange (nm)	70	85
SM2MinRange (nm)	3	5
SM2Pk	0.6	0.8
CIWSPk	0.05	0.2
CIWSMaxRange (nm)	0.9	1.1
5inMaxRange (nm)	4.5	5.5
5inMinRange (nm)	1.8	2.2
5inSpeed (nm/s)	0.78	0.81
5"Pk	0.2	0.3
ESSMPk	0.25	0.35
ESSMMaxRange (nm)	9	10.5
ESSMMinRange (nm)	0.9	1.2
ESSMSpeed (nm/s)	0.7	0.75
TomahawkPhit	0.65	0.85
TomahawkPk	0.4	0.6
TomahawkMaxRange (nm)	900	1050
TomahawkMinRange (nm)	8	12
TomahawkSpeed (nm/s)	0.4	0.5
AGSPk	0.27	0.3
AGSMaxRange (nm)	6	8
AGSMinRange (nm)	1.8	2.2
AGSSpeed (nm/s)	0.42	0.46
EMCON Condition		
EMCON Condition	0	1

Blue Force Weapon Properties		
Factor	**Low Value**	**High Value**
HarpoonPhit	0.5	0.7
HarpoonPk	0.3	0.5
HarpoonMaxRange (nm)	60	80
HarpoonMinRange (nm)	4	6
HarpoonSpeed (nm/s)	0.32	0.38
OASUWPhit	0.8	0.9
OASUWPk	0.4	0.7
OASUWMaxRange (nm)	120	130
OASUWMinRange (nm)	4	6
OASUWSpeed (nm/s)	0.36	0.4
Blue Force Sensors		
UEWR Pd	0.6	0.8
Cobra Dane Pd	0.6	0.7
TPY-2 Pd	0.5	0.6
STSS Pd	0.65	0.75
SKA Pka	0.25	0.35
DSP Pd	0.45	0.55
DDG Type 1 SPY Radar Pd	0.85	0.95
DDG Type 1 Surface Radar Pd	0.6	0.7
DDG Type 2 SPY Radar Pd	0.88	0.98
DDG Type 2 Surface Radar Pd	0.65	0.75
CG Spy Radar Pd	0.83	0.93
CG Surface Radar Pd	0.6	0.7
DDG Type 3 AMDR Radar Pd	0.92	0.99
DDG Type 3 Surface Radar Pd	0.7	0.8
LCS 3D Radar Pd	0.6	0.7
LCS Surface Radar Pd	0.15	0.25
HVU Air/Surface Radar Pd	0.7	0.8
Blue Force Ships		
DDG Type 1	0	4
DDG Type 2	0	3
DDG Type 3	0	1
CG	0	3
LCS	0	2
HVU	0	1
Weapons Select Preference		
PselTomahawk	0	1
PselHarpoon	0	1
PselSM-6	0	1

Table 4. ExtendSim Factor Value Assumptions

DDG Type 1 Weapons			LCS Weapons		
Factor	**Low Value**	**High Value**	**Factor**	**Low Value**	**High Value**
DDG Type 1 SM3	0	16	LCS Harpoon	0	0
DDG Type 1 SM6	0	20	LCS OASUW	0	8
DDG Type 1 SM2	0	26	LCS GWS Rounds	100	200
DDG Type 1 Harpoon	0	4	LCS CIWS	1000	3000
DDG Type 1 ASROC	0	6	**HVU Weapons**		
DDG Type 1 Tomahawk	0	20	HVU CIWS	1000	3000
DDG Type 1 SEWIP	0	2	HVU OASUW	0	8
DDG Type 1 GWS Rounds	100	200	**Red Forces**		
DDG Type 1 ESSM	0	32	NumSRBM	0	20
DDG Type 1 CIWS Rounds	1000	3000	SRBMDetectRange (nm)	100	600
DDG Type 2 Weapons			SRBMSpeed (nm/s)	0.78	0.82
DDG Type 2 SM3	0	0	SRBMStartRange (nm)	500	700
DDG Type 2 SM6	0	26	NumASBM	0	20
DDG Type 2 SM2	0	32	ASBMDetectRange (nm)	20	400
DDG Type 2 ASROC	0	6	ASBMSpeed (nm/s)	1.7	1.9
DDG Type 2 Tomahawk	0	24	ASBMStartRange (nm)	300	600
DDG Type 2 SLQ-32	0	2	NUMICBM	0	6
DDG Type 2 GWS Rounds	100	200	ICBMDetectRange (nm)	1500	2500
DDG Type 2 ESSM	0	32	ICBMSpeed (nm/s)	3.8	4.5
DDG Type 2 CIWS Rounds	1000	3000	ICBMStartRange (nm)	2000	3000
DDG Type 3 Weapons			NumASCM(Fast)	0	20
DDG Type 3 SM3	0	15	ASCM(Fast)DetectRange (nm)	5	100
DDG Type 3 SM6	0	18	ASCM(Fast)Speed (nm/s)	0.485	0.655
DDG Type 3 SM2	0	30	ASCM(Fast)StartRange (nm)	80	120
DDG Type 3 ASROC	0	6	NumASCM(Slow)	0	20
DDG Type 3 Tomahawk	0	19	ASCM(Slow)DetectRange (nm	5	90
DDG Type 3 SEWIP	0	2	ASCM(Slow)Speed (nm/s)	0.12	0.18
DDG Type 3 AGWS Rounds	100	200	ASCM(Slow)StartRange (nm)	70	90
DDG Type 3 ESSM	0	32	NumAircraftType1	0	10
CG Weapons			AircraftType1DetectRange (n	90	110
CG SM3	0	0	AircraftType1Speed (nm/s)	0.25	0.35
CG SM6	0	30	AircraftType1StartRange (nm	110	170
CG SM2	0	50	NumAircraftType2	0	10
CG Harpoon	0	8	AircraftType2DetectRange (n	30	50
CG ASROC	0	10	AircraftType2Speed (nm/s)	0.15	0.165
CG Tomahawk	0	30	AircraftType2StartRange (nm	90	110
CG SEWIP	0	2	NumShipType1	0	8
CG GWS Rounds	200	400	ShipType1DetectRange (nm)	25	35
CG ESSM	0	32	ShipType1Speed (nm/s)	15	30
CG CIWS Rounds	1000	3000	ShipType1StartRange (nm)	5	40
			Mission Definition		
			Mission Type	1	3

2. Description of ExtendSim Model

ExtendSim software modeling incorporates the architecture developed in Chapter III and applies it to the scenario developed. Figure 24 presents a high-level overview of the behaviors represented in the ExtendSim model. Note that the probability of detection for each of the enemy threats is calculated in an initialization sequence (shown at the top of Figure 25). Distinct sequences for engagement of SRBMs, ASBMs, ASCMs (Fast), ASCMs (Slow), Aircraft Type 1 (Fighter), Aircraft Type 2 (Bomber) are highlighted in red. The sequence for the Distributed Lethality engagement is highlighted in green. Both the red defensive engagements and the green DL engagement are constrained by a shared set of resources (in terms of number of blue force ships and number of weapons available to each ship) shown in blue at the bottom of Figure 24.

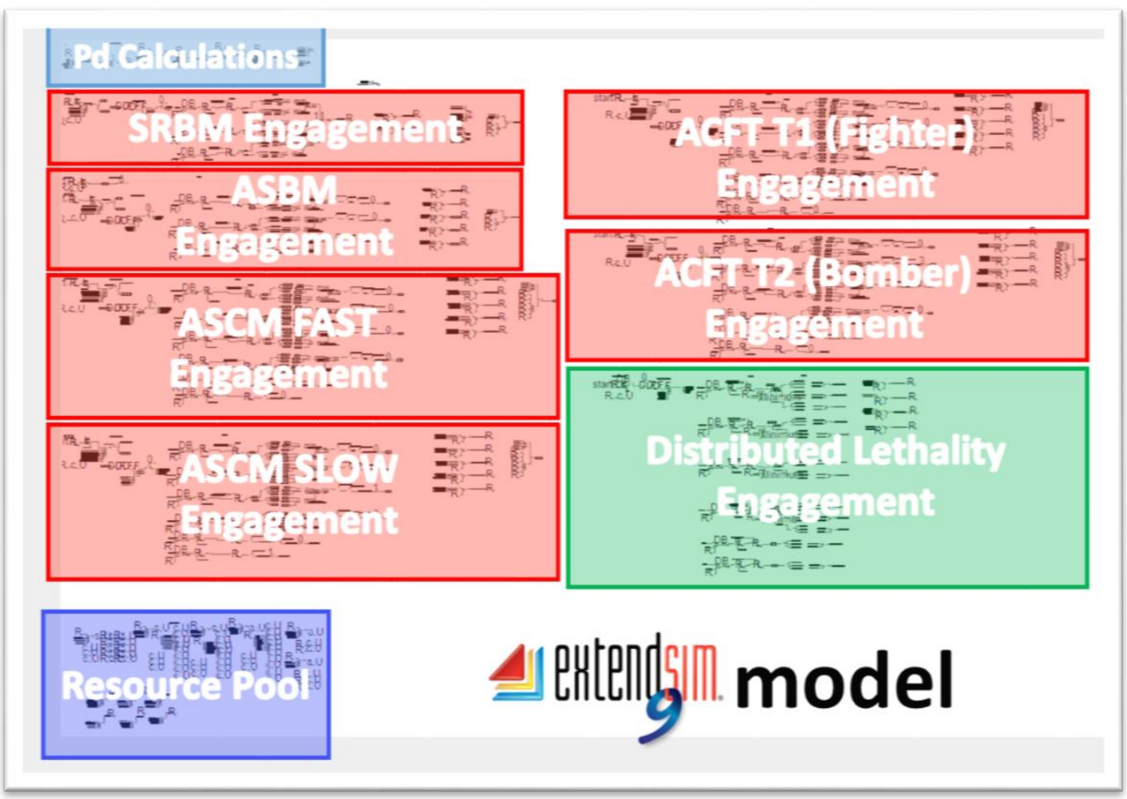


Figure 24. ExtendSim Model.

Blue force weapon systems are all assumed to be networked and share fire control quality data with each other. Each ship's sensors have unique probability of detection for their primary air search radar as well as their surface search radars. The sensor specific *Pd* calculations section of the model applies logic that evaluates the number of threats (*T*) and degrades a base probability of detection (Pd_{base}), for the specified sensor as shown in Table 3, by a scaling factor (α , β ,… χ) and finally aggregates an overall Pd_a for each threat as shown in equation 1.

$$Pd_a = Pd_{base} - (\alpha \times T1) - (\beta \times T2)...(\chi \times TN) \quad (1)$$

The calculated threat Pd_a for a specified sensor is aggregated as shown in equation 2 to develop an overall probability of detection for the specified threat.

$$Pd_{overall} = (1 - ((1 - Pd_a)(1 - Pd_b)...(1 - Pd_n)) \quad (2)$$

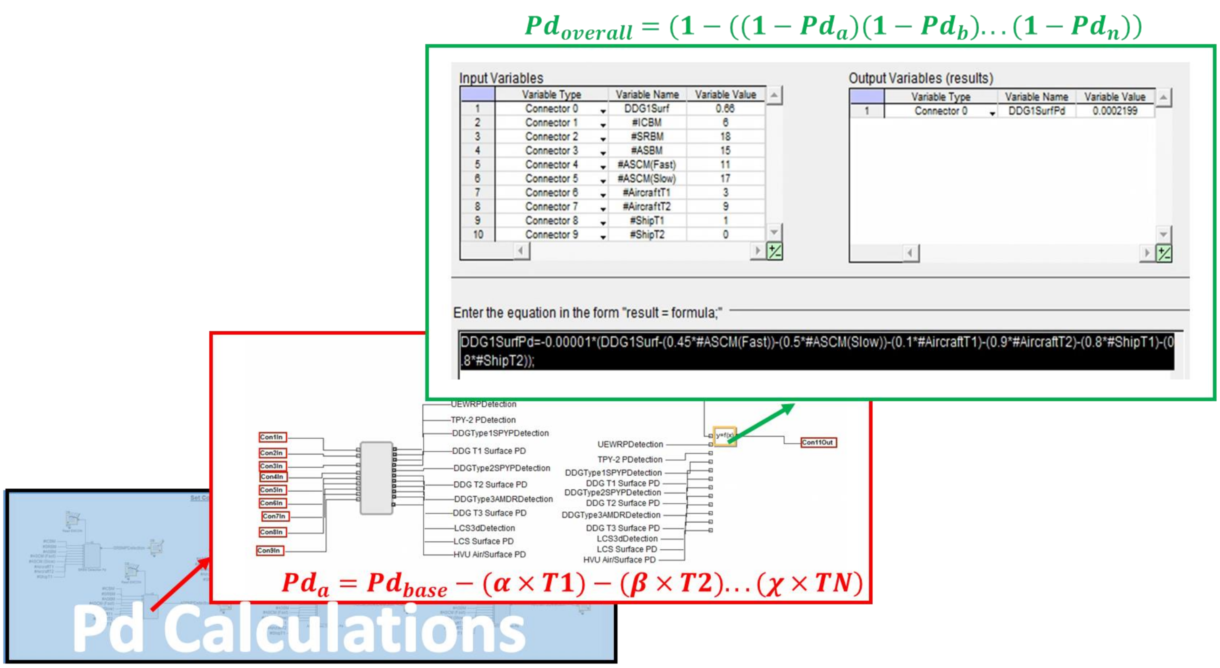


Figure 25. Probability of Detection Calculation.

