2018-09

SYSTEM ARCHITECTURE AND ANALYSIS FOR AMERICA CLASS EXPANDED ADAPTIVE FORCE PACKAGE

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NAVAL POSTGRADUATE SCHOOL

MONTEREY, CALIFORNIA

THESIS

SYSTEM ARCHITECTURE AND ANALYSIS FOR AMERICA CLASS EXPANDED ADAPTIVE FORCE PACKAGE

by

Gregory P. DeJute

September 2018

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

1. AGENCY USE ONLY ***(Leave blank)***	**2. REPORT DATE** September 2018	**3. REPORT TYPE AND DATES COVERED** Master's thesis

4. TITLE AND SUBTITLE SYSTEM ARCHITECTURE AND ANALYSIS FOR AMERICA CLASS EXPANDED ADAPTIVE FORCE PACKAGE	**5. FUNDING NUMBERS**
6. AUTHOR(S) Gregory P. DeJute	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Naval Postgraduate School Monterey, CA 93943-5000	**8. PERFORMING ORGANIZATION REPORT NUMBER**
9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES) OPNAV N-96, Arlington, VA	**10. SPONSORING / MONITORING AGENCY REPORT NUMBER**

11. SUPPLEMENTARY NOTES The views expressed in this thesis are those of the author and do not reflect the official policy or position of the Department of Defense or the U.S. Government.

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

13. ABSTRACT (maximum 200 words)

Since 2015, when naval leadership first introduced the tactic of distributed lethality, significant work from academia and fleet tacticians has established the requirements, capabilities, and functions a force package needs to successfully execute the tactic. To this point, researchers have focused on using traditional surface combatants to conduct surface warfare and ballistic missile defense. This thesis examines incorporating the AMERICA Class, General Purpose Amphibious Assault Ship (LHA-6) and Marine Corps F-35 Joint Strike Fighter—which are not designed to conduct surface warfare—with traditional surface combatants to form an expanded adaptive force package (EAFP) and conduct distributed lethality tactics under the recently established tactic of distributed maritime operations. Using traditional systems engineering approaches and the Department of Defense Architectural Framework, an executable architecture modeled in Vitech's Core Schema outlines the functions and components of this EAFP. Simulating the EAFP architecture in a realistic threat environment shows an increase in lethality and a reduction in the number of hits, when compared to a traditional surface action group, though this comes with a tradeoff of a 20-percent chance the LHA sustains at least one hit during an engagement. Recommendations for follow-on work include modeling more functionality and architecting other aspects of distributed lethality beyond the tactics.

14. SUBJECT TERMS naval tactics, distributed lethality, sea control, expanded adaptive force package, distributed maritime operations, Department of Defense Architectural Framework, littoral combat ship, guided missile destroyer, Amphibious Assault Ship, unmanned system	**15. NUMBER OF PAGES** 103
	16. PRICE CODE

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

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

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SYSTEM ARCHITECTURE AND ANALYSIS FOR AMERICA CLASS EXPANDED ADAPTIVE FORCE PACKAGE

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Submitted in partial fulfillment of the
requirements for the degree of

MASTER OF SCIENCE IN SYSTEMS ENGINEERING

from the

NAVAL POSTGRADUATE SCHOOL
September 2018

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ABSTRACT

Since 2015, when naval leadership first introduced the tactic of distributed lethality, significant work from academia and fleet tacticians has established the requirements, capabilities, and functions a force package needs to successfully execute the tactic. To this point, researchers have focused on using traditional surface combatants to conduct surface warfare and ballistic missile defense. This thesis examines incorporating the AMERICA Class, General Purpose Amphibious Assault Ship (LHA-6) and Marine Corps F-35 Joint Strike Fighter—which are not designed to conduct surface warfare—with traditional surface combatants to form an expanded adaptive force package (EAFP) and conduct distributed lethality tactics under the recently established tactic of distributed maritime operations. Using traditional systems engineering approaches and the Department of Defense Architectural Framework, an executable architecture modeled in Vitech's Core Schema outlines the functions and components of this EAFP. Simulating the EAFP architecture in a realistic threat environment shows an increase in lethality and a reduction in the number of hits when compared to a traditional surface action group, though this comes with a tradeoff of a 20-percent chance the LHA sustains at least one hit during an engagement. Recommendations for follow-on work include modeling more functionality and architecting other aspects of distributed lethality beyond the tactics.

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LIST OF ACRONYMS AND ABBREVIATIONS

A2/AD	anti-access/anti-denial
AFP	adaptive force package
ANOVA	analysis of variance
ARG	amphibious readiness group
ASCM	anti-ship cruise missile
ASUW	anti-surface warfare
ASW	anti-submarine warfare
C2	command and control
CG	Guided Missile Cruiser
COAL	combined operating activities list
CONOPS	concept of operations
CRUDES	cruiser destroyer
DDG	Guided Missile Destroyer
DL	distributed lethality
DMO	distributed maritime operations
DODAF	Department of Defense Architectural Framework
EAFP	expanded adaptive force package
EMCON	emission control
JSF	Joint Strike Fighter
LCS	Littoral Combat Ship
LHA	General Purpose Amphibious Assault Ship
LHD	Multiple Purpose Amphibious Assault Ship
MOE	measure of evaluation
MOP	measure of performance
NPS	Naval Postgraduate School
NIFC-CA	navy integrated fire control-counter air
OA	operational activity
SAG	surface action group
SLOC	sea line of communication

SM	standard missile
STOVL	short takeoff vertical landing
UAV	unmanned aerial vehicle
USV	unmanned surface vehicle
UVS	unmanned vehicle system
USFF	United States Fleet Forces Command

EXECUTIVE SUMMARY

Currently, the solution set researched and proposed for employing distributed lethality (DL) included conventional surface combatants of Guided Missile Destroyers, Guided Missile Cruisers, and Littoral Combat Ships grouped to form a surface action group (SAG), possessing quick strike capabilities as a hunter-killer unit. This thesis proposes a new force composition architecture through the insertion of an AMERICA Class, Amphibious Assault Ship (LHA) with a complete air-wing of 24, F-35B, Joint Strike Fighters (JSF) into the SAG to form an expanded adaptive force package (EAFP).

In 2015, Admirals Rowden, Gumataotao, and Fanta proposed the tactic of DL in an article published in U.S. Naval Institute Proceedings. They argued that American naval supremacy is at risk from adversaries possessing near peer capabilities with the ability to challenge America's long-held freedom of the seas. The consequence of this restriction is that the United States Navy must first fight to gain control of strategic sea lines of communication (SLOC) to execute missions, such as power projection through naval strikes, previously conducted freely and unchecked from adversary nations. The admirals argue the U.S. Navy must go on the offensive and cannot rely solely on a carrier strike group to win the next naval engagement. Their concluding argument is that small SAGs tasked to control SLOCs will disrupt enemy defenses, confounding the strategy of adversaries and temporarily holding and freeing strategic maritime regions from which to conduct further missions. Concurrent to the development of DL, United States Fleet Forces command is also developing a fleet-wide tactic of distributed maritime operations (DMO) that takes the core tenets of DL, a naval surface warfare tactic, and scales them to a larger level from which aviation, cyber, and maritime forces can also employ the tactic.

Johnson (2016) published an initial thesis on DL in 2016 outlining the initial requirements and function of a SAG. Follow-on research came soon afterward from Harlow (2016), Casola (2017), and Davis (2017). These theses along with stakeholder input on DL and DMO as well as knowledge on the capabilities of an LHA form the basis for the requirements of EAFP. One reason researchers did not consider an LHA as a unit to

include in a SAG is that its designed purpose is for expeditionary warfare. The ship organically possesses no offensive surface warfare capability and limited defensive capability. With LHAs now beginning to deploy JSF, a fifth-generation fighter aircraft, it now possesses a lethal offensive and defensive weapon, which makes it viable to include in a SAG conducting DL as a subset of DMO.

Utilizing the Department of Defense Architecture Framework as the schema for the overall architecture, the initial requirements for an EAFP decompose into functions and operational activities, which components (objects), and nodes (humans), respectively, perform. Each architectural element in the system architecture traces back to the original requirements and capabilities expected from stakeholders. A review of the EAFP architecture revealed that it contained almost identical views as a SAG architecture, but possessed an operational activity—Naval Integrated Fire Control (NIFC)—that a SAG does not. This operational activity permits a ship's fire control systems to engage with a target that the firing unit does not have on radar. Particularly, with an EAFP, a JSF scouting ahead of the force package can provide targeting data to a guided missile ship, allowing earlier engagement beyond a ship's maximum radar line of sight.

A specific system architecture only represents a single solution set to a given problem, not necessarily the optimal one. Just as a house or tent meets stakeholder requirements for shelter, both a SAG and EAFP meet stakeholder requirements for DL. This necessitates simulation to quantify the degree to which the architecture performs the mission in a realistic environment. Placing an EAFP in a threat environment consisting of a mix of inbound hostile bombers and fighters carrying fast and slow anti-ship cruise missiles as well as patrolling adversary SAGs represents a realistic scenario an EAFP must face when tasked to control a SLOC. ExtendSim provided the simulation tool to test the EAFP in the given threat environment. The model included 64 input factors including whether to execute the NIFC operational activity, the level of EMCON, time to deactivate EMCON, red probability of detection as well as unclassified blue force weapon and sensor performance. The model captured seven measures of performance (MOPs) including: percentage of red killed offensively, percentage of red leakers, percent of red retreating, percent of red killed defensively, percent of red hits, number of hits, and number of hits the LHA sustains. Results indicate an EAFP offensively performs better than a SAG and sustains fewer hits during an engagement. Defensive capability remained identical between the two force packages. NIFC, detection range, and EMCON all significantly impacted the MOPs evaluated. An uncontrollable variable, the number of red units, also showed significance in modeling the MOPs. Architecting this new force package and modeling the developed system in a realistic anti-surface warfare mission in a discrete simulator resulted in a four hundred percent increase in offensive lethality over previous SAG forces and one hit reduction on blue forces per simulation trial. The tradeoff of this increased capability came from the LHA incurring at least one hit in 20 percent of the trials conducted.

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ACKNOWLEDGMENTS

Thanks go to Professor Paulo and Professor Beery for their assistance, patience, and guidance while I was researching and writing this thesis. I would also like to thank Ms. Barbara Berlitz for her multiple reviews and for keeping my formatting and citations correct. Most important, a special thank you to my wife, Heather, for her love and support.

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I. INTRODUCTION

If it floats, it fights.

—Rear Admiral Peter Fanta

A. BACKGROUND

The advancement of adversary technology, tactics, and power projection limits U.S. Naval forces' freedom of the seas and the ability to project power ashore, the Navy's mission for the past half a century. Distributed lethality (DL), the Navy's newest surface warfare tactic, puts U.S. Naval ships on the offensive with the goal of disrupting adversary tactics, forcing adversaries to respond to U.S. fleet actions rather than following their own battle plan and preventing them from accessing key surface lines of communication (Rowden, Gumataotao, and Fanta 2015).

At its core, DL takes Guided Missile Destroyers (DDG), Guided Missile Cruisers (CG), and Littoral Combat Ships (LCS) that would usually deploy independently and combines them into a hunter-killer surface action group (SAG) (Filipoff 2016). The combined lethality of the ships represents a significant advantage over the lethality of one ship (Filipoff 2016). Additionally, the mobility and ability to disperse quickly if necessary marks an improvement over a traditional carrier strike group, which brings tremendous fire power but lacks quick striking capabilities and presents a high-value unit on which adversaries can concentrate fire (Leonardo 2015). The expectation of the SAG is to establish and maintain sea control for follow-on missions to occur. The goal of DL is not to control the whole ocean, but to control concentrated areas with strategic interest. As such, DL views sea control similarly to the islands in the Pacific Ocean during World War II: strategic positions from which to meet follow-on objectives (Rowden, Gumataotao, and Fanta 2015).

As surface forces leadership continues to develop the tactic of DL, United States Fleet Forces Command (USFF) is taking the concept of DL further to include all naval components, including air assets, sensors, cyber, and space in a distributed maritime operating environment. CDR Jason Canfield presented the cornerstone requirements of distributed maritime operations (DMO) at Naval Postgraduate School (NPS) on 18 September 2017, which included Integration, Distribution, and Maneuvering. CDR Canfield concluded the presentation stating that technology alone will no longer achieve naval success, but a total system approach is necessary to win future engagements

The tactic of DL is not without risk. The SAG tasked to gain sea control will face an entrenched enemy possessing a layered defense of long-range anti-ship cruise missiles (ASCM), attack bomber aircraft, such as the Chinese H-6, and adversary SAG looking to deter the American ships. A SAG needs to maintain an offensive posture while still employing self-defense capabilities from air and surface threats.

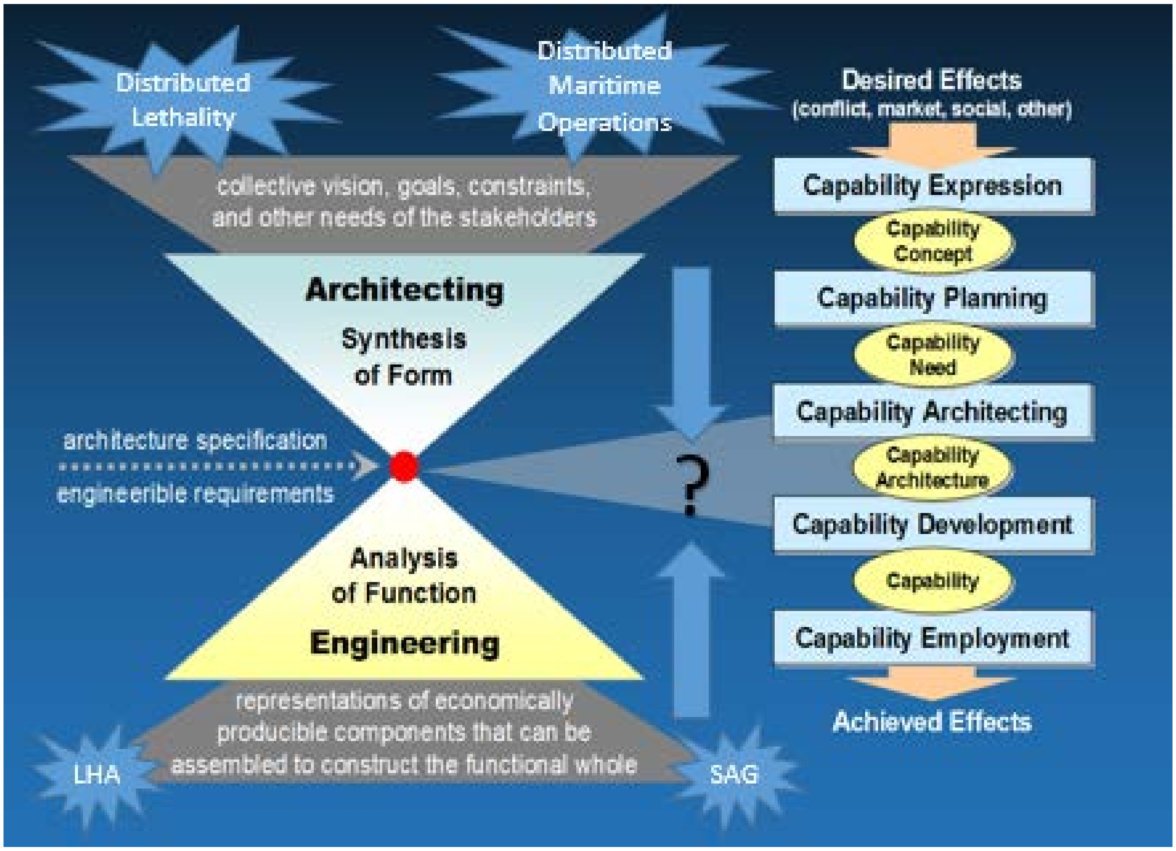
The original intention of DL, where small surface combatants combine as a SAG to gain sea control, limits potential that might be available from looking at other U.S. Navy assets. Employing the concept of DMO and applying it to DL, the use of an AMERICA Class Amphibious Assault Ship (LHA) with a complete air-wing of 24, F-35B, Joint Strike Fighters (JSF), other unmanned aerial vehicles (UAV) and other unmanned systems combined with a traditional SAG will bring both offensive and defensive capabilities beyond that of the original SAG. This non-traditional employment of an LHA pushes the Navy's offensive posture further developing an expanded adaptive force package (EAFP). To avoid confusion, this thesis will reference a SAG when referring exclusively to combatants (cruiser and destroyers) and will reference EAFP when referring to the combined unit of a SAG and LHA force package.

B. SCOPE AND METHODOLOGY

OPNAV N-96 provided the specific scope of this research, which includes developing the required system architecture of an AMERICA class ship and traditional SAG to gain sea control in a contested maritime environment. The specific scope of this research is to evaluate this architecture specifically as it applies anti-surface warfare (ASUW) and provide the corresponding analysis for the performance an EAFP needs to have to meet the offensive sea control objective. Through this analysis, this author provides additional architectural context to give a holistic view of the trade space and provide insight into areas that require further research, but the author will decompose specifically the operational mission set of an EAFP executing ASUW tactics.

The method employed for this research is a combination of system engineering and architecting principles as well as employing the Department of Defense Architecture Framework (DODAF) and finally statistical analysis. Initially, a developer conducts a high-level needs, goals, and requirement analysis to establish the intent of the system and ensure a thorough understanding of its goals. From this analysis, the architect decomposes the system into required functions. Understanding the system's functions, physical architectural views trace components performing actions to the required functions. Establishing relationships among all these disparate items ensures that all the components that make up the system are directly traceable to the initial system goal.

The problem set presented in this thesis is associated with additional challenges in that the physical components exist prior to the development of the architecture. This is equivalent to building a house before completing the blueprints. Traditionally, a system architect provides the engineer a starting point from which to begin designing the components of the system. Brad Mercer, Principle System Architect at the Mitre Corporation, during his 2008 NPS System Engineering Colloquium presentation, termed this starting point the "engineerible requirements." Figure 1 shows Mercer's description of the flow of designing a system from architecting to engineering.



Adapted from Brad Mercer, NPS Colloquium Presentation (January 31, 2008).

Figure 1. System Architecting

As Figure 1 highlights, the LHA, JSF, and SAG components already exist. The methodology of this thesis, however, will not reverse engineer a system architecture to match the existing requirements but develops the system architecture and determine if the designed components possess the capability required in the architecture. This thesis validates that the capabilities from an LHA combined with a SAG meets the engineerible requirements and thus meets the stakeholder's desired effects.

C. PURPOSE OF RESEARCH

The advancement of technology resulting in anti-access/anti-denial (A2/AD) maritime regions requires the U.S. Navy to alter its strategy and employment of tactics to counter this threat. Additionally, with the timeline and large expenditures required to design and acquire new ships, platforms, and sensors, leveraging existing technology in a nontraditional manner helps fill this tactical gap. The purpose of the research is to architect and analyze an LHA as a light aircraft carrier supported by a SAG of mixed combatants to meet a threat that traditionally only a carrier strike group confronted. Architecting this system allows stakeholders to view the additional capabilities an LHA-6 with F-35B and unmanned systems provides and better assess if the augmented EAFP system meets their needs. Additionally, through analyzing the system via a simulation, a tradeoff between the risk to high value units and enhanced functionality provides stakeholders another basis from which to make tactical and acquisition related decisions. This research and its corresponding architecture will give OPNAV N-96 leadership the ability to make a more informed decision over the advantage of allocating resources to this type of EAFP and begin developing more in-depth tactics to utilize an LHA as an offensive unit, rather than a simply an expeditionary one.

D. RESEARCH QUESTIONS

- How does DL refine the tactics of DMO? Specifically, how does an expanded force package (EAFP) consisting of an AMERICA Class ship integrate with existing research into DL and DMO?

- For a given concept of operations (CONOPS), surface warfare, what requirements and capabilities are necessary to achieve mission success within the strategy of DMO? To meet the established requirements, what is the physical and functional architecture for an AMERICA Class EAFP?

- Using modeling software, Imagine That Inc. ExtendSim, what are the lethality and survivability tradeoffs by employing an AMERICA Class EAFP when compared to a traditional SAG? Specifically, does the increased sensor coverage from an embarked F-35 make the EAFP less susceptible? What is the risk to the high value unit, the LHA?