The red areas shown in Figures 24 and 26 represent the IAMD modeling section of the ExtendSim model. Creation of the threats occurs independently; however, a common resource pool provides necessary elements such as ships, missiles, and guns.

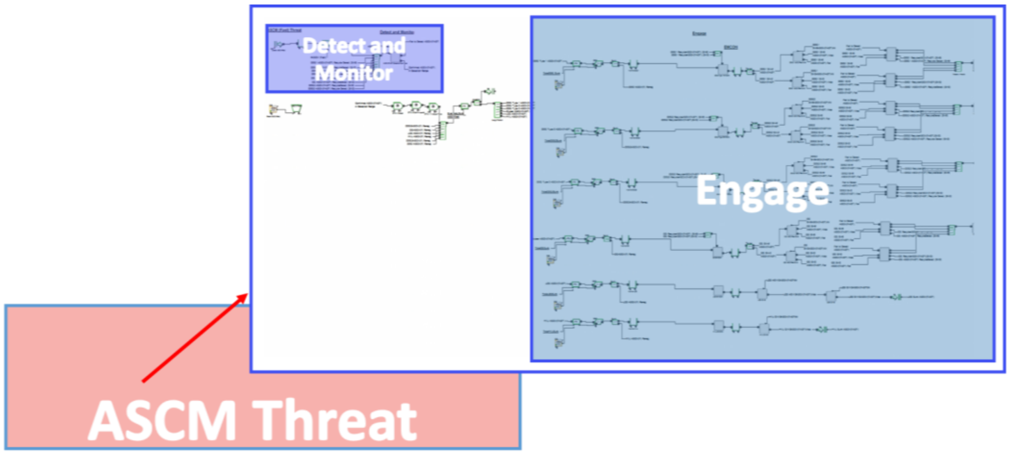


Figure 26. Threat Engagement Section.

The green area is the DL portion of the model and includes logic to implement EMCON, mission type changes and weapon select logic as indicated in Tables 3 and 4 and shown in Figure 27.

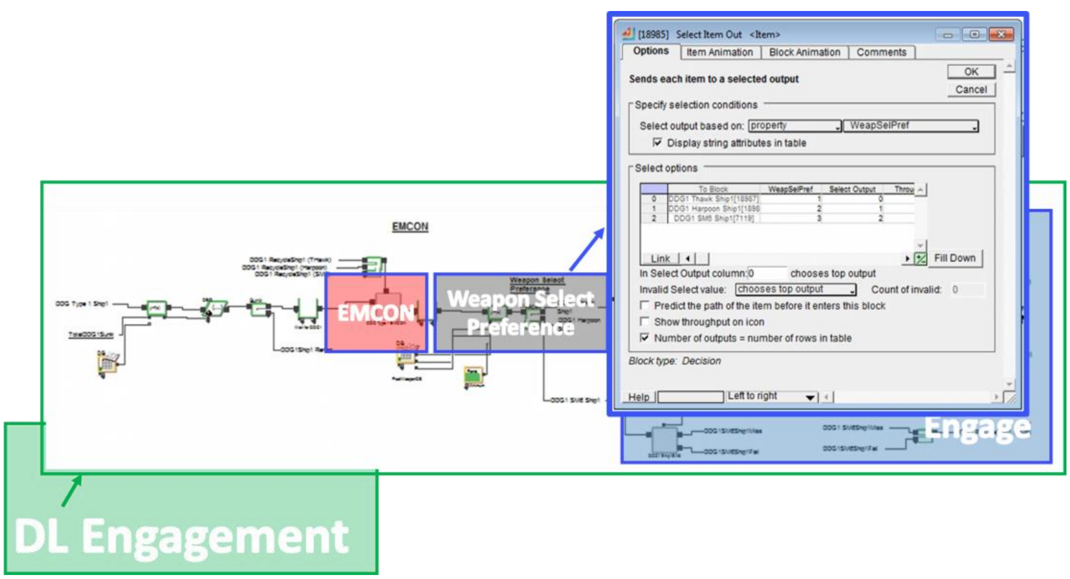


Figure 27. DL Engagement Logic.

Selection logic for DDG type 1 platform (shown in Figure 27) illustrates how, upon exiting the EMCON logic, threat routing is based on the weapon preference. A table of percentages ranging from 0–100% represents the commander’s likelihood of selecting a harpoon, maritime strike tomahawk (MST) or SM-6 to engage the red surface threat. Upon selection, the threat is sent the engagement section of the model.

When conducting anti-surface engagements, a commander must choose the most effective weapon possible. A lack of published weapon selection doctrine for DL operations, as well as a need to explore the impacts of weapon selection on a DL mission, necessitates the use of a weapon select preference logic. The weapon selection logic is modeled using a space filling mixture design of experiments (DOE) shown on the left of Figure 28. The correlation and scatterplot matrix to the right provide a visual representation of the design space covered by the selected DOE and indicate that the design space is well covered for feasible combination of weapon select preferences, based on the restriction that requires the sum of the preference to be equal to one.

Weapons Select Preference		
PselTomahawk	PselHarpoon	PselSM-6
0.086446638	0.512031971	0.401521391
0.137120101	0.065757343	0.797122557
0.966460647	0.032914001	0.000625352
0.479854592	0.00088105	0.519264358
0.025360979	0.962589206	0.012049815
0.539404844	0.416154152	0.044441005
0.000012432	0.342922318	0.65706525
0.683845721	0.132763347	0.183390932
0.385250321	0.285201691	0.329547988
0.216199447	0.655209285	0.128591268

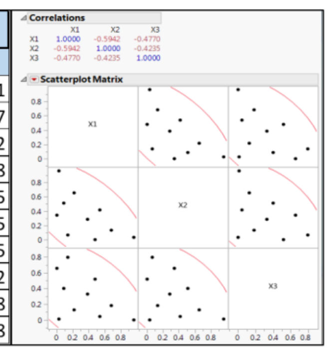


Figure 28. Weapon Selection DOE.

3. Measures of Effectiveness

Evaluation of the model requires the selection of specific measure of effectiveness (MOE). MOEs are used to assess the level of significates that a particular factor has on the response variable. The two MOEs selected for evaluation in this model are:

MOE 1: Blue Force Vulnerability (# of hits of the opposing force on blue forces)

B. MOE 2: PERCENT OF TARGETS DESTROYED (# OF OPPOSING FORCE DESTROYED DIVIDED BY TOTAL TARGETS) EVALUATION

The first step in conducting an evaluation of the ExtendSim model created to represent the architecture developed in Chapter III of this thesis is to identify the input (independent) and output (dependent) factors. For both MOEs, the factors identified in Tables 3 and 4 will be used as the inputs. The output or response variables will vary based on the MOE evaluated. The next step is the creation of a DOE based on the input variables.

1. Design of Experiments.

Identification of 150 input factors necessitates the use of a DOE capable of exploring a complex design space in a logical manner. The goal of the DOE is to reduce the correlation between input variables, which is easily accomplished through utilization of orthogonal (or, at least, nearly orthogonal) design matrices. Vieira (2012) developed a spreadsheet that uses a nearly orthogonal and balanced design (NOB). He states, "Nearly orthogonal means that the maximum absolute pairwise correlation between any two design columns is minimal. Nearly balanced means that for any single factor column, the number of occurrences for each factor level is nearly equal" (Vieira 2012). The spreadsheet allows for the creation of a DOE capable of examining up to 300 input variables using 512 design points in which 100 of the factors can be continuous and the remaining occur in blocks of 20 k-level discrete factors (where k = 2, 3 … 11 levels).

The NOB design was then crossed with the previously created weapon selection DOE shown in Figure 29, resulting in a 5,120-point design. Each of the 10 design points were evaluated against every possible combination of factors created by the NOB design. Testing correlation of factors ensures validity of the DOE. To save space, the full correlation matrix is not shown. Instead, Figure 29 shows the first seven lines of the full matrix.

	PselTomahawk	PselHarpoon	PselSM-6	NumSRBM	SRBMDetectRange	SRBMSpeed	SRBMStartRange
PselTomahawk	1.0000	-0.5942	-0.4770	0.0000	-0.0000	0.0000	0.0000
PselHarpoon	-0.5942	1.0000	-0.4235	0.0000	-0.0000	-0.0000	-0.0000
PselSM-6	-0.4770	-0.4235	1.0000	-0.0000	0.0000	-0.0000	0.0000
NumSRBM	0.0000	0.0000	-0.0000	1.0000	-0.0040	0.0066	-0.0050
SRBMDetectRange	-0.0000	-0.0000	0.0000	-0.0040	1.0000	0.0038	-0.0157
SRBMSpeed	0.0000	-0.0000	-0.0000	0.0066	0.0038	1.0000	-0.0128
SRBMStartRange	0.0000	-0.0000	0.0000	-0.0050	-0.0157	-0.0128	1.0000

Figure 29. Input Variable Correlation Matrix.

The matrix values range from -1 to +1. A value of +1 indicates a positive correlation and that the variables increase or decrease in a perfectly synchronized manner, while -1 value indicate a negative correlation indicating that while one variable increases the other decreases. The correlation matrix indicates most values are near zero and therefore very little correlation exists between input variables in the design.

2. MOE 1: Percent of Targets Destroyed.

Per the design matrix presented in the previous section, the 5,120-point design was run in ExtendSim and output data was collected. The regression analysis indicates that mission type is the dominant factor. Mission type is defined by three possible scenarios: mission type one is a purely IAMD mission, type two is a DL mission while mission type three is a combined mission. Figure 30 shows a partial display of the effect summary. The full summary of main effects screening is included in Appendix E.

Effect Summary

Source	LogWorth	PValue
MissionType	24.219	0.00000
AircraftType2StartRange	18.936	0.00000
CG SM6	16.423	0.00000
DDG Type 1 SM2	15.334	0.00000
LCS CIWS	14.338	0.00000
NumSRBM	13.900	0.00000

Figure 30. Partial Effects Summary for Red Forces Destroyed.

Further analysis is required to determine which if any additional factors influence the defined MOE. Analysis of the mean difference in percent of red forces lost by mission type indicates that there is also a statistical difference when viewed by mission type. A mean value of 58.5% and maximum value of 97.1% of the red forces were destroyed when conducting a purely IAMD mission. The number of red forces destroyed increased to a mean value of 69.2% and a maximum of 97.6% when the DL concept was applied in an IAMD environment. Figure 31, created utilizing the JMP 13 software package, provides a visual representation of the analysis by mission type.

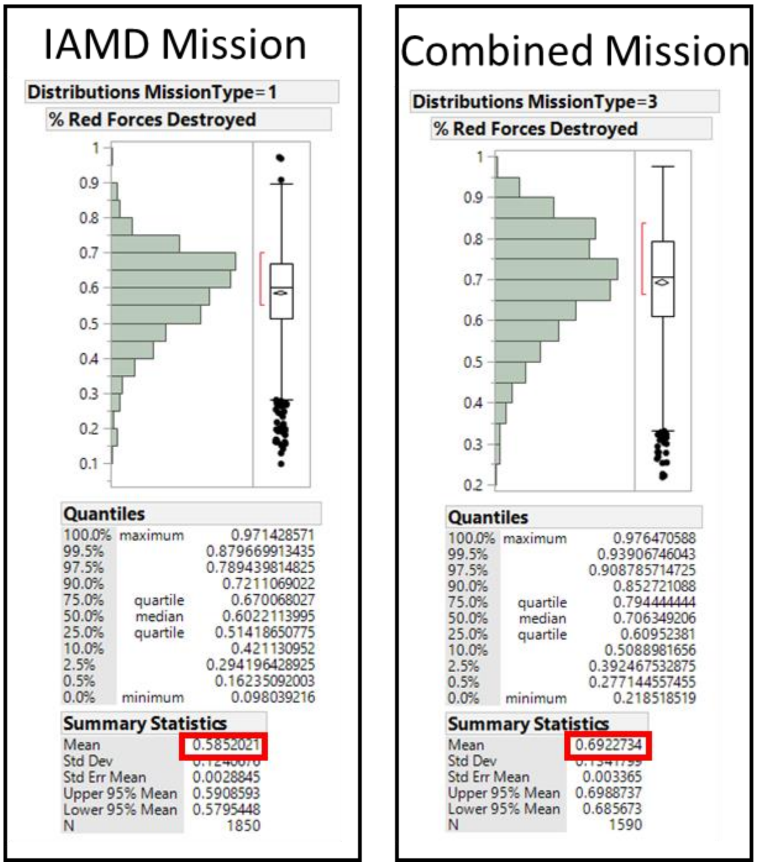


Figure 31. Red Force Losses by Mission Type.

Factor isolation is conducted by removing mission type from the modeling effects equation and applying it as a variable to split the analysis. While removing the mission type from the analysis will ultimately decrease the amount of variation described by the fitted model, it allows segmented analysis to occur that prioritizes the variables that have the most statistically significant impact on performance in each mission type. Figure 32 shows the results of the factor isolation by mission type.

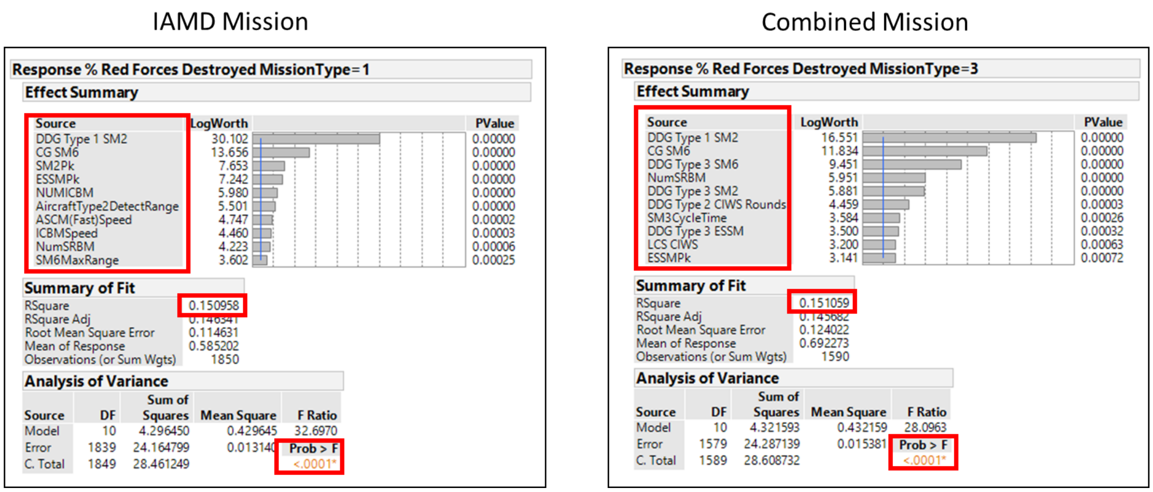


Figure 32. Effect Summary by Mission Type.

The IAMD mission model developed has a low RSquare value of 0.15, indicating that statistically it may have limited predictive utility. The low RSquare value is due to separating factor isolation necessary to view the mission areas separately. Warfare commanders may still find that operational utility of the model is still very relevant, and isolation by mission type shows that when conducting an IAMD mission the dominating factors are the number of missiles and performance of those missiles. Statistically significant factors for IAMD mission include:

- number of SM2 on DDG Type 1
- probability of kill for SM2 and ESSM
- number of SM6 on Cruiser
- max range of SM6
- number of threat ICBM and SRBM
- detection range of Aircraft Type 2
- speed of ASCM

Analysis of the factors influencing the combined mission indicates some overlap in the necessity for increased numbers of SM2 and SM6. The statistically significant factors for a combined mission are:

- number of SM2 on DDG type 2 and 3

- number CIWS rounds on DDG type 2
- number of SM6 on Cruiser
- number of ESSM on DDG type 3
- probability of kill for ESSM
- probability of hit for SM6
- cycle time for SM3
- number of SRBM
- detection range of ASCM Fast

Statistically significant factors for each mission type are focused around performance characteristics of blue force missiles as well as the numbers of SM2s available to both Cruisers and Destroyers. The number of SM6s available to Destroyers has a significant statistical impact on the performance in both mission types. Threat characteristics such as the number and speed of threats showed statistical significance as well.

3. MOE 2: Blue Force Vulnerability

Initial analysis of the data is conducted using simple averaging techniques. The losses are averaged by mission type and Figure 33 indicates a small increase in the average number of blue forces lost when shifting from an IAMD mission to a combined IAMD/DL mission. The results of this analysis also indicate that the most capable platform (DDG Type 3) sustained the least losses, while the defended area incurred the most hits. The LCS and HVU platforms modeling included fewer layered defense options in comparison to other platforms and, as such, sustained a larger number of hits when compared to the DDGs with a layered defense system.

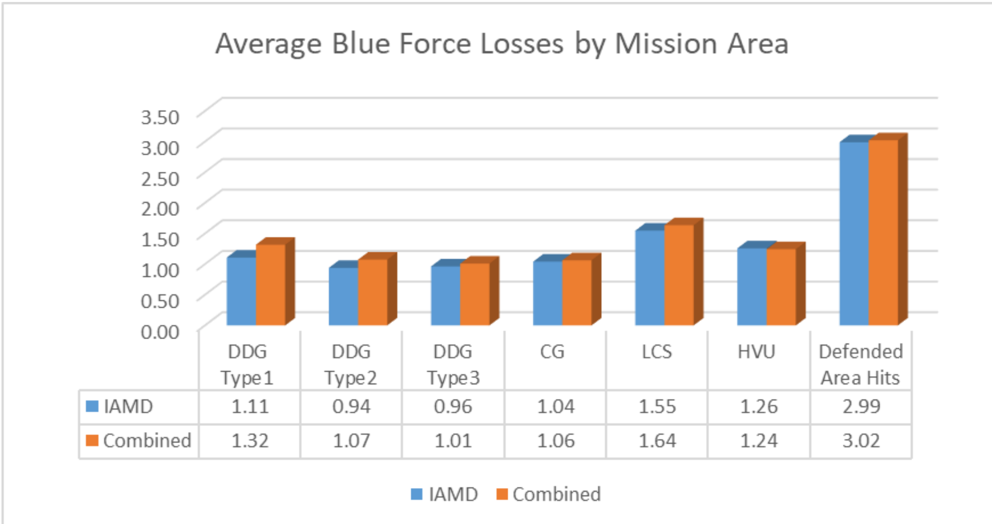


Figure 33. Average Blue Force Losses by Mission Area.

Further analysis to determine the implications of combining an IAMD and DL mission is done by using main effects screening (see Appendix E). Regression analysis of the results indicated that the mission type did not have a statistically significant effect on the number of blue forces lost. Although not statistically significant, mission type may be operationally significant, and analysis is conducted to examine the impact of mission types. EMCON condition showed a statistically significant effect and will be used for further analysis.

Examination of Figure 34 shows that the mean difference in blue force losses by mission indicates a change from 9.84 to 10.36 yielding an increase of 0.52 or half a ship loss average when conducting a combined DL/IAMD mission.

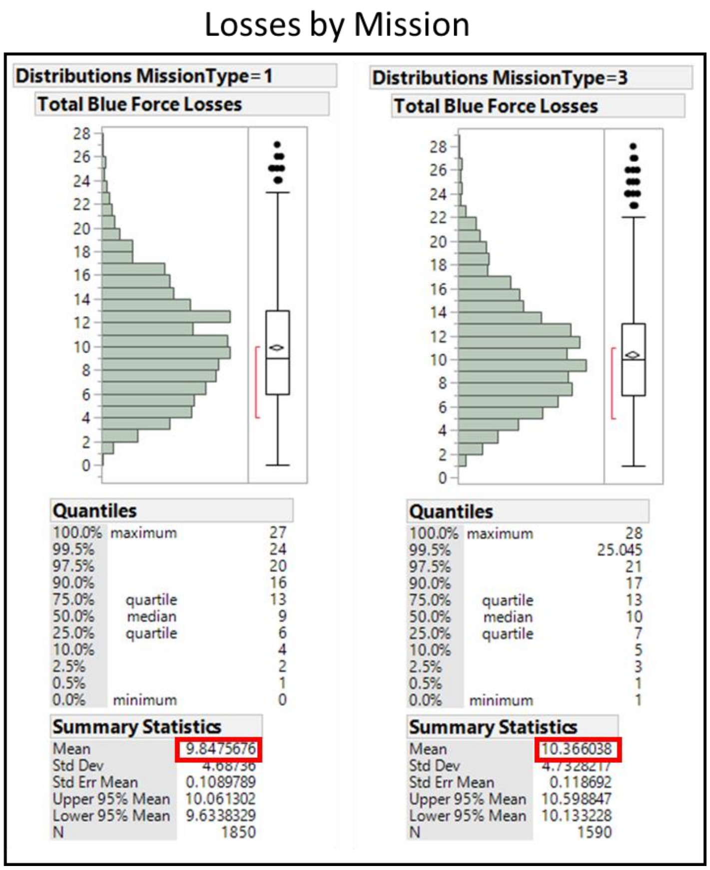


Figure 34. Blue Force Losses by Mission Type and EMCON Condition.

Analysis of EMCON conditions (Figure 35) shows losses increased from an average of 6.34 blue forces to 7.21 blue forces when not in an EMCON condition. Increases may be attributed to an EMCON change delay of five seconds, which is incorporated in the model to simulate the time, required to receive indication of a target and subsequently begin radiating radars and building a track file.

Losses by EMCON Condition

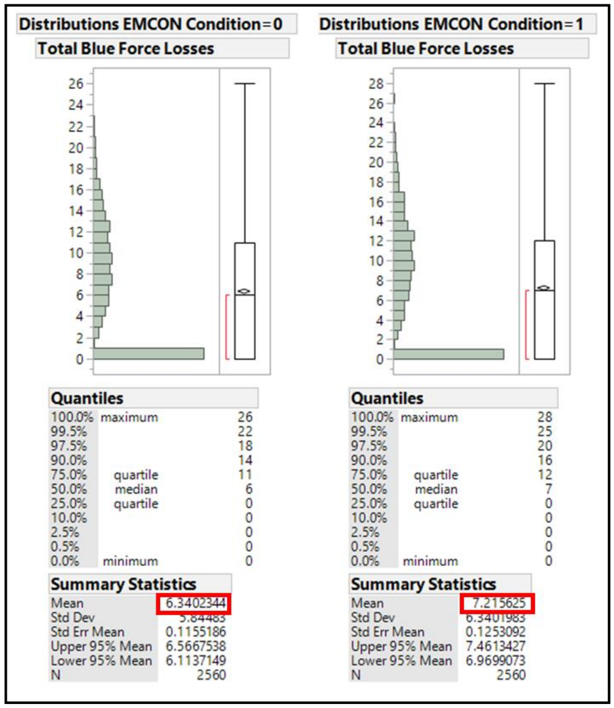


Figure 35. Blue force Losses by Mission Type and EMCON condition.

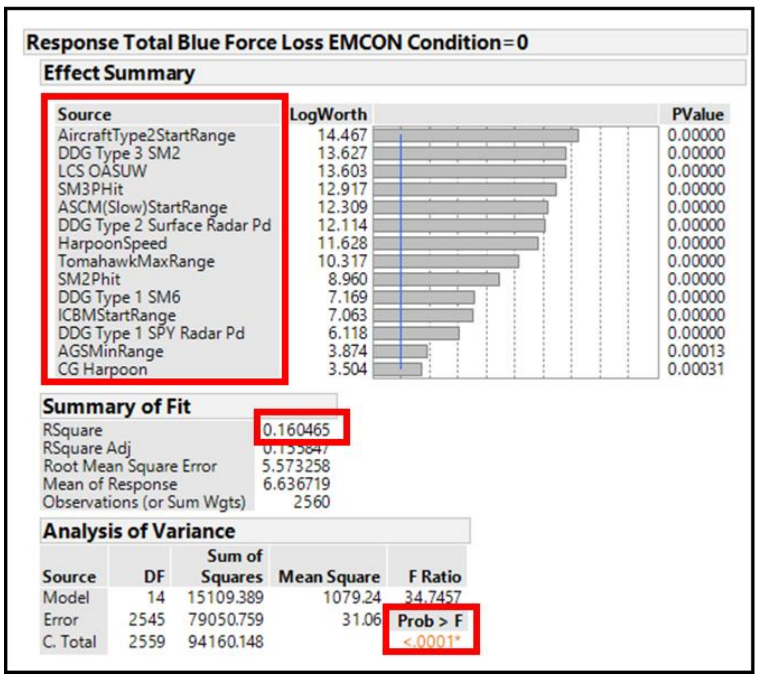
To determine the primary factors affecting blue force losses, regression analysis was conducted by mission type as well as by EMCON condition. Table 5 provides a summary of the top 10 factors that affected blue force losses.