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II. BACKGROUND

A. LITERATURE REVIEW

The author reviewed applicable information on DMO and DL as they apply to developing an LHA EAFP. The concept of DMO is still in its infancy with limited information available other than online military journals from industry experts and a presentation to the NPS community on current tenets of DMO. The tactic of DL is more mature with more literature from key stakeholders who are available to refine the requirements and capabilities required from an adaptive force package (AFP) executing this mission. Additionally, four theses and one capstone project from NPS students provide a starting point for understanding DL. A subsequent section in this thesis will review each published thesis in more detail. Finally, the research proposal from the principle investigator, NPS Professor of Practice Jeffrey Kline, which this research connects to, provides clarification on the background and analysis objectives for quantifying the military value of an AMERICA Class EAFP.

B. EXISTING WORK IN DISTRIBUTED LETHALITY

Four NPS systems engineering curriculum students researched the concept of DL and published thesis papers on the topic from 2016 through 2017 and as more research and understanding on DL becomes known, the better the overall system model becomes. Johnson (2016) includes an overarching overview on the architecture of DL with an in-depth look at an ASUW mission. Harlow (2016) reviewed the required logistical framework necessary for a group of surface ships to implement the DL strategy. Casola (2017) took the work originally conducted on DL and expands it through injecting an unmanned surface vehicle (USV) into the SAG to bring additional functionality, and Davis (2017) combines ships conducting DL and integrated air and missile defense (IAMD). The author analyzed this previous work to ensure that the architecture and analysis presented in this thesis either extends or modifies existing work into DL and DMO.

1. System Architecture for Distributed Lethality

Johnson (2016) produced the first research at defining the system architecture for a SAG utilizing DL tactics. His research proposed 11 requirements or high-level needs for DL represented in Figure 2. Johnson also refined DL into its required capabilities as highlighted in Figure 3. These two figures represent the starting requirements and capabilities from which the EAFP pulls its own requirements. An EAFP still possesses the following requirements: deceptive, Marine Corps integration and offensive and uses the logistics capability as a requirement.

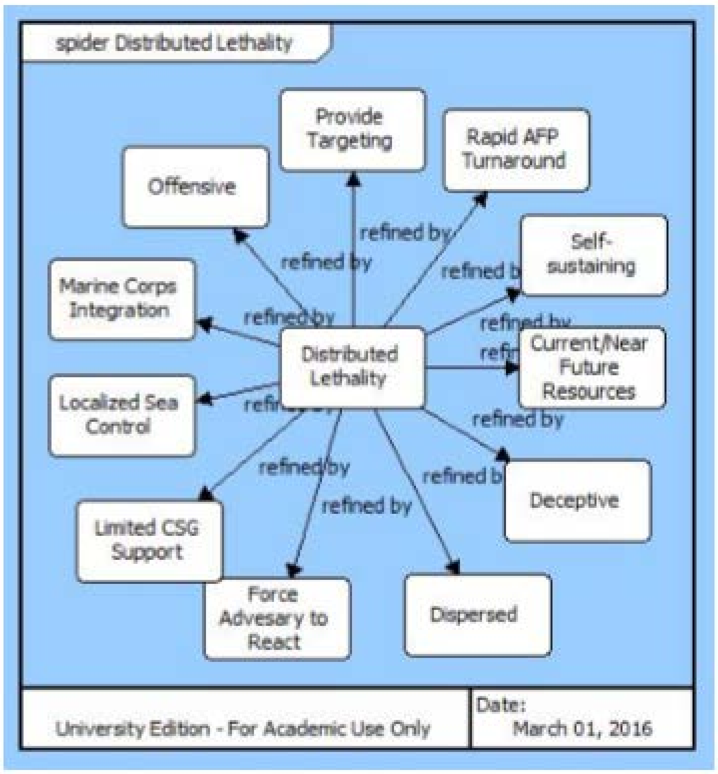

Figure 2. Johnson's DL Requirements. Source: Johnson (2016).

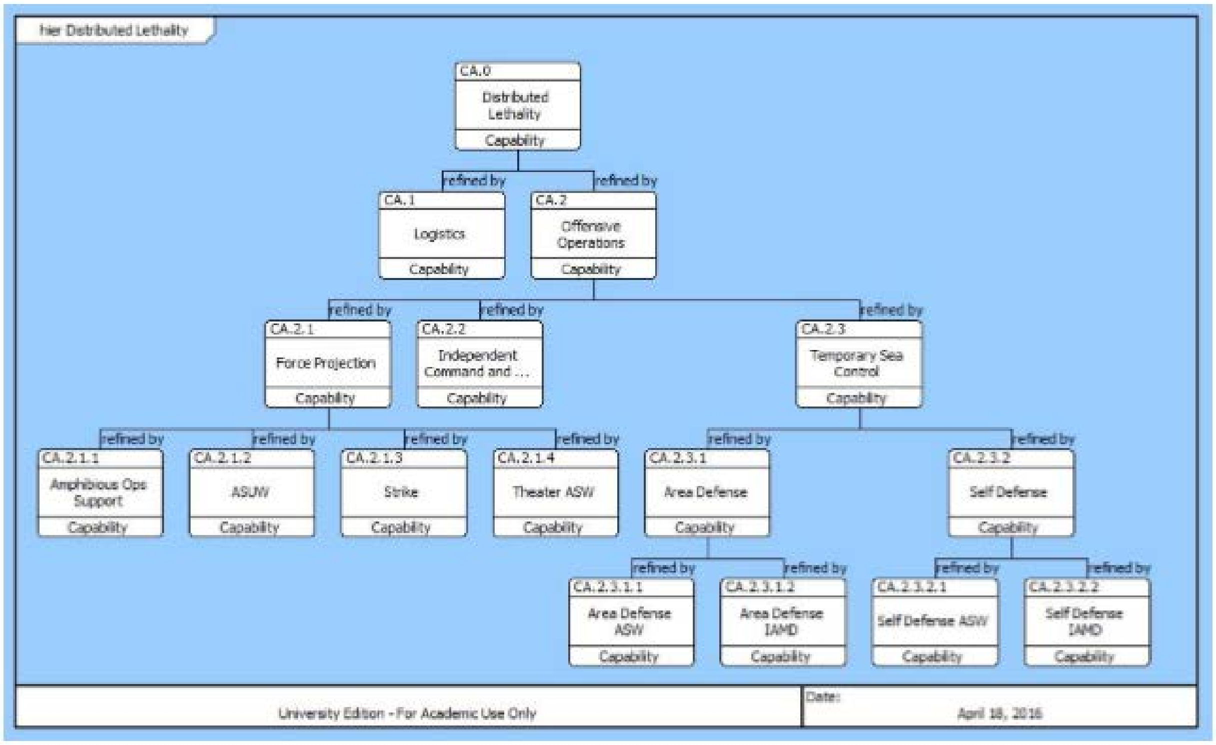

Figure 3. Johnson DL Capabilities. Source: Johnson (2016).

2. System Architecture for Logistics of a Distributed Naval Surface Force

Harlow (2016) addressed the issue of DL logistics in his thesis. His research expands Johnson's (2016) capability 1 (CA.1) in Figure 3. Figure 4 shows the requirements Harlow identified as the requirements of DL logistical support with the requirement of multiple platform support especially important to an EAFP with a larger ship contained in the force package. Harlow (2016) fills in and provides additional fidelity to Johnson (2016). Johnson focused on the offensive operation capabilities realizing the logistics needed its own dedicated research. This thesis employs a similar methodology identifying requirements, components or capabilities but not fully decomposing or providing an in-depth analysis on them.

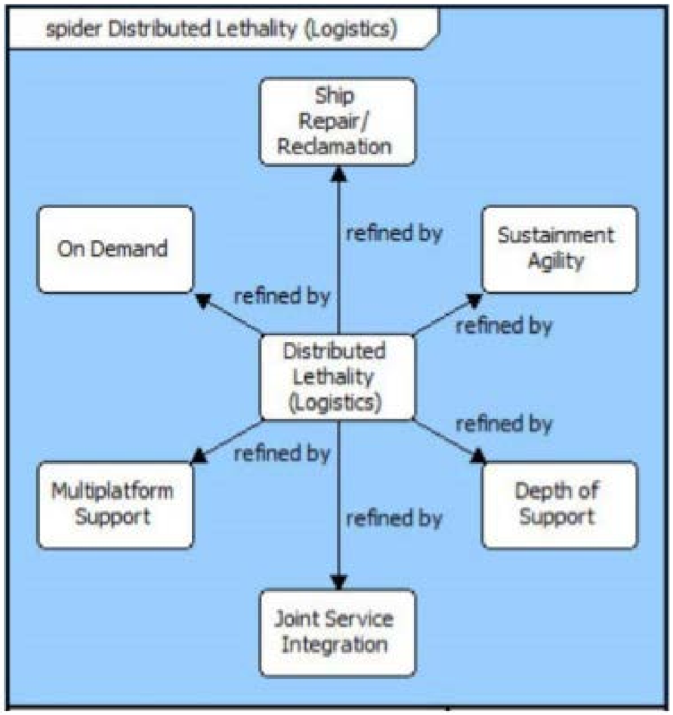

Figure 4. DL Logistics Requirements. Source: Harlow (2016).

3. System Architecture for Unmanned Surface Vehicle Component of Distributed Lethality

Casola (2017) injected an USV as a component of a SAG conducting ASUW. His research identified capabilities an USV added to the DL tactic and proposed five requirements that the USV system must have to meet the goal of improving DL capabilities. These needs included integration, logistics, system size/scalability, command and control (C2), and lethality. Additionally, Casola's (2017) thesis analyzed whether a USV could act as a low-cost screen capable of absorbing adversary missiles or whether it was more beneficial to place offensive weapons onboard to counter incoming threats.

4. System Architecture for Combined Distributed Lethality and Integrated Air and Missile Defense

Davis' (2017) thesis on DL modeled and simulated the results from a SAG group conducting both DL and IAMD missions. The DL mission relies on stealth through electromagnetic emission control (EMCON) while the IAMD mission needs ships actively radiating radars and sensors to detect ballistic missile threats and employ weapons to destroy them. Through modeling, Davis (2017) demonstrated that ships tasked to complete the combined DL and IAMD mission increased a SAG's overall lethality but also increased its vulnerability as both DL and IAMD operating conditions do not complement each other.