Table 5. Top 10 Factors Affecting Blue Force Losses

Top 10 Factors Affecting Blue Force Losses			
Mission		EMCON	
IAMD	Combined IAMD/DL	Not in EMCON	EMCON
Number of SRBM	Number of SRBM	Start Range of Aircraft (Bomber)	Number of SM6 on DDGT2
Number of ASCM (Fast)	Number of ASCM (Slow)	Number of SM2 on DDGT3	Number of SM2 on DDGT3
Number of ASCM (Slow)	Number of ASCM (Fast)	Number of OASUW on LCS	Number of SM2 on Cruiser
Number of Aircraft (Fighter)	EMCON Condition	Probability of Hit for SM3	Cycle Time for SM3
Number of SM6 on DDGT1	Number of Aircraft (Bomber)	Start Range of ASCM (Slow)	Probability of Kill for SM2
Number of SM2 on DDGT3	Number of SM2 on DDGT3	Surface Radar Pd for DDG Type 2	Detection Range for SRBM
Number of SM2 on DDGT1	Number of SM2 on Cruiser	Speed of Harpoon	Speed of ASCM (Fast)
Number of SM2 on Cruiser	Number of SM2 on DDGT2	Max Range of Tomahawk	Probability of Kill for Tomahawk
Number of ASBM	Number of ASBM	Probability of Hit for SM2	Number of CIWS on HVU
Number of SM6 on DDGT2	Probability of Hit for SM6	Number of SM6 on DDG Type 1	Speed of ICBM

Initial Factor isolation of the blue force losses by EMCON condition using regression analysis indicated the numbers of threat missiles dominated the results (see Figures 53 and 54 in Appendix E). The number of threat missiles is not an easily actionable factor; therefore, additional regression analysis removed the number of threat missiles as potential components of the regression, to isolate additional factors of interest. Figures 36 and 37 provide the results of the regression analysis.

No EMCON



Response Total Blue Force Loss EMCON Condition=0

Effect Summary

Source	LogWorth	PValue
AircraftType2StartRange	14.467	0.00000
DDG Type 3 SM2	13.627	0.00000
LCS OASUW	13.603	0.00000
SM3PHit	12.917	0.00000
ASCM(Slow)StartRange	12.309	0.00000
DDG Type 2 Surface Radar Pd	12.114	0.00000
HarpoonSpeed	11.628	0.00000
TomahawkMaxRange	10.317	0.00000
SM2Phit	8.960	0.00000
DDG Type 1 SM6	7.169	0.00000
ICBMStartRange	7.063	0.00000
DDG Type 1 SPY Radar Pd	6.118	0.00000
AGSMinRange	3.874	0.00013
CG Harpoon	3.504	0.00031

Summary of Fit

RSquare	0.160465
RSquare Adj	0.155847
Root Mean Square Error	5.573258
Mean of Response	6.636719
Observations (or Sum Wgts)	2560

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	14	15109.389	1079.24	34.7457
Error	2545	79050.759	31.06	Prob > F
C. Total	2559	94160.148		<.0001*

Figure 36. Tailored Blue Force Effect Summary by EMCON Condition (Non-EMCON Mission).

EMCON Mission

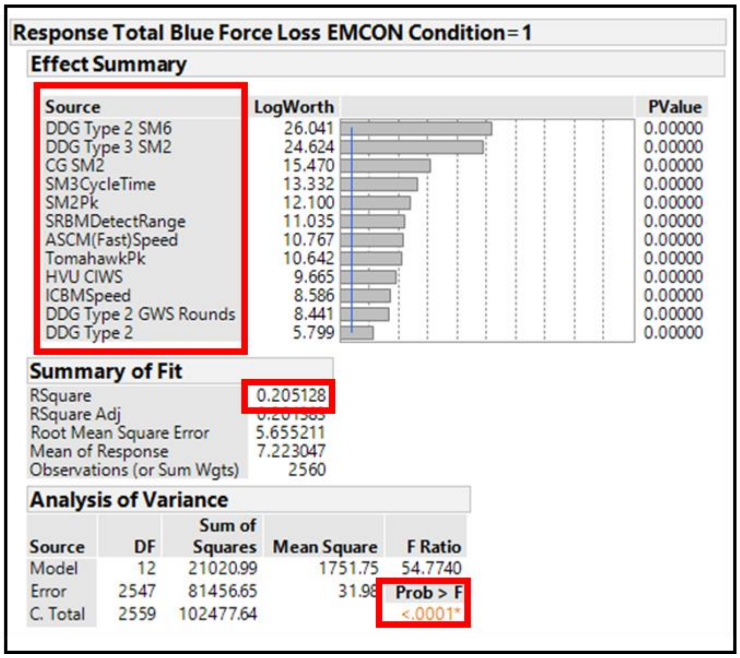


Figure 37. Tailored Blue Force Effect Summary by EMCON Condition (EMCON Mission).

The tailored analysis of the blue force losses by EMCON condition results indicate the primary factors for non-EMCON mission are the start range of aircraft type 2, number of SM2s on DDG type 3 as well as the number of Offensive Anti-Surface Warfare (OASUW) missiles. Some other important factors shown were the speed of the harpoon and number of harpoons on the cruiser. Interestingly, the main factors in an EMCON mission were the number of SM-2 and SM-6 missiles. The probability of kill for the SM2 and tomahawk missiles were statistically significant factors discovered in the regression analysis. While the results are not definitive, it is possible that the change in parameter impact by EMCON condition can be attributed to a reduced harpoon and tomahawk engagement window due to the increase in detection time resulting from the assumed five-second transition from an EMCON condition to having sensors available to engage the target. The higher speed associated with the SM6 and SM2 missiles allowed for more engagement opportunities in a smaller engagement window than that of the slower OASUW and harpoon missiles.

Ultimately, the discrete event simulation analysis indicates that combined operations can yield nearly an 11% increase in red force losses but this benefit is achieved at the cost of an average blue force increase of half a ship. Therefore, employment of the DL concept must be weighed against the acceptable level or risk allowed for the mission.

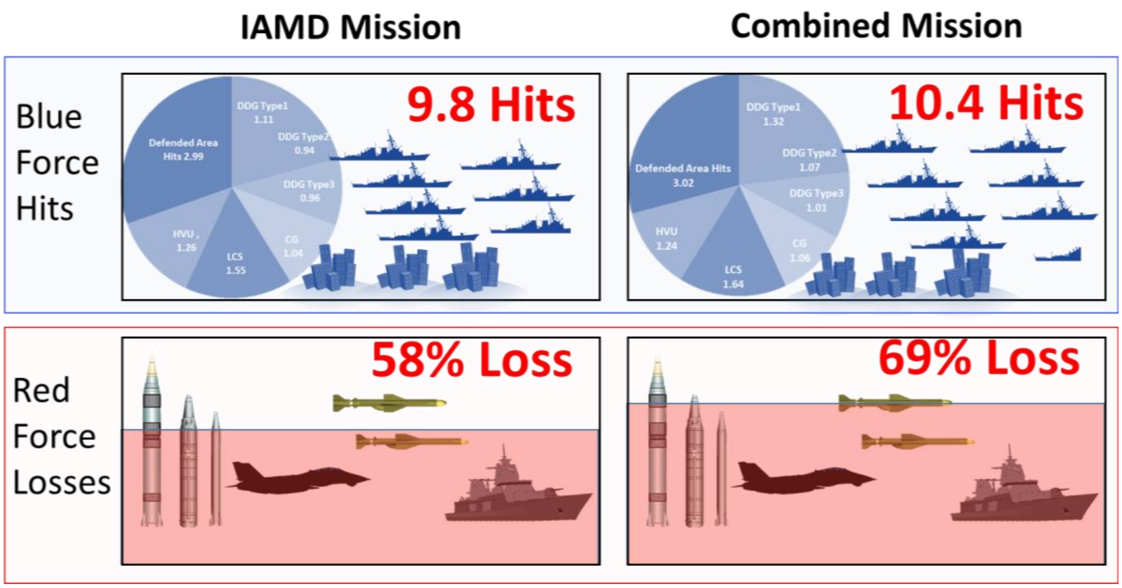


Figure 38. Comparison of Blue Force Hits to Red Force Losses.

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V. CONCLUSIONS

A. KEY POINTS

The basis for this thesis was a focus on developing an integrated architecture that combines integrated air and missile defense missions with the proposed distributed lethality concept. The developed architecture could then be used to analyze the performance of the DL factors in an IAMD environment.

In Chapter I, the DL concept and IAMD mission area were introduced and the methodology for analysis was presented. The chosen research method is the analysis method, which allowed for the completion of the defined research objectives:

- Apply standardized systems architecture tools and techniques to integrate architectures for IAMD and DL.
- Develop and analyze a discrete event simulation consistent with the systems architecture that identifies key performance drivers and operational decisions that balances conflicting requirements for IAMD and DL.

Chapter II introduced relevant research that has been conducted in the areas of DL and IAMD. The idea was presented, explaining that DL is an offensive concept, which takes advantage of deceptive and dispersed naval forces, and thereby, introduces an increased level of uncertainty for enemy commanders. Conversely, IAMD was presented as a warfare area, which seeks to provide defense to friendly forces in an overt manor. The chapter also provided a brief survey of SE tools utilized to form the foundation for the architectural development in Chapter III.

Chapter III presented the MBSE MEASA process as well as the architecture schema utilized to develop a combined architecture. The schema presented a process that enabled the requirements for DL as well as IAMD to be derived, evaluated, and then traced to a relevant mission capability derived from JCAs. To achieve the required capabilities operational activities were identified using the Unified Naval Task List and associated NTAs. Finally, the OAs were enabled by operational tasks, all of which were developed using Innoslate as a tool for creating executable architectures.

Chapter IV presented the developed architecture and tied it to a relevant threat scenario, which formed the basis of the discrete event simulation model created using ExtendSim software. From this, a design of experiments was presented incorporating 150 input factors to analyze their effects on the percentage of red force losses as well as the losses incurred by blue forces.

Results from the architecture development and subsequent execution of the discrete event simulation yield the following insights based on the assumptions presented.

1. IAMD and DL share a large number of requirements as well as operational activities; however, it is possible to create a shared architecture that can meet the demands of both IAMD missions as well as DL missions.

2. There is a statistically significant difference in terms of the percent of red forces lost when conducting a IAMD mission vs a combined mission, which results in the ability to destroy a greater number of red forces when conducting a combined mission.

3. Number and performance of blue force weapons has a statistically significant impact of the number of red force casualties.

4. EMCON condition is a distinguishing factor, which must be considered when conducting combined operations.

The distributed lethality concept provides for a new and innovative approach to warfighting that shifts naval tactics to a more offensive paradigm. This shift is one that requires consideration in the development of supporting technologies. This research indicates that by leveraging standardized systems engineering tools, and developing architectures that fully embrace offensive and defensive warfighting requirements, development of systems that can provide the necessary capabilities to achieve individual or combined mission sets is promising.

B. FURTHER RESEARCH

The concept of DL is still very much in the early stages of development. While this thesis presented some of the prior research that has been conducted and further added to the body of knowledge, there are still a number of opportunities to enhance the understanding of the DL concept and the implications it may have on other warfighting areas. Some potential areas of future research include the following:

(1) Classified adaptation of the discrete event simulation

While a succinct architecture has been created and modeled, the outputs of the model are a direct reflection of the input assumptions. All assumptions and perimeter estimations were made based on unclassified research. A researcher could support advancements in the research of the impact of DL in an IAMD environment by implementing a classified adaptation of this research. The architecture development and simulation using Innoslate and ExtendSim software can be quickly replicated in a secure computing environment and results will support further decision making by warfighting and technology development leadership.

(2) Integration of unmanned systems to the architecture and simulation

The scope of the modeling to examine the interaction of DL and IAMD considered traditional naval forces structures. Further research would benefit from adapting a refined model to consider the effects of unmanned systems. The proliferation of unmanned technologies may play an advantageous roll in the completion of both missions using systems to increase situational awareness, aid in the preparation of the battlespace, conduct remote engagements, or store large quantities of missiles.

(3) High fidelity modeling of factors impacting probability of detection

The factors that affect the probability of detections are complex and change as a function of time, threat, range, radar cross section, environment and more. A more elaborate calculation to determine the impact of high-density threat environments on radar detection would yield a more predictive model.

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APPENDIX A. INTEGRATED AIR AND MISSILE DEFENSE (IAMD) TIER I

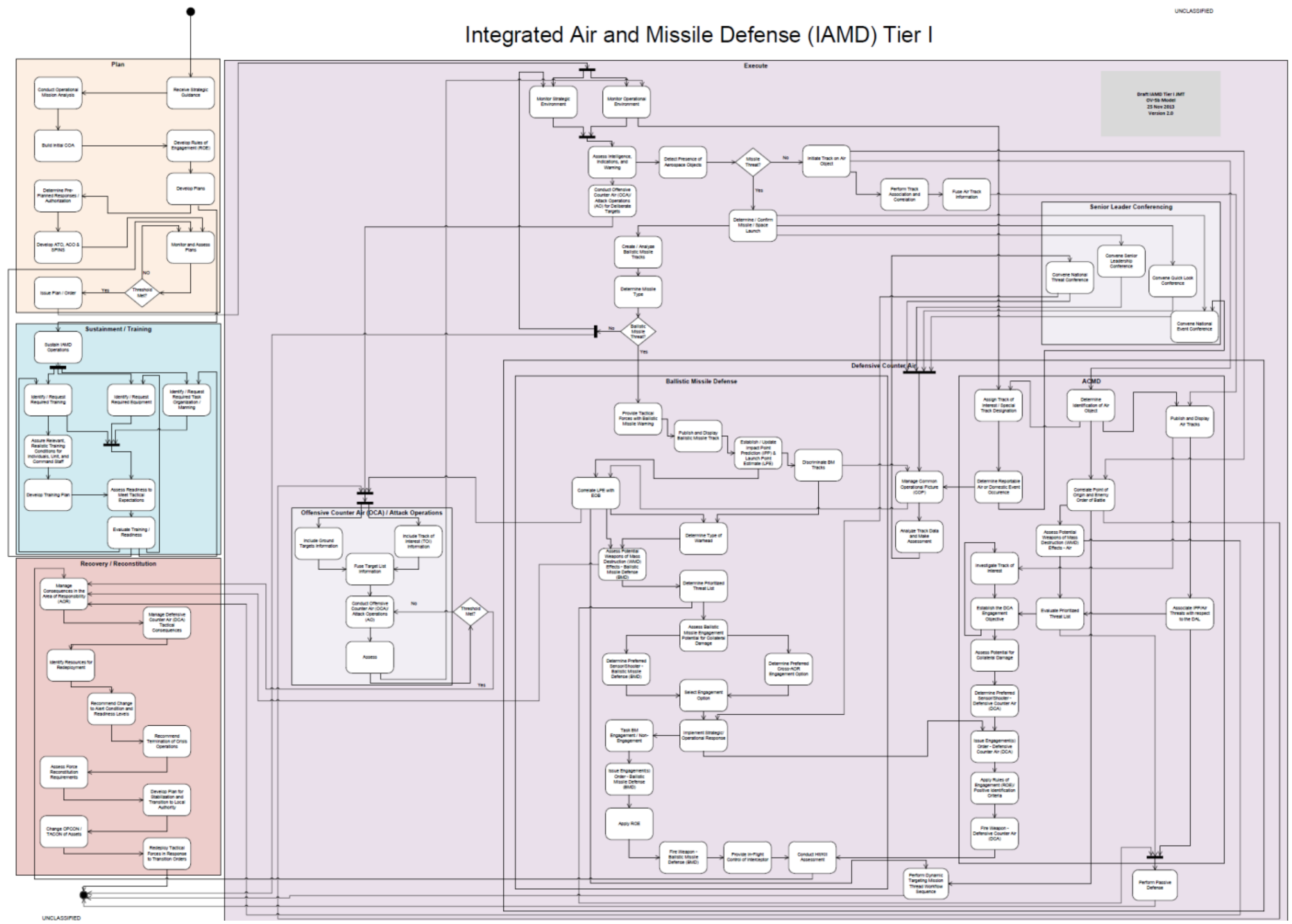

Figure 39. IAMD Tier I. Source: Joint Staff J6 (2013).

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APPENDIX B. INNOSLATE ARCHITECTURE PRODUCTS.

A. INTEGRATED AIR AND MISSILE DEFENSE PRODUCTS

Figure 40 provides an overview of IAMD Operational Task 2.1 Observe:

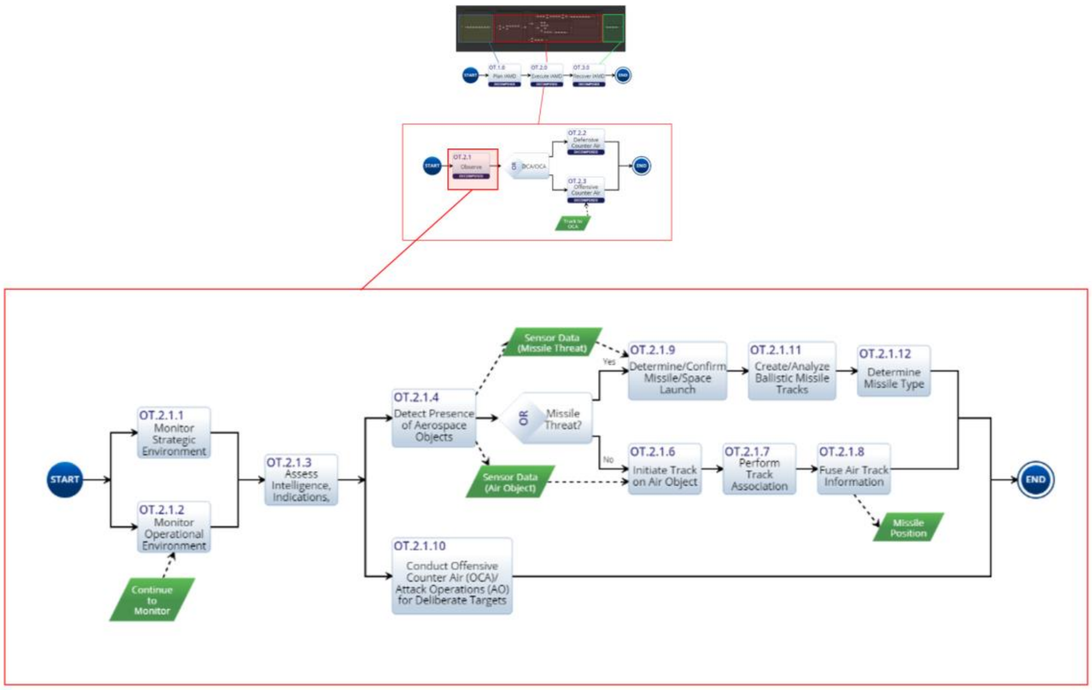

Figure 40. IAMD Operational Task Observe.

IAMD Operational Task 2.2 Defensive Counter Air:

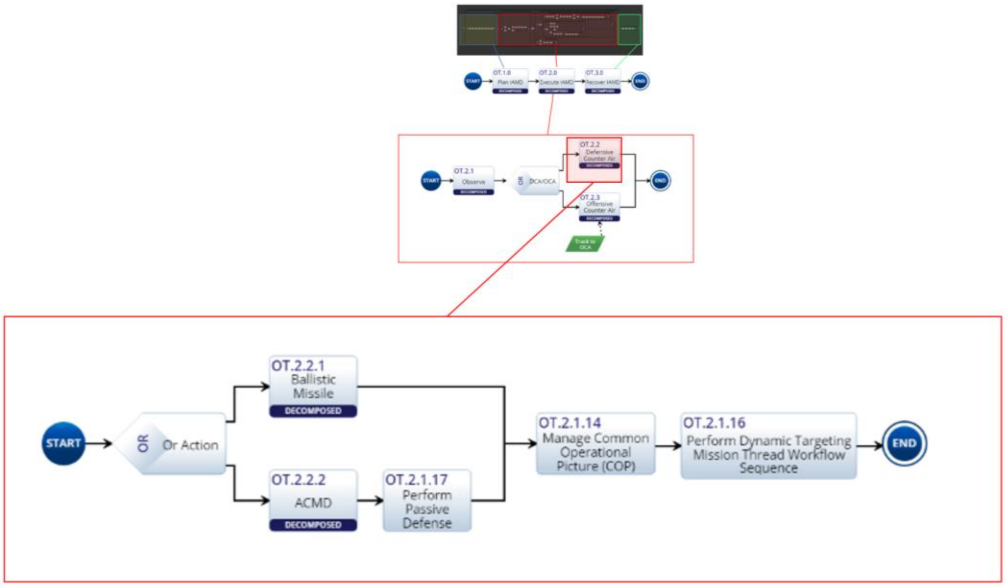

Figure 41. IAMD Operational Task Defensive Counter Air.

IAMD Operational Task 2.2.1 Ballistic Missile Defense:

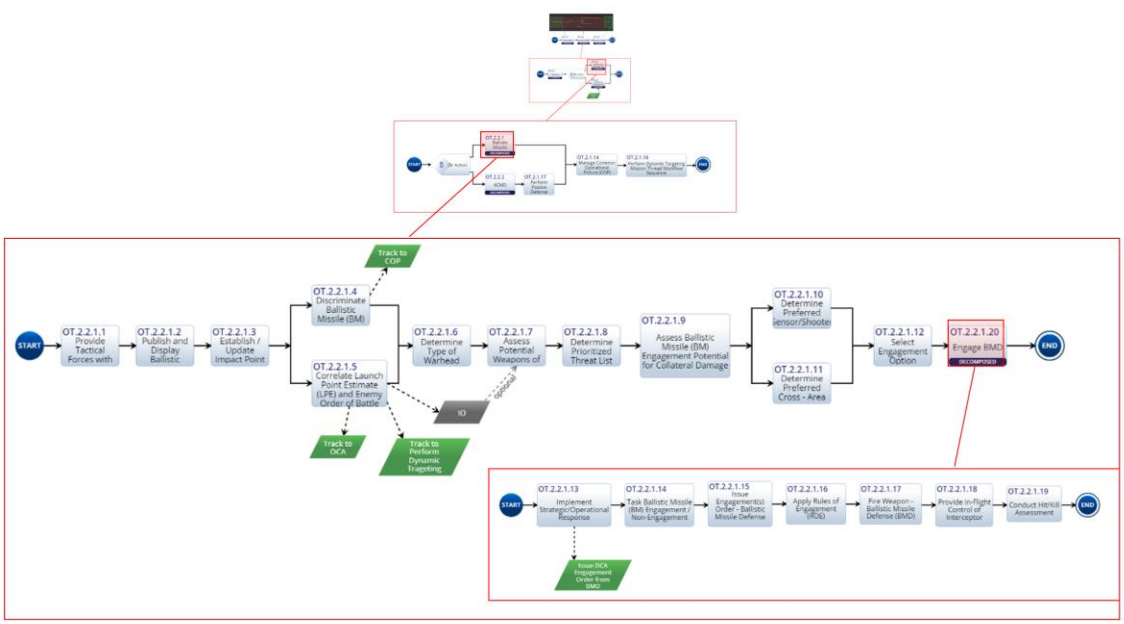

Figure 42. IAMD Operational Task Ballistic Missile Defense.

IAMD Operational Task 2.2.2 Anti-cruise Missile Defense:

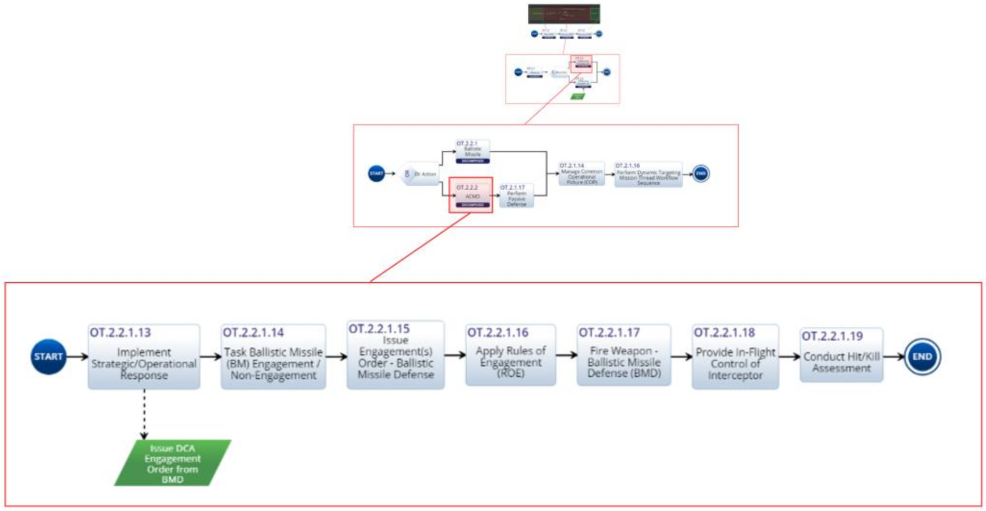

Figure 43. IAMD Operational Task Anti-cruise Missile Defense.