5. Prior Research Applicability to EAFP Architecture

Each thesis touches on a different topic of DL. Given the complexity of naval operations, an EAFP requires analysis on multiple sub-systems of the operation. For the research on an EAFP, Johnson's (2016) research gives a starting point from which to begin developing the architecture model required for an LHA. When architecting a system as the system grows, the ability to architect specific areas of the original architecture grows as well. Harlow's (2016) research amplifies the original DL architecture to describe better what logistical capabilities and requirements an AFP needed to remain operational. Casola's (2017) research aligns closely with creating an EAFP architecture. His research showed how expanding the scope of the original force package to include other components could bring additional offensive and defensive capabilities to a SAG AFP. The decomposition of the original DL architecture from Harlow (2016) and Casola (2017) highlights the complexity of the overall DL system. Davis (2017) research shows the flexibility of a SAG. Combining two mission profiles improved the overall effectiveness of the SAG in accomplishing each individual mission profile, DL and IAMD.

The previous research conducted on DL provides a base from which to architect an EAFP. The research presented in this thesis takes components from this past research done specifically in Casola's (2017) and Johnson's (2016) thesis. Johnson's (2016) architecture shows the initial framework to include components and functions needed for DL that an EAFP expands on. Casola's work on putting an USV into a SAG is like placing an LHA into the original SAG concept. The capabilities and size of an LHA and the required mission are the primary changes between this thesis and Casola's (2017) research. Additionally, Davis's (2017) modeling created the basis from which to analyze the EAFP's effectiveness. Harlow's (2016) research remains valid for an EAFP and provides context to support the required operational architecture. Incorporating an LHA into a SAG will still require a logistical need and would require a re-evaluation of the research Harlow completed.

C. AMPHIBIOUS ASSAULT SHIP ROLE IN SURFACE WARFARE

Prior to the attack on Pearl Harbor on 7 December 1941, the U.S. Navy possessed no seagoing vessel capable of bringing heavy tanks ashore without piers or cranes (United States Navy 2018). Through the course of World War II, as American forces island hopped across the Pacific, a powerful force of amphibious ships (AMPHIB) emerged, affectionately called the gator navy (United States Navy 2018). The largest AMPHIB in the U.S. Navy is the Amphibious Assault Ship, comprised of the General Purpose Amphibious Assault Ship (LHA) AMERICA Class and the Multiple Purpose Amphibious Assault Ship (LHD) (United States Navy 2018). The newest ship class, the AMERICA Class, LHA ships, deploy F-35B JSF, the United States Navy’s fifth generation strike fighter, shown operating together in Figure 5, the MV-22 Osprey and a mix of transport and attack helicopters. Designers included improvements to the LHA over the previous LHDs to operate these additional aviation platforms including advanced maintenance spaces, larger hanger bay, increased fuel storage capacity, and enhanced (C2) capability (United States Navy 2018).

Figure 5. F-35Bs Fly Over LHA-6. Source: Eckstein (2017).

Engineers designed these amphibious ships to meet the Marine Corps requirement to conduct operational maneuver from the sea, capable of reaching 75% of the world's beaches, and consequently designed with limited offensive capability in a surface engagement (United States Navy 2018). The ships include limited armament and usually require other cruisers or destroyers (CRUDES) to act as escorts in an Amphibious Readiness Group (ARG). The primary mission for the LHD and LHA platforms, dating back to WWII, is expeditionary warfare and humanitarian aid. Additionally, the design for aircraft deployed on an AMPHIB primarily allow them to accomplish the mission of expeditionary warfare. The aircraft aboard include assault helicopters and heavy lift helicopters to bring personnel and equipment ashore. The JSF variant deployed on an LHA includes short takeoff and vertical landing (STOVL) and optimized capabilities to provide close air support to Marines engaged with enemy forces.

An LHA possesses limited surface fighting capability on its own. However, its large flight deck, mixed armament of aircraft and advanced C2 capabilities make it an ideal platform to include in an enhanced adaptive force package where the sum of the whole is significantly greater than each individual component. The offensive and defensive capabilities that an LHA can leverage when joined with a traditional SAG provides an adaptive force able to operate in any blue water engagement allowing an LHA to conduct ASUW and consequently gain sea control.

D. SYSTEM ARCHITECTING

System architecture takes vague stakeholder needs and synthesizes them into understandable "blueprints" called views. From these views, a stakeholder can determine whether the designed system meets its needs or if the system requires additional functionality. Additionally, after conducting a robust system architecture through relating components and functions, it is easy to determine if the architect overdesigned the system. This would result in a system that has too much functionality or a major component is missing and thus the system will not function or perform its designed actions. The advantage of architecting a system is stakeholders better understand the system and ensures the system addresses their concerns and at the same time, the architecture provides engineers a starting point from which to begin designing and engineering components that will meet the stakeholder's need.

In his lecture presentation on 5 October 2017, NPS Assistant Professor Paul Beery presented the relationship between traditional system engineering and system architecting, summarized in Figure 6. System architecting begins with defining a problem that takes stakeholder inputs and needs and develops an initial set of requirements and operational concept from which to develop the system architecture. The operational concept becomes the input to all follow-on tasks. The initial requirements control the functional architecture that generates functions the system will do. From these functions, a physical architecture defines the components in the system that the architect allocates to specific components. For example, an architect allocates an aircraft component to a JSF. Once the architect specifies all the components in the system, they propose a candidate solution to meet the initial problem definition. At each step of architecting, feedback ensures the proposed architecture meets the initial requirements and can accomplish the operational concept.

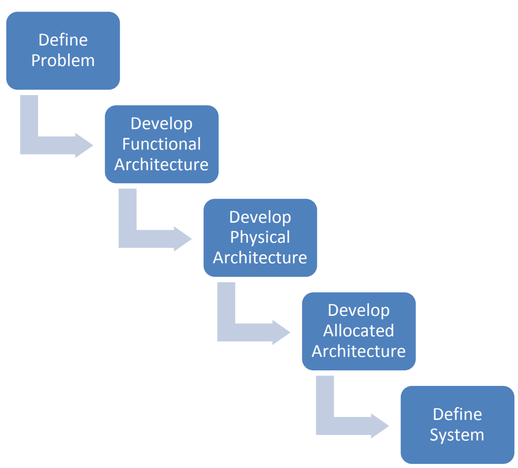

Image from Paul Beery, lecture presentation at the Naval Postgraduate School (October 9, 2017).

Figure 6. Overview System Architecting

With complex military systems, the Department of Defense undertook developing their own architectural framework to help better understand its system and establish common viewpoints and vocabulary when describing a system. In 2007, the Department of Defense released DODAF 1.5 and subsequently issued DODAF 2.0 in 2013 that revised the focus of the architecting from product development to data collection (Department of Defense Chief Information Officer 2017). DODAF 1.5 included four viewpoints separated into 29 views an architect created to show stakeholders the functionality of the system. The current DODAF 2.0 includes eight viewpoints decomposed into 52 separate views. Figure 7 highlights and describes the viewpoints and the information contained within each one.

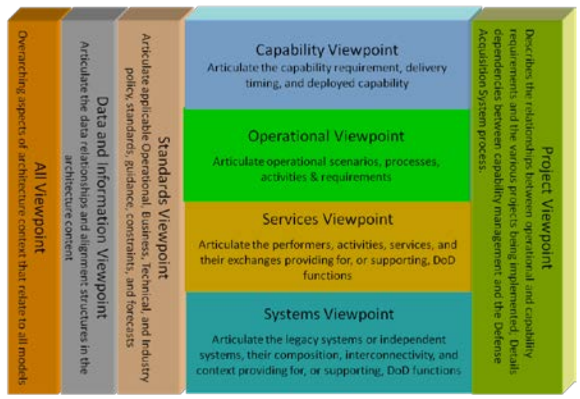

Figure 7. DODAF 2.0 Viewpoints. Source: Johnson (2016).

The purpose of architecting is not to complete each viewpoint thoroughly but to focus on the views that communicate the required information to the stakeholder for making decisions relating to the system. As such, this thesis focuses on the capability viewpoint, operational viewpoint, and systems viewpoint. The capability viewpoint highlights the goals and needs for the system. The operational viewpoint establishes the users of the system their relationship and operational activities the users will perform. The systems viewpoint is analogous to the operational viewpoint but highlights the physical, non-human, components of the system and the functions they perform.

Vitech's CORE software program enables system architects to model DODAF architecture through its schema. The software program acts as a database that ties together specific items in the architecture through relationships. The advantage of using CORE's software is the schema employed ensures that system views remain consistent since the software pulls data from the same central database. In addition, the schema prevents the architect from introducing invalid relationships. Figure 8 highlights the schema employed to relate architectural elements together.

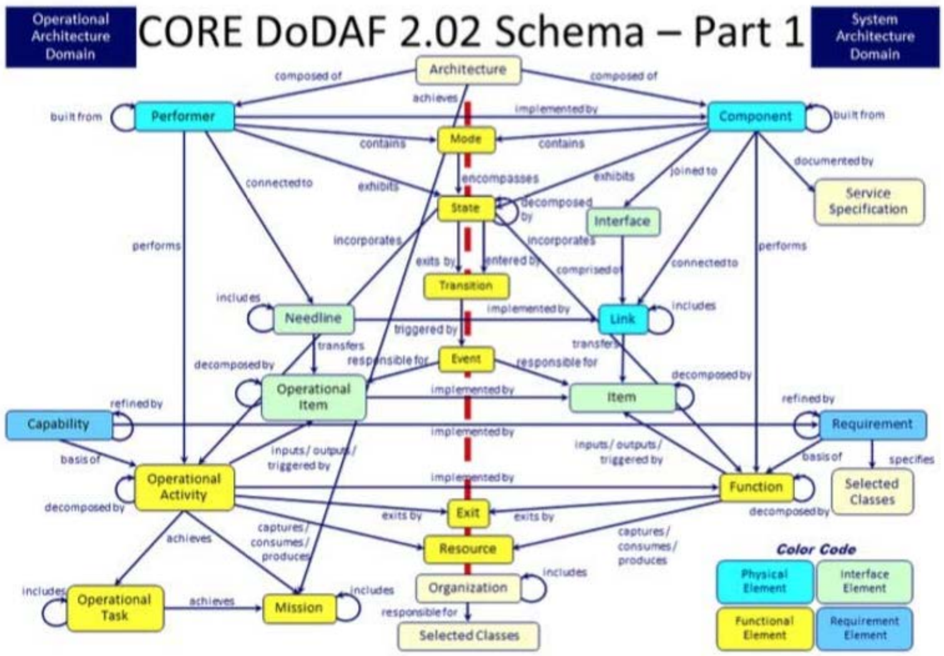

Figure 8. Vitech CORE Schema. Source: Johnson (2016).

E. OPERATIONAL SCENARIO

During a personal interview with Professor Kline on 11 August 2017, he stated that during previous war-games and modeling simulations demonstrated that a DL AFP exhibited vulnerability from a multi-layered adversary defense network. Specifically, if a swarm of low cost, land-based bombers scouted the force package and engaged it, the AFP could repel the initial wave through use of active sensors, but this sudden electromagnetic signature gave away their position to adversary patrolling SAGs allowing them to close on the AFP and sink the remaining ships. If the AFP maintained its passive search and engagement, the bombers sank the AFP. Additionally, the AFP exhibited vulnerability from land-based ASCM because the ships lacked the capability to detect the missile beyond their radar horizon thus reducing the time to engage. This establishes the operational need and the current capability gap that an EAFP attempts to solve.

Based on this capability gap, the operational need modeled in this architecture takes an AMERICA Class, LHA, and combines it with CRUDES or LCS ships, with the order to gain control of a sea line of communication (SLOC). Intelligence indicates an adversary SAG patrolling the waters 24 hours prior and airspace remains contested. Additionally, adversary's ASCM ranges contain the SLOC. Thus, the EAFP needs to attack and defend against a layered defense. The objective of the EAFP is not to seize control and hold it permanently but to seize and maintain sea control long enough to allow follow on missions. Additionally, the tasked objective is not to control an entire ocean or even an entire adversary's coast but only to control a small operating area. Once the EAFP gains sea control higher echelon command will task the EAFP with follow on orders that may include a strike, amphibious assault, or follow on ASUW mission.

F. STAKEHOLDER CONCERNS

Following research into the topic of DMO including previous NPS theses, Table 1 summarizes stakeholder concerns as they relate to an EAFP.

Reviewing the background on past research into DL and understanding the capabilities and limitations of an amphibious ship provides the basis for establishing the requirements and subsequent architecture for an EAFP. The architecture must account for stakeholder concerns and meet the needs gaps from the operational scenario presented. Following a system engineering approach produces an architecture that can meet the system requirements and is executable.

Table 1. Stakeholder Concerns

Stakeholders	Inputs and Concerns
Commander, Fleet Forces Command	1. Gain sea control to allow follow on missions 2. Develop naval strategic objectives to counter the movements and tactics of adversary nations 3. Naval forces networked to maximize overall fleet’s offensive and defensive capabilities 4. Logistics established to allow the operator to achieve its assigned tasking 5. Integration of air and sea assets 6. Maintain DMO 7. Minimize casualties resulting from surface engagements 8. Achieve localized sea control in a contested maritime environment. 9. Maintain EMCON amongst a SAG 10. Scalable force packages that allow for deception and concealment increasing uncertainty and adding complexity to an adversary’s targeting problem
Commander, Naval Surface Forces	1. Optimize available fire power from naval surface forces 2. Meet mission requirements from higher echelon commands 3. Train operators to execute required tactics 4. Maintain tools (depot-level repairs) to ensure enough resources available for tasking 5. Incentivize and retain high-level talent to ensure mission success 6. Coordinate necessary logistics for surface forces
Operators (Ship’s Crew)	1. Trained to complete all missions assigned. 2. Familiarity with other ships in EAFP composition 3. Maintenance on systems and components (particularly components executing missions for which they are originally designed to perform) 4. Defend against incoming threats both air and surface 5. Pass tracking and identification data of incoming threats to all members of the SAG to help achieve a common operating picture on all platforms 6. Accomplish assigned tasking from higher echelon command 7. Manage deception and counter-deception. Try to remain as conspicuous and stealthy to the adversary as possible
Marine Corps	1. Support navy advances 2. Maintain AMPHIB capabilities to bring Marines ashore 3. Assets available to support amphibious operations (i.e., JSF available for close air support)
Adversaries	1. Maintain sea control over regions held; restrict American freedom of movement and American naval assets from projecting power ashore from the sea. 2. Execute predetermined battle plan during an armed conflict with needing to minimally pivot to counter American naval actions 3. Defeat American naval assets both air and sea 4. Anticipate and know American maneuvers before they occur 5. Control SLOC

Chapter III takes the initial requirements established in the literary review and stakeholder concerns and creates a DODAF compliant architecture for an EAFP to include system viewpoints and operational viewpoints breaking the system down into functions and components.

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III. SYSTEM ARCHITECTURE

A. SYSTEM REQUIREMENTS

The operational concept presented, and stakeholder inputs, provide the basis for developing an initial set of requirements for the EAFP. These requirements establish the foundation for future system architecting and provide the link between the function and components realized the original need statement, and stakeholder concerns. Figure 9 displays the architected requirements for the system in a hierarchal view, with those requirements that an EAFP architecture meets highlighted in blue. These requirements for DL and DMO come from Canfield (2017) and Filipoff (2016). Requirements 1.1 through 1.3 provide the high-level requirements for DMO. The distributed requirement forces tactician to not mass forces as a single battle group. Integrated means these distributed air, sea, cyber, and space systems must talk and network with each other. Finally, a requirement for maneuvering means the system must operate in various environments (i.e., littoral or open-ocean).

As DL belongs to Surface Forces Command, a lower echelon command to Fleet Forces Command, DL falls under the tactic of DMO shown in the hierarchal relationship of the requirements. Admiral Rowden explains that four requirements exist for DL: tactics, talent, training, and tools (Filipoff 2016). The tactical requirement creates the basis for the way a DL task force needs to operate and thus creates the requirements for an EAFP. Talent refers to the requirement to retain high performing sailors to execute the tactics. A training requirement necessitates a training system, which the navy continues developing through its newly established Naval Surface and Mine Warfighting Development Center, and finally, a tools requirement dictates a developmental and acquisition system to provide innovative technology to better conduct DL.

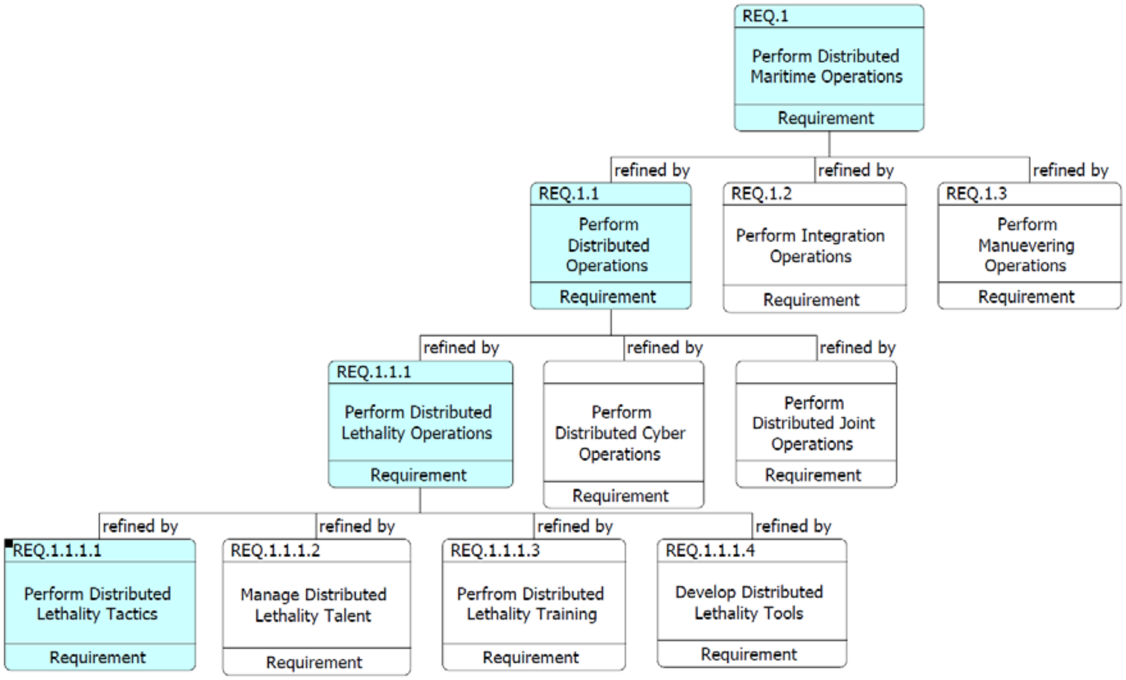


Figure 9. DMO Requirements

REQ.1.1.1.1, Perform Distributed Tactics, decomposes further to show the specific requirements an EAFP force structure needs to meet, showing how it performs DMO by DL. The other, un-highlighted, requirements need their own architecting and separate research beyond the scope of this thesis. To exemplify this system-of-system complexity and show related systems that provide input to the EAFP system, Figure 10 provides the context of other systems in which an EAFP operates, including the adversary's own military system and architecture.