B. DISTRIBUTED LETHALITY PRODUCTS

Figure 44 provides and overview of DL Operational Task 5.1 Observe:

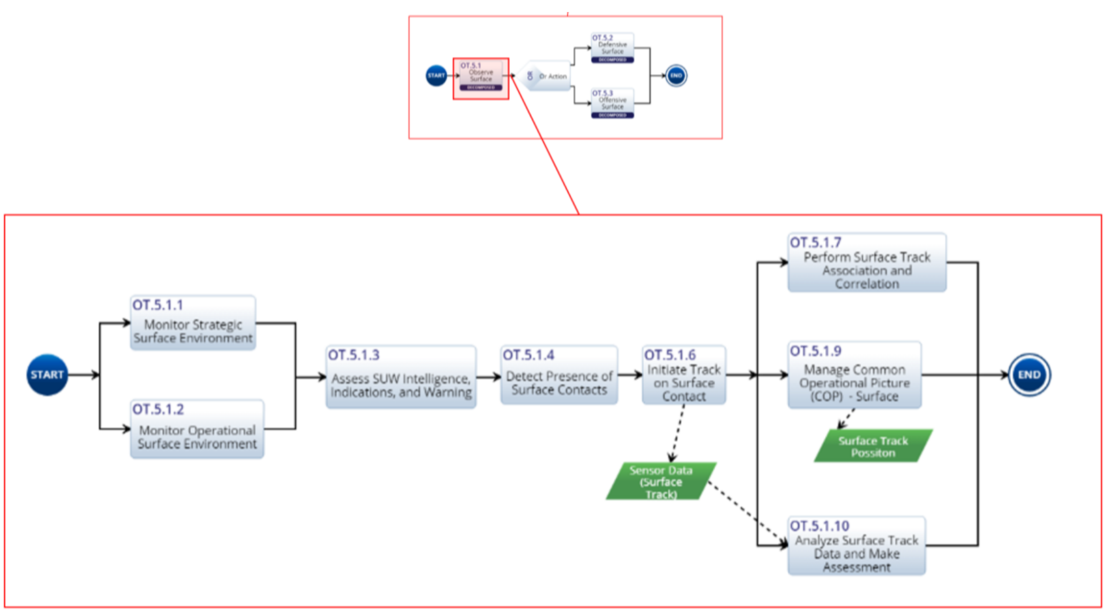

Figure 44. DL Operational Task Observe.

DL Operational Task 2.2 Defensive Surface:

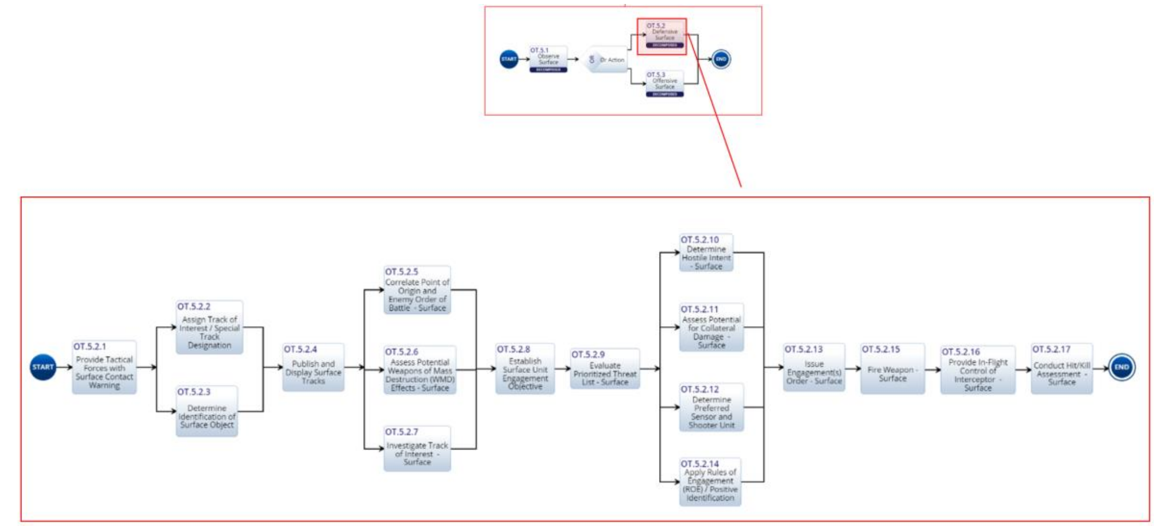

Figure 45. DL Operational Task Defensive Surface.

DL Operational Task 2.3 Offensive Surface:

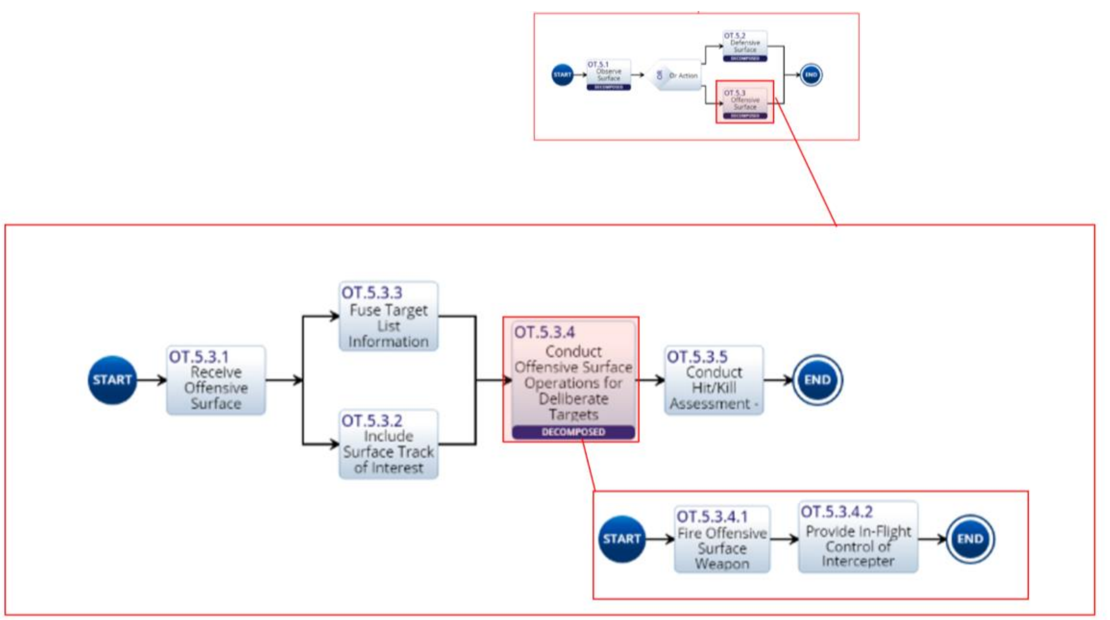

Figure 46. DL Operational Task Offensive Surface.

APPENDIX C. JOINT CAPABILITY AREAS

Figure 47. Joint Capability Areas. Source: Assistant Secretary of the Navy, Research, Development and Acquisition, Chief Systems Engineer (ASN RDA, CHENG) (2007).

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APPENDIX D. ARCHITECTURE MAPPING

Requirements																								Requirements to Capabilities Mapping
R.10.2 Ballistic Missile Defense	R.10.1 Anti-cruise missile defense	R.10.0 Defensive	R.9.2 Offensive Counter Air (OCA) / Attack	R.9.1 Anti-ship	R.9.0 Offensive	R.8.3 Air Force Integration	R.8.2 Army Integration	R.8.1 Marine Corps Integration	R.8.0 Operate in joint environment	R.7.2 Localized Sea Control	R.7.1 Localized air control	R.7.0 Localized control	R.6.2 Mobile	R.6.1 Force adversary to react	R.6.0 Dispersed	R.5.0 Deceptive	R.4.0 Current/Near Future Resources	R.3.0 Self-Sustaining	R.2.0 Rapid AFP turnaround	R.1.2 Track contacts	R.1.1 Sense contacts	R.1.0 Provide targeting	R.0.0 Perform combined DL and IAMD mission	Capabilities
																								C.0 Combined DL and IAMD
	X	X		X	X				X	X		X	X	X	X	X	X	X	X	X	X	X		C.1 Surface Warfare
	X	X							X	X		X	X	X	X	X	X	X	X	X	X	X		C.1.1 Provide Self-Defense Against Surface Threats
				X	X				X	X		X	X	X	X	X	X	X	X	X	X	X		C.1.2 Conduct Offensive Operations Against Surface Threats
					X				X	X		X	X	X	X			X	X	X	X			C.2 Maritime Interdiction
					X					X		X	X	X	X			X	X	X	X			C.2.1 Sea Lines of Communication (SLOC) Disruption
					X					X		X	X	X	X			X	X	X	X			C.2.2 Maritime Interception Operations
					X					X		X	X	X	X				X	X	X			C.3 Maneuver
					X	X	X	X	X	X	X	X	X					X	X	X	X			C.3.1 Forward Presence
								X																C.3.2 Marine Force Configurations
		X			X								X	X		X				X	X			C.3.3 Informational Operations
			X		X						X	X	X	X	X	X				X	X	X		C.4 Offensive Counterair Operations
			X		X						X	X	X	X	X	X				X	X	X		C.4.1 Suppression of Enemy Air Defensed (SEAD)
			X		X						X	X	X	X	X	X				X	X	X		C.4.2 Offensive Counterair Sweep
		X									X	X	X											C.4.3 Escort
			X		X						X	X	X	X	X	X				X	X	X		C.4.4 Offensive Counterair Attack Operations
X	X	X				X	X	X	X	X	X	X	X				X		X	X	X	X		C.5 Integrated Air and Missile Defense
	X	X				X	X	X	X	X	X	X	X				X		X	X	X	X		C.5.1 Defensive Counterair Operations
X		X				X	X	X	X	X	X	X	X				X		X	X	X	X		C.5.2 Theater Ballistic Missile Defense
X	X	X				X	X	X	X	X	X	X	X				X		X	X	X	X		C.6 Theater Air and Missile Defense
	X	X						X	X	X	X	X	X				X		X	X	X	X		C.6.1 Provide Self-Defense Against Air and Missile Threats
X		X						X	X	X	X	X	X				X		X	X	X	X		C.6.2 Provide Maritime Air and Missile Defense
X	X	X						X	X	X	X	X	X				X		X	X	X	X		C.6.3 Provide Overland Air and Missile Defense
X	X	X						X	X	X	X	X	X				X		X	X	X	X		C.6.4 Conduct Sea-Based Missile Defense
X	X	X	X	X	X	X	X	X	X	X	X	X		X	X	X	X		X	X	X	X		C.7 Command and Control
X	X	X	X	X	X	X	X	X	X	X	X	X		X	X	X	X		X	X	X	X		C.7.1 Communications
																X	X					X		C.7.2 Situational Awareness
																X	X					X		C.7.3 Information Processing & Storage
																X	X							C.7.4 Decision Making
																	X							C.7.5 Collaborative Planning
		X			X	X	X	X	X															C.7.6 Interoperability
																	X							C.7.7 New Capabilities
															X	X				X	X	X		C.8 Battlespace Awareness
		X			X											X								C.8.1 Planning and Direction for Collection and ISR
		X			X											X					X			C.8.2 Observation and Collection
		X			X											X								C.8.3 Processing and Exploitation
		X			X											X								C.8.4 Analysis and Production
		X			X											X								C.8.5 Discrimination and Integration
		X			X											X								C.8.6 Develop and Maintain Shared Situational Awareness
		X			X											X								C.8.7 Evaluation and Feedback

Figure 48. Requirements to Capabilities Mapping.

CV-6 Capability to Operational Activities Mapping	Operational Activities																								
Capabilities	OA.0 Operational Activities for DL/IAMD	OA.1 Deploy / Conduct Maneuver	OA.1.1 Move Naval Tactical Forces	OA.1.2 Navigate and Close Forces	OA.1.3 Maintain Mobility	OA.1.4 Conduct Countermobility	OA.1.5 Dominate Operational area	OA.2 Develop Intelligence	OA.3 Employ Firepower	OA.3.1 Process Targets	OA.3.2 Attack Targets	OA.3.3 Conduct Special Weapons Attack	OA.4 Perform Logistics and Combat Service Support	OA.4.1 Arm	OA.4.2 Fuel	OA.4.3 Repair/Maintain Equipment	OA.5 Exercise Command and Control	OA.5.1 Acquire, Process and Communicate Information and Maintain Status	OA.5.2 Analyze and Assess Situation	OA.5.3 Determine and Plan Actions and Operations	OA.5.4 Direct, Lead and Coordinate Forces	OA.5.5 Conduct Information Warfare (IW)	OA.6 Protect the Force	OA.6.1 Enhance Survivability	OA.6.2 Provide Security for Operational Forces
C.0 Combined DL and IAMD																									
C.1 Surface Warfare		X	X	X	X	X	X	X	X	X	X		X	X	X	X	X	X	X	X	X		X		X
C.1.1 Provide Self-Defense Against Surface Threats									X	X	X	X					X	X	X	X	X				X
C.1.2 Conduct Offensive Operations Against Surface Threats									X	X	X	X					X	X	X	X	X				X
C.2 Maritime Interdiction		X	X	X	X	X	X						X		X	X	X								
C.2.1 Sea Lines of Communication (SLOC) Disruption		X	X	X	X	X	X						X		X	X	X								
C.2.2 Maritime Interception Operations		X	X	X	X	X	X						X		X	X	X								
C.3 Maneuver		X	X	X	X		X						X		X	X	X								
C.3.1 Forward Presence		X						X	X				X				X								
C.3.2 Marine Force Configurations									X			X					X						X	X	X
C.3.3 Informational Operations									X													X			
C.4 Offensive Counterair Operations							X	X	X	X	X	X					X	X	X	X	X	X	X	X	X
C.4.1 Suppression of Enemy Air Defensed (SEAD)							X	X	X	X	X	X					X	X	X	X	X	X	X	X	X
C.4.2 Offensive Counterair Sweep							X	X	X	X	X	X					X	X	X	X	X	X	X	X	X
C.4.3 Escort								X									X	X	X	X	X			X	X
C.4.4 Offensive Counterair Attack Operations							X	X	X	X	X	X					X	X	X	X	X	X	X	X	X
C.5 Integrated Air and Missile Defense		X	X	X			X		X	X	X	X					X	X	X	X	X	X			X
C.5.1 Defensive Counterair Operations		X	X				X		X	X	X	X					X	X	X	X	X	X			X
C.5.2 Theater Ballistic Missile Defense							X		X	X	X	X					X	X	X	X	X	X			X
C.6 Theater Air and Missile Defense		X	X	X			X		X	X	X	X					X	X	X	X	X	X	X	X	X
C.6.1 Provide Self-Defense Against Air and Missile Threats							X		X	X	X						X	X	X	X	X	X		X	X
C.6.2 Provide Maritime Air and Missile Defense							X		X	X	X	X					X	X	X	X	X	X	X	X	X
C.6.3 Provide Overland Air and Missile Defense							X		X	X	X	X					X	X	X	X	X	X	X		X
C.6.4 Conduct Sea-Based Missile Defense							X		X	X	X	X					X	X	X	X	X	X	X		X
C.7 Command and Control																	X	X	X	X	X	X			
C.7.1 Communications																	X	X	X	X	X	X			
C.7.2 Situational Awareness																	X	X				X			
C.7.3 Information Processing & Storage																	X	X	X	X	X	X			
C.7.4 Decision Making																	X	X	X	X	X	X			
C.7.5 Collaborative Planning																	X	X	X	X	X	X			
C.7.6 Interoperability																	X	X	X	X	X	X			
C.7.7 New Capabilities																	X	X	X	X	X	X	X	X	
C.8 Battlespace Awareness								X		X							X					X	X	X	X
C.8.1 Planning and Direction for Collection and ISR								X														X			
C.8.2 Observation and Collection								X		X												X			
C.8.3 Processing and Exploitation								X		X												X			
C.8.4 Analysis and Production								X		X												X			
C.8.5 Discrimination and Integration								X		X												X			
C.8.6 Develop and Maintain Shared Situational Awareness								X		X												X			
C.8.7 Evaluation and Feedback								X		X												X			

Figure 49. CV-6 Capability to Operational Activities Mapping.

APPENDIX E. ADDITIONAL ANALYSIS

Effect Summary

Source	LogWorth	PValue
MissionType	24.219	0.00000
AircraftType2StartRange	18.936	0.00000
CG SM6	16.423	0.00000
DDG Type 1 SM2	15.334	0.00000
LCS CIWS	14.338	0.00000
NumSRBM	13.900	0.00000
NumAircraftType1	12.420	0.00000
ASCM(Fast)Speed	12.323	0.00000
OASUWPhit	11.215	0.00000
DDG Type 1 ASROC	10.778	0.00000
HVU	10.091	0.00000
AircraftType2DetectRange	9.902	0.00000
CG	9.005	0.00000
5inMaxRange	7.996	0.00000
ShipType1DetectRange	7.676	0.00000
TomahawkMaxRange	7.192	0.00000
TomahawkPhit	7.008	0.00000
5"Pk	6.805	0.00000
HarpoonSpeed	6.561	0.00000
DDG Type 3 SM2	6.201	0.00000
SM2Pk	6.179	0.00000
DDG Type 3 ESSM	5.832	0.00000
DDG Type 2 CIWS Rounds	5.798	0.00000
SM6MaxRange	5.597	0.00000
ICBMSpeed	5.427	0.00000
ESSMPk	5.276	0.00001
SRBMSpeed	5.175	0.00001
SM3CycleTime	5.145	0.00001
DDG Type 1 Surface Radar Pd	5.041	0.00001
DDG Type 3 SM6	4.968	0.00001
NUMICBM	4.386	0.00004

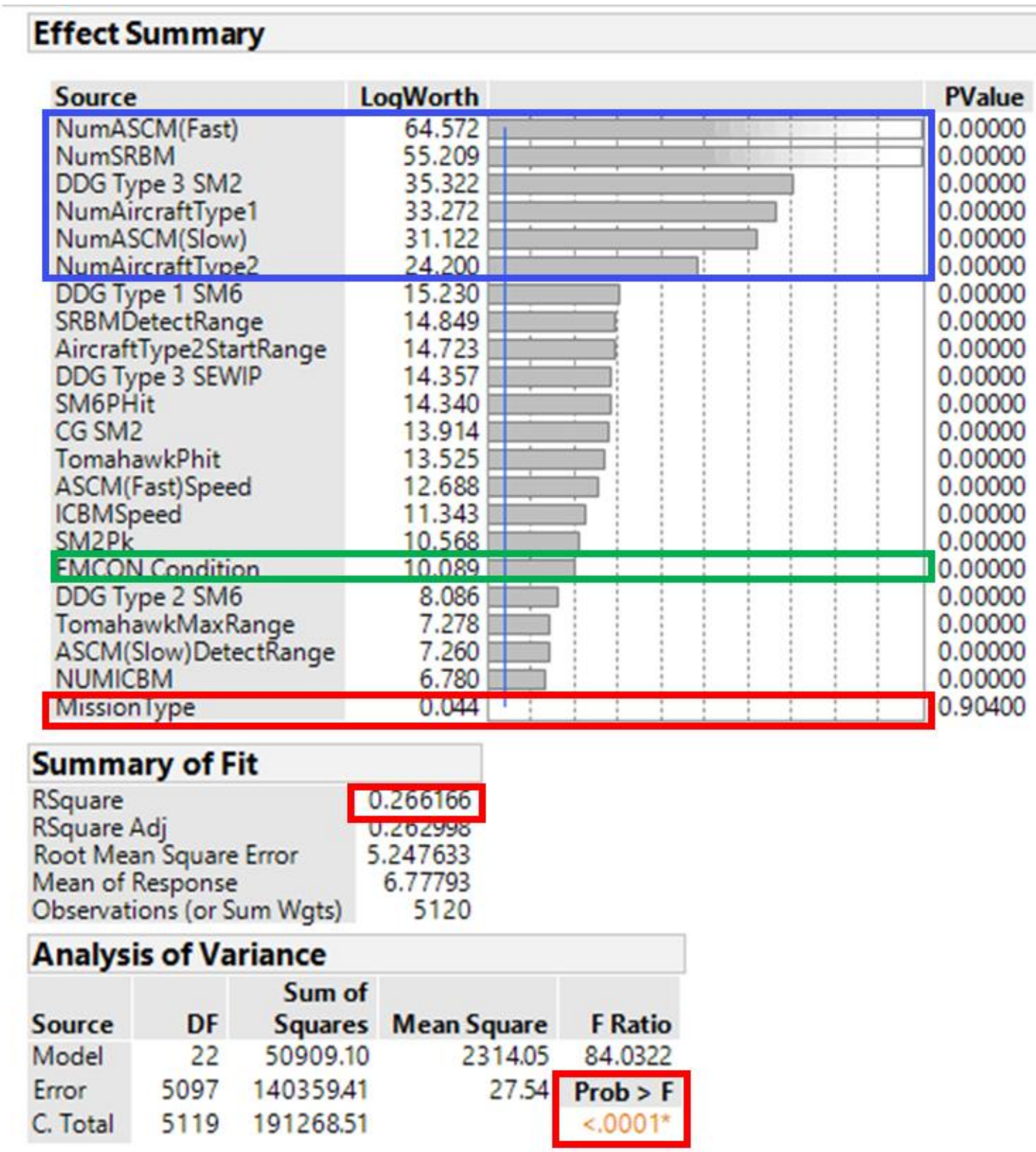
Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	31	67.45688	2.17603	37.6954
Error	5088	293.71280	0.05773	Prob > F
C. Total	5119	361.16968		<.0001*

Summary of Fit

RSquare	0.186773
RSquare Adj	0.181819
Root Mean Square Error	0.240264
Mean of Response	0.469295
Observations (or Sum Wgts)	5120

Figure 50. MOE 1: Red Force Main Effects Screening.



Effect Summary

Source	LogWorth	PValue
NumASCM(Fast)	64.572	0.00000
NumSRBM	55.209	0.00000
DDG Type 3 SM2	35.322	0.00000
NumAircraftType1	33.272	0.00000
NumASCM(Slow)	31.122	0.00000
NumAircraftType2	24.200	0.00000
DDG Type 1 SM6	15.230	0.00000
SRBMDetectRange	14.849	0.00000
AircraftType2StartRange	14.723	0.00000
DDG Type 3 SEWIP	14.357	0.00000
SM6PHit	14.340	0.00000
CG SM2	13.914	0.00000
TomahawkPhit	13.525	0.00000
ASCM(Fast)Speed	12.688	0.00000
ICBMSpeed	11.343	0.00000
SM2Pk	10.568	0.00000
EMCON Condition	10.089	0.00000
DDG Type 2 SM6	8.086	0.00000
TomahawkMaxRange	7.278	0.00000
ASCM(Slow)DetectRange	7.260	0.00000
NUMICBM	6.780	0.00000
MissionType	0.044	0.90400

Summary of Fit

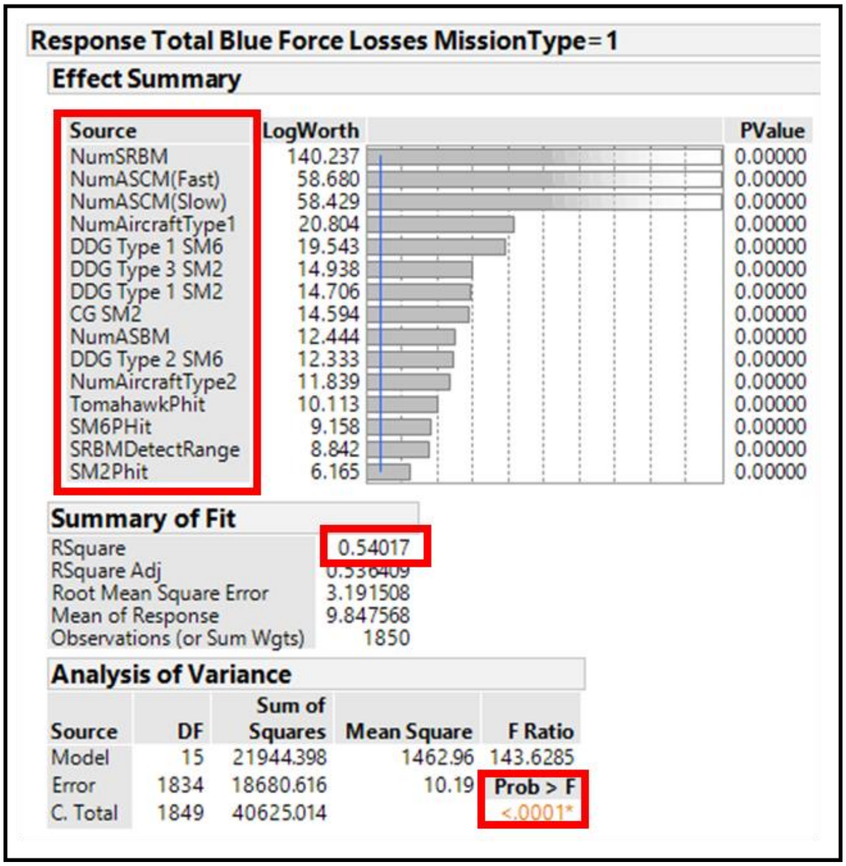
RSquare	0.266166
RSquare Adj	0.262998
Root Mean Square Error	5.247633
Mean of Response	6.77793
Observations (or Sum Wgts)	5120

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	22	50909.10	2314.05	84.0322
Error	5097	140359.41	27.54	Prob > F
C. Total	5119	191268.51		<.0001*

Figure 51. MOE 2: Blue Force Main Effects Screening.