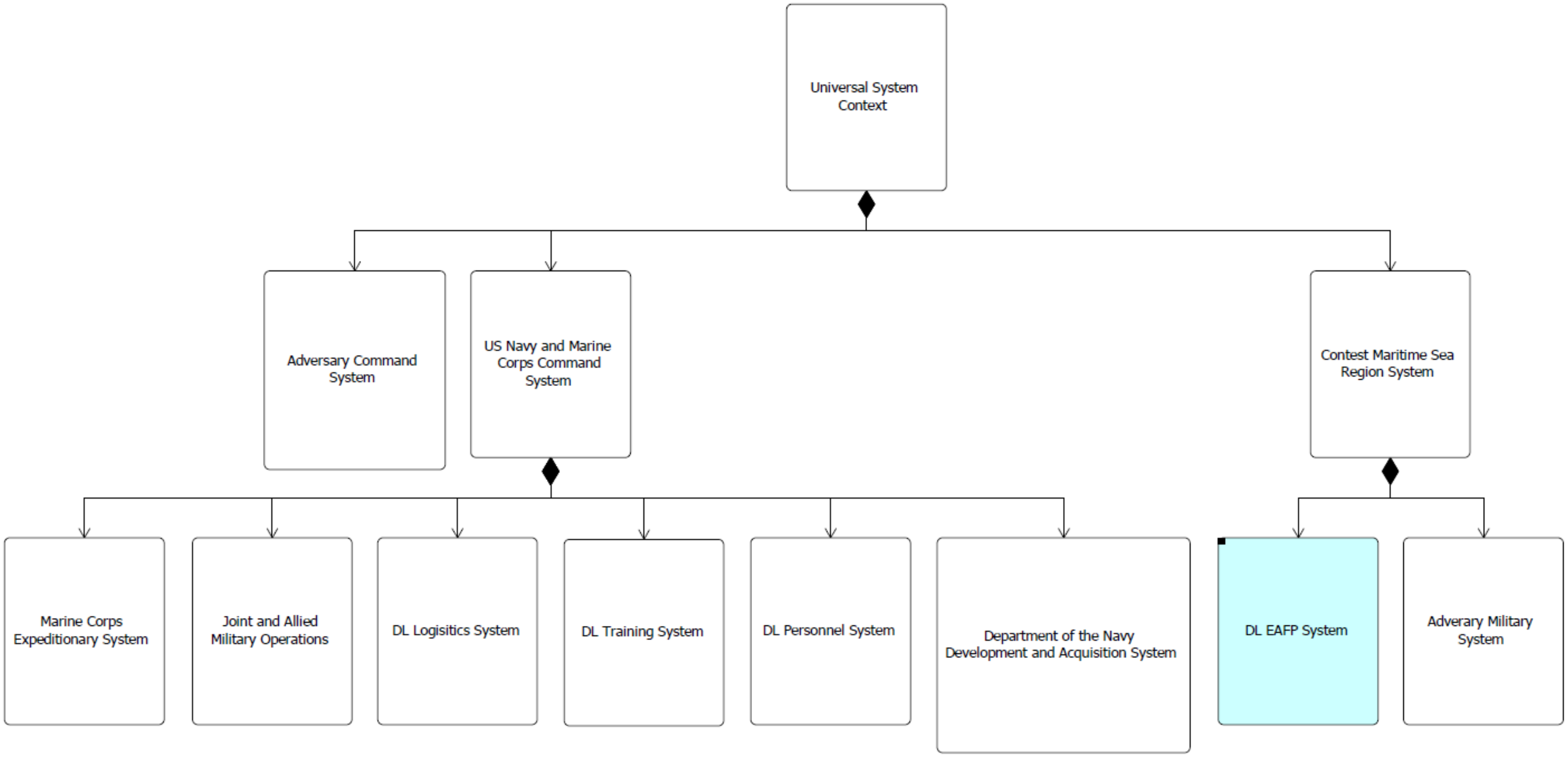


Figure 10. System of System Context for DMO

Requirement 1.1.1.1 decomposes further and relates directly to Johnson's (2016) thesis, which initially established 11 requirements for a DL force package to meet as shown previously in Figure 2. Most of the requirements remain, highlighted in yellow, in Figure 11 to Figure 13, but over the past two years since publication of Johnson's thesis, the concept of DL evolved necessitating updated requirements.

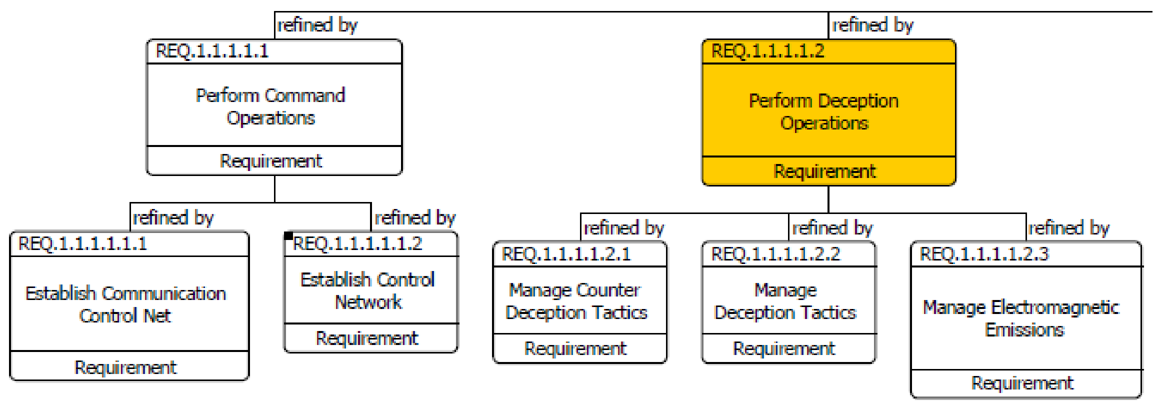


Figure 11. EAFP Requirements

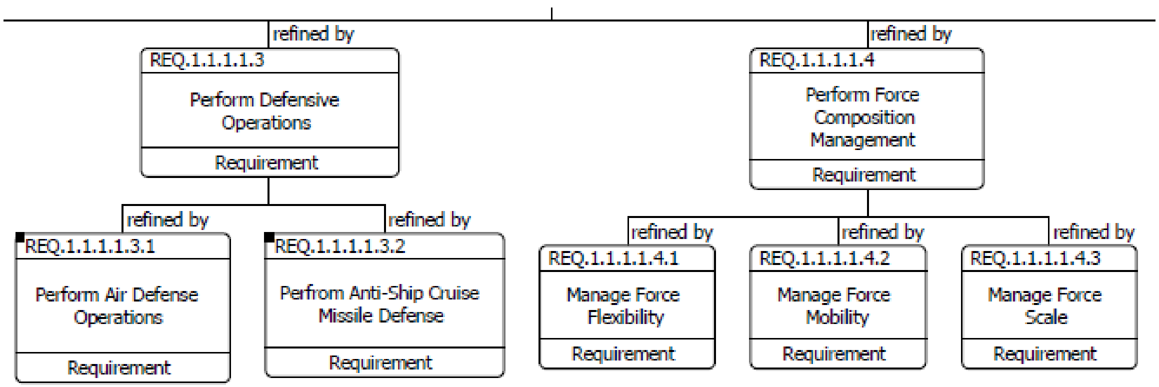


Figure 12. EAFP Requirements

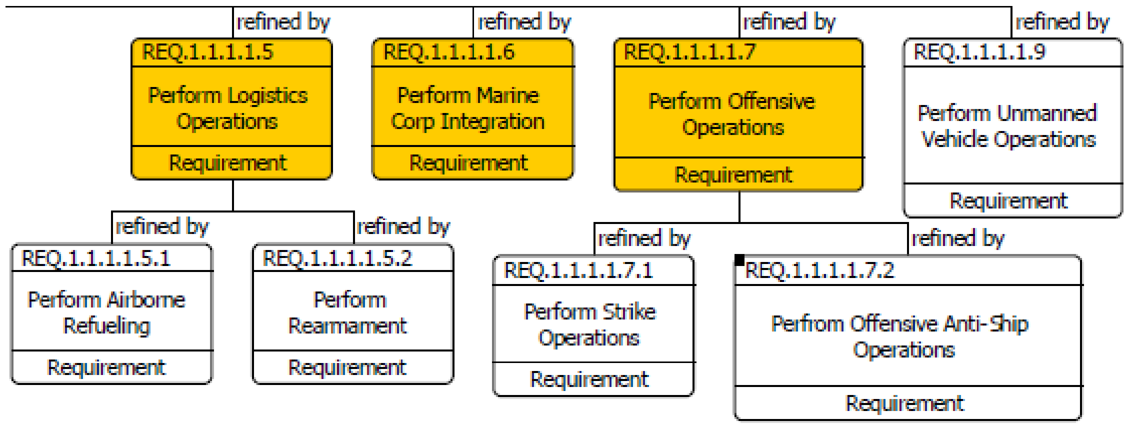


Figure 13. EAFP Requirements

The first refinement to previously established DL requirements includes the requirement to perform C2 operations and relates directly to the original Proceedings article on DL, which specifically states an AFP needs to communicate both internally and externally (Rowden, Gumataotao, Fanta 2015). Additionally, (Kline 2016) argues that in a reduced electromagnetic condition, known as EMCON, the AFP must establish autonomous control within itself and not require higher echelon command, to engage a target (Kline 2016).

During his interview with CIMSEC, Admiral Rowden specifically states, "DL is not just about offensive weapons" (Filipoff 2016). The EAFP needs to perform defensive operations but also for DL tactic to work effectively, mobile force packages need to engage the enemy at multiple points confusing the targeting solutions of the adversary and saturating their capabilities to defend. Perform defensive operations and force composition management addresses these requirements.

Replacing Johnson's (2016) generic requirement of "current/near future resources," this author established a specific requirement for an EAFP to include unmanned vehicle operations. This requirement supports the conclusions presented in Casola's (2017) thesis on including an USV into an AFP, enhancing the EAFP's operational capabilities, a priority for all stakeholders. The requirement to include unmanned systems also necessitates an inexpensive way to create a wider sensor net, supporting the DMO requirement for integration.

B. FUNCTIONAL ARCHITECTURE

The functional architecture identifies the action the system must perform to meet the requirements of the system. DODAF architecture breaks the functions between actions system operators perform and those that physical systems perform.

1. Operational Activities

Figure 14 shows the operating activities of an EAFP from receiving orders to deploy to a specific location through gaining control of that contested region and finally receiving follow on orders or returning to home port. The operational activities come from the Combined Operating Activities List (COAL) V2.0, provided as reference material during NPS class SE4150 and highlighted in orange, as well as this author’s knowledge and experience of required operator actions. The COAL provides standardized operational activities (OA) but does not include enough sub-activities to provide fidelity for further simulation analysis. The architecture also shows adversaries actions occurring in parallel to American naval actions. The figure displays the order in which the action occurs as well as the operator performing the action.

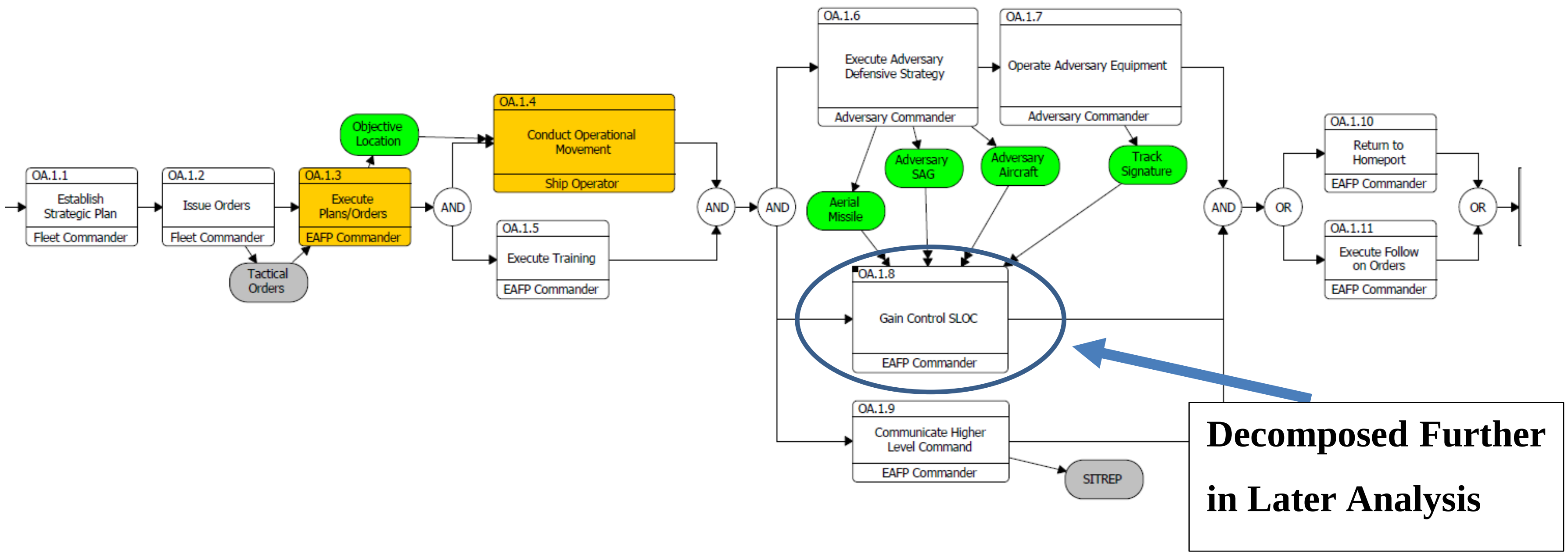


Figure 14. Contextual Operational Activities

Operational Activity 1.8, Gain Control SLOC, decomposes further in Figure 15 to specific sub-activities necessary to meet the system's requirements to gain SLOC control. Activities highlighted in orange come from the COAL and a description for them is included in a table within the document (Combined Operation Activities List). OA 1.8 displays all activities within gain sea control as occurring simultaneously but in theater, the operational commander will dictate the necessary activities to perform to gain a strategic advantage.

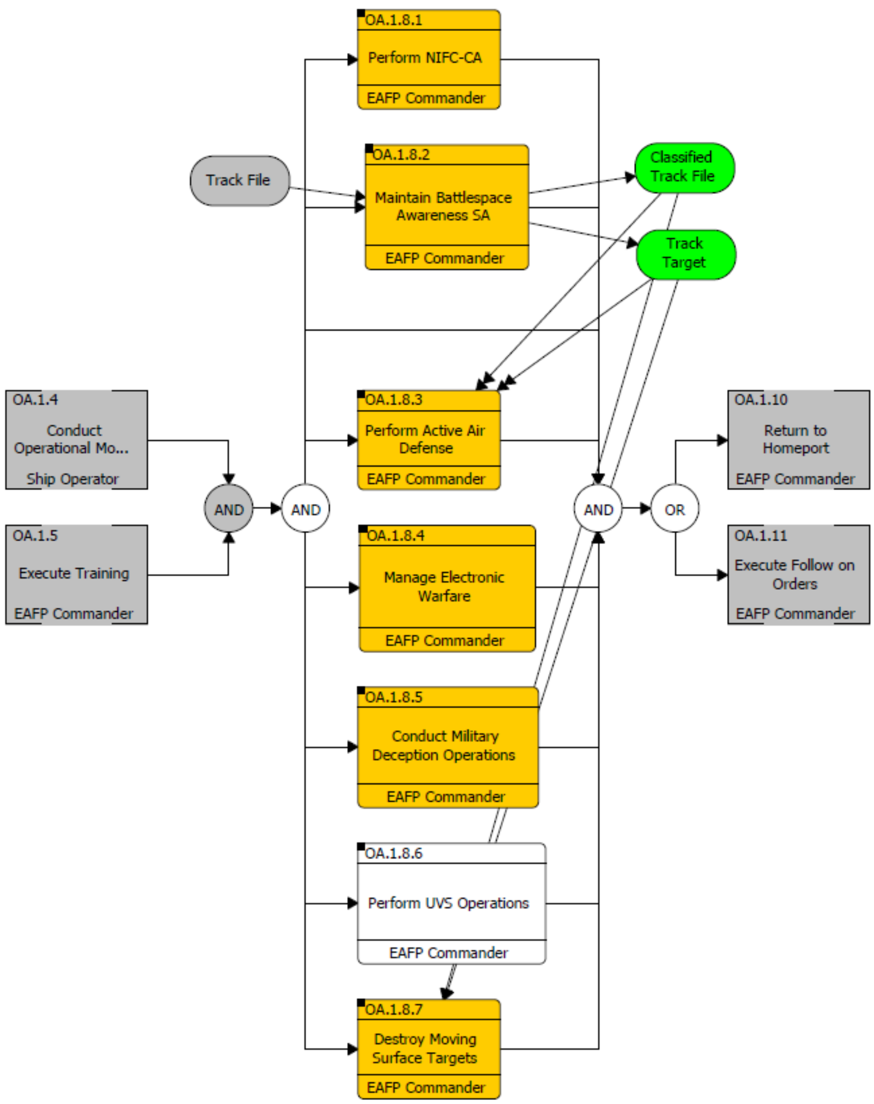


Figure 15. OA Gain Control SLOC

Decomposing Gain Control SLOC operational activities OA1.8.2–7, further identifies the individual activities that an operator must perform to accomplish the given parental OA and provides traceability to the requirements hierarchy. This decomposition leads to the conclusion that Naval Integrated Fire Control-Counter Air (NIFC-CA) is the only activity that relies on aircraft activities to perform its functionality. The other activities, for example, Maintain Battlespace Awareness, include aircraft operational activities as occurring simultaneous to other search and analysis activities but not exclusively relying on an airborne capability. Figure 16 and Figure 17 depict the individual actions required for NIFC-CA. The decomposition of the remaining operational activities are located in Appendix A, Figure 36 to Figure 41.

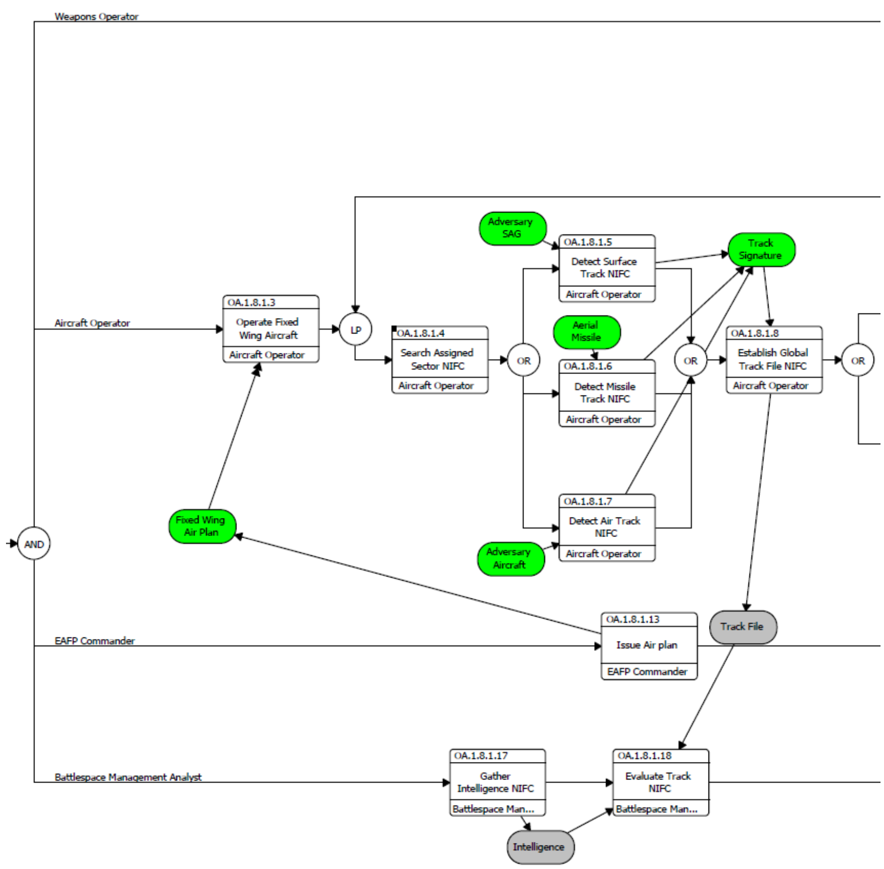


Figure 16. Perform NIFC (1 of 2)