IAMD Mission



Response Total Blue Force Losses MissionType=1

Effect Summary

Source	LogWorth	PValue
NumSRBM	140.237	0.00000
NumASCM(Fast)	58.680	0.00000
NumASCM(Slow)	58.429	0.00000
NumAircraftType1	20.804	0.00000
DDG Type 1 SM6	19.543	0.00000
DDG Type 3 SM2	14.938	0.00000
DDG Type 1 SM2	14.706	0.00000
CG SM2	14.594	0.00000
NumASBM	12.444	0.00000
DDG Type 2 SM6	12.333	0.00000
NumAircraftType2	11.839	0.00000
TomahawkPhit	10.113	0.00000
SM6PHit	9.158	0.00000
SRBMDetectRange	8.842	0.00000
SM2Phit	6.165	0.00000

Summary of Fit

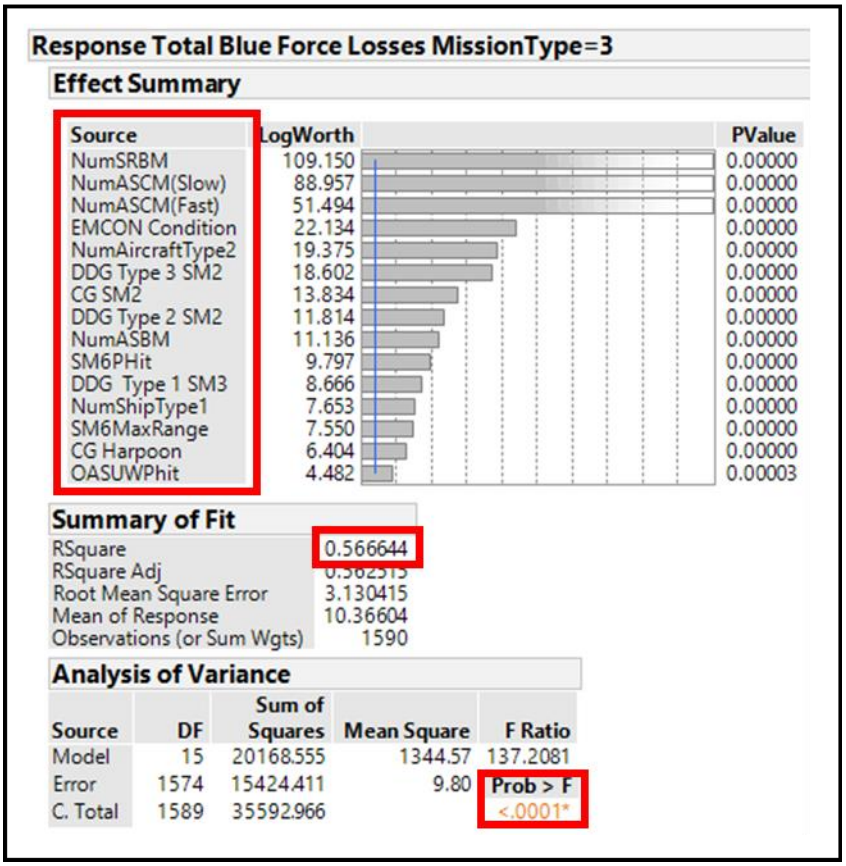
RSquare	0.54017
RSquare Adj	0.536409
Root Mean Square Error	3.191508
Mean of Response	9.847568
Observations (or Sum Wgts)	1850

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	15	21944.398	1462.96	143.6285
Error	1834	18680.616	10.19	Prob > F
C. Total	1849	40625.014		<.0001*

Figure 52. Blue Force Effect Summary by IAMD Mission Type.

Combined Mission


Response Total Blue Force Losses MissionType=3

Effect Summary

Source	LogWorth	PValue
NumSRBM	109.150	0.00000
NumASCM(Slow)	88.957	0.00000
NumASCM(Fast)	51.494	0.00000
EMCON Condition	22.134	0.00000
NumAircraftType2	19.375	0.00000
DDG Type 3 SM2	18.602	0.00000
CG SM2	13.834	0.00000
DDG Type 2 SM2	11.814	0.00000
NumASBM	11.136	0.00000
SM6PHit	9.797	0.00000
DDG Type 1 SM3	8.666	0.00000
NumShipType1	7.653	0.00000
SM6MaxRange	7.550	0.00000
CG Harpoon	6.404	0.00000
OASUWPhit	4.482	0.00003

Summary of Fit

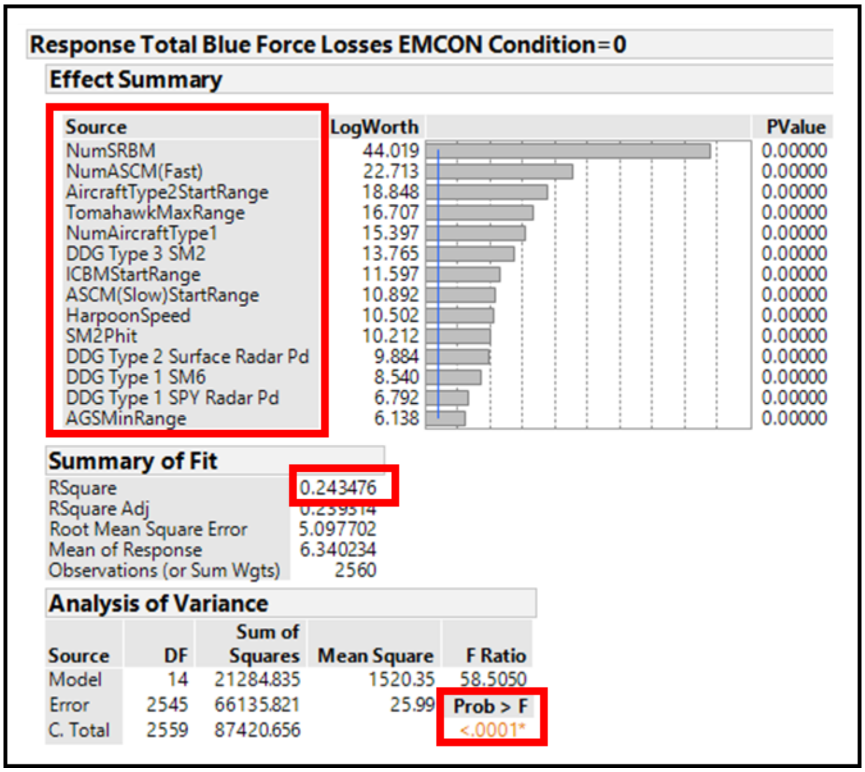
RSquare	0.566644
RSquare Adj	0.562515
Root Mean Square Error	3.130415
Mean of Response	10.36604
Observations (or Sum Wgts)	1590

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	15	20168.555	1344.57	137.2081
Error	1574	15424.411	9.80	Prob > F
C. Total	1589	35592.966		<.0001*

Figure 53. Blue Force Effect Summary by Combined Mission Type.

No EMCON



Response Total Blue Force Losses EMCON Condition=0

Effect Summary

Source	LogWorth	PValue
NumSRBM	44.019	0.00000
NumASCM(Fast)	22.713	0.00000
AircraftType2StartRange	18.848	0.00000
TomahawkMaxRange	16.707	0.00000
NumAircraftType1	15.397	0.00000
DDG Type 3 SM2	13.765	0.00000
ICBMStartRange	11.597	0.00000
ASCM(Slow)StartRange	10.892	0.00000
HarpoonSpeed	10.502	0.00000
SM2Phit	10.212	0.00000
DDG Type 2 Surface Radar Pd	9.884	0.00000
DDG Type 1 SM6	8.540	0.00000
DDG Type 1 SPY Radar Pd	6.792	0.00000
AGSMinRange	6.138	0.00000

Summary of Fit

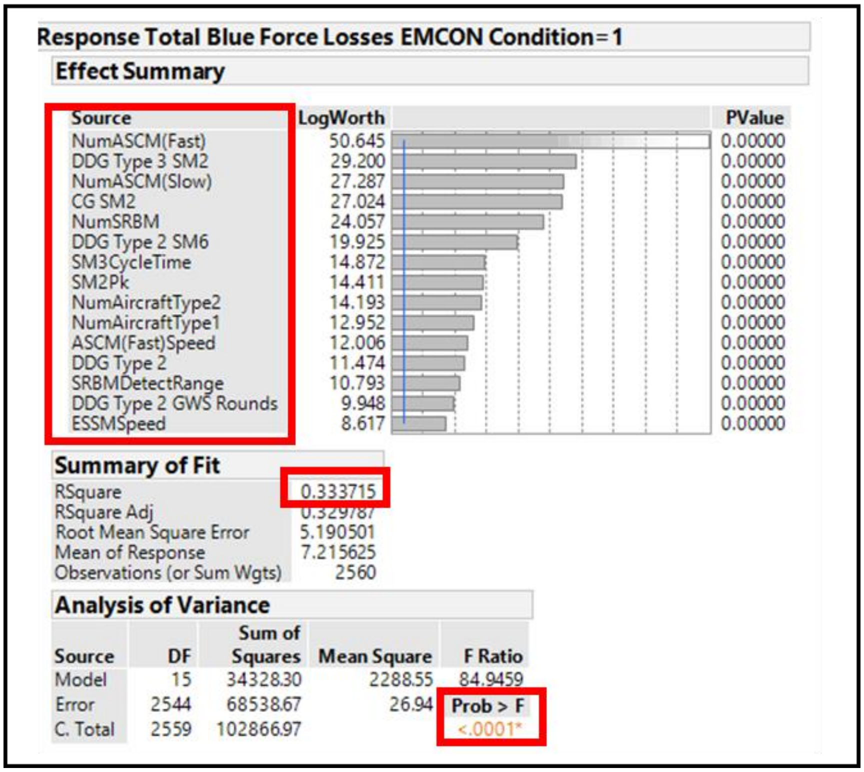
RSquare	0.243476
RSquare Adj	0.239514
Root Mean Square Error	5.097702
Mean of Response	6.340234
Observations (or Sum Wgts)	2560

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	14	21284.835	1520.35	58.5050
Error	2545	66135.821	25.99	Prob > F
C. Total	2559	87420.656		<.0001*

Figure 54. Blue Force Effect Summary No EMCON Mission.

EMCON Mission



Response Total Blue Force Losses EMCON Condition=1

Effect Summary

Source	LogWorth	PValue
NumASCM(Fast)	50.645	0.00000
DDG Type 3 SM2	29.200	0.00000
NumASCM(Slow)	27.287	0.00000
CG SM2	27.024	0.00000
NumSRBM	24.057	0.00000
DDG Type 2 SM6	19.925	0.00000
SM3CycleTime	14.872	0.00000
SM2Pk	14.411	0.00000
NumAircraftType2	14.193	0.00000
NumAircraftType1	12.952	0.00000
ASCM(Fast)Speed	12.006	0.00000
DDG Type 2	11.474	0.00000
SRBMDetectRange	10.793	0.00000
DDG Type 2 GWS Rounds	9.948	0.00000
ESSMSpeed	8.617	0.00000

Summary of Fit

RSquare	0.333715
RSquare Adj	0.329787
Root Mean Square Error	5.190501
Mean of Response	7.215625
Observations (or Sum Wgts)	2560

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	15	34328.30	2288.55	84.9459
Error	2544	68538.67	26.94	Prob > F
C. Total	2559	102866.97		<.0001*

Figure 55. Blue Force Effect Summary EMCON Mission.

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