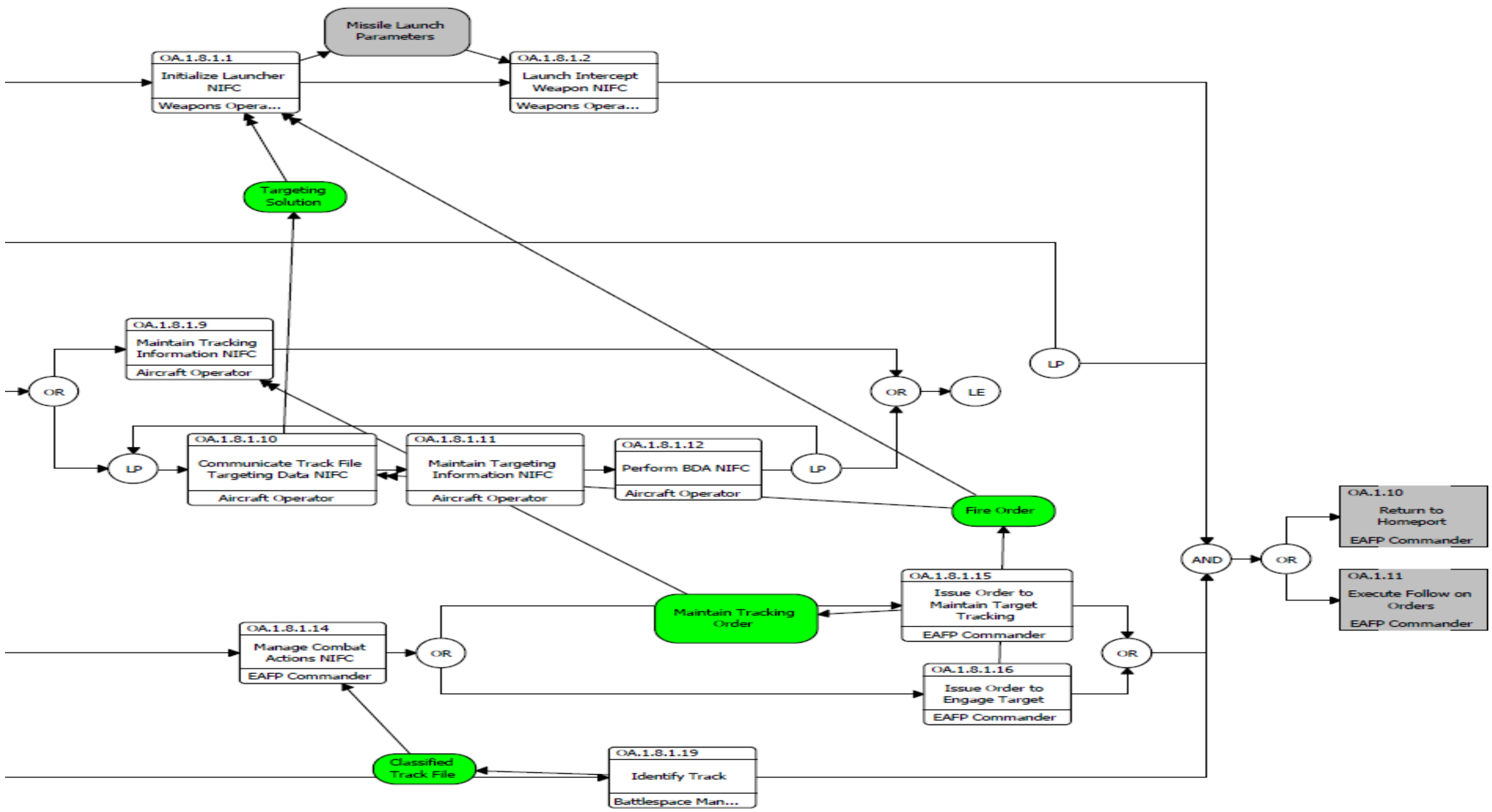


Figure 17. Perform NIFC-CA (2 of 2)

The greatest advantage gained from including the LHA in a SAG is the capability to launch and recover aircraft. No components in a traditional SAG can accomplish this. The aircraft become the ship's primary weapon system since the ship contains no other surface warfare offensive capability. The ship already employs a defensive weapon system. The ability to launch aircraft effectively extends the radar horizon of the EAFP and linking the aircraft's sensor data to the respective warfare commander on a ship enables faster detection and identification allowing more time to counter a threat. Additionally, the ability of aircraft to actively radiate and transmit the information back to the EAFP increases the stealth ability of the EAFP and prevents detection without compromising vulnerability.

By providing sensor data, Naval Integrated Fire Control extends the radar horizon further and permits a weapons operator to launch a weapon on an identified threat that the weapon operator's radar system has yet to detect. The F-35B provides targeting information to the missile on the threat's location all the way to the terminal phase of flight. Next, the missile's onboard radar equipment acquires and tracks the target through detonation. Engineers proved this CONOP to work in a live fire missile test on September 13, 2016, at White Sands Missile Test Range. An F-35B acquired a UAV, simulating an adversary aircraft, and the F-35, using its own organic sensors, passed the tracking information through its Multifunction Advanced Data Link (MADL) to a shore-based facility simulating an AEGIS weapon platform (LaGrone 2016). The AEGIS site, outfitted with a MADL antenna, passed the targeting information to an advance standard missile (SM) that launched on the target and consummated an intercept (LaGrone 2016).

2. Functions

While the operational activities describe the "actions" the operators need to do for the system to perform, the system functions highlight the tasks that the components need to execute for the system to perform. Figure 18 shows the high-level functions for an EAFP to transit to a SLOC and gain control of that maritime region. The architecture shows three specific systems that need to perform actions including a ship system, unmanned vehicle system (UVS), and aircraft system. System functionality derives from the Universal Naval

Task List and this author's own professional experience operating and studying naval systems (Chief of Naval Operations 2007).

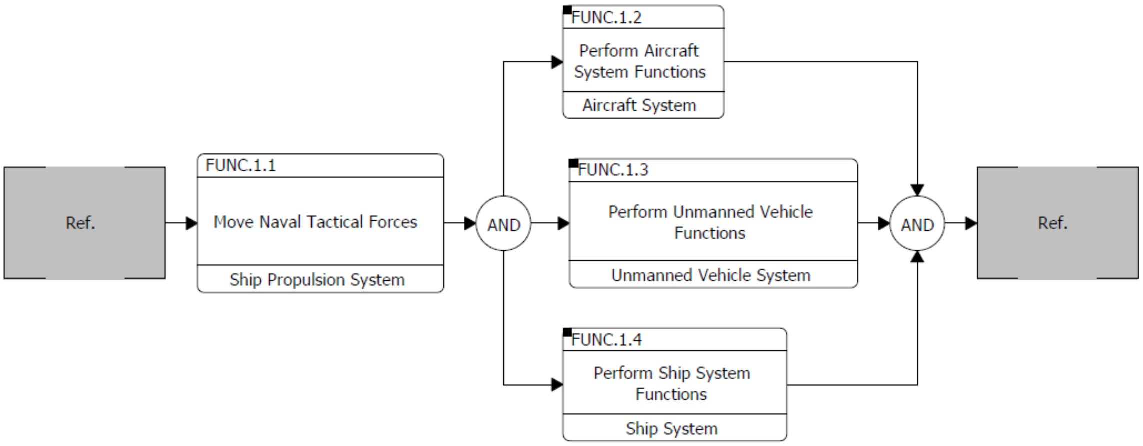


Figure 18. EAFP System of Systems Functions

The aircraft system and UVS decompose further to include functionality for a fixed wing aircraft, rotary wing aircraft, USV and UAV, decomposed in Figure 19 and Figure 20.

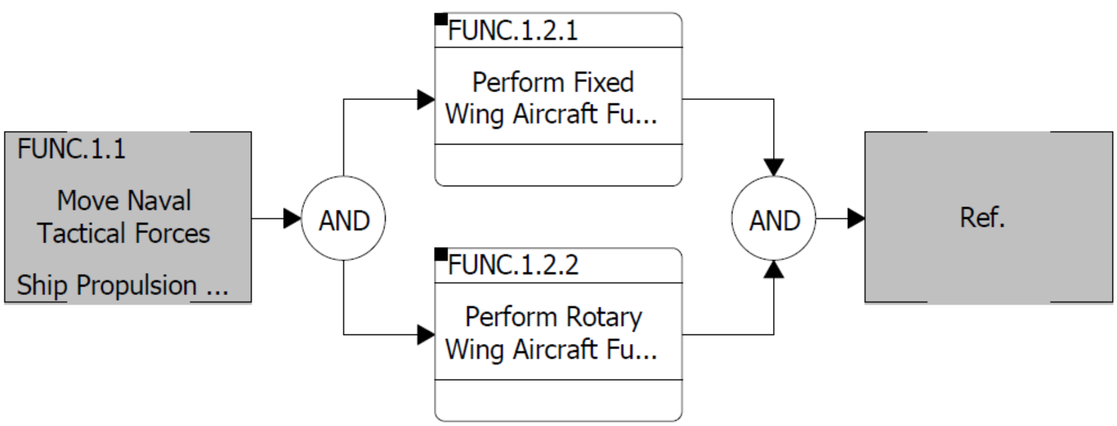


Figure 19. Aircraft System Functions

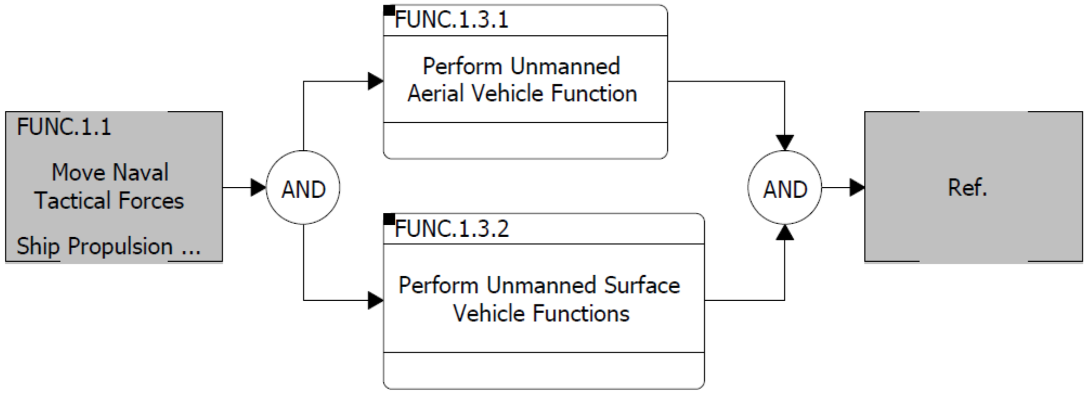


Figure 20. UVS Functions

Appendix B contains Figure 42 to Figure 46, decomposing the functionality of each architected system. The figures show that each system possesses core, common functionality. The physical system needs to propel and control (maneuver) itself, perform both active and passive searching from which onboard computer equipment can analyze and provide human operators an output to conduct further analysis. Additional core functionality includes the ability to transmit data and voice communications to other systems (the UAV, with no onboard operator, does not transmit voice communications) and finally the ability to process targeting data to employ a weapon (whether from its own sensors or off-board sensor data), either in an offensive or defensive mode, against a surface or aerial target. As the ship system functions as the central unit from which the other systems operate, its architecture includes specialized functions such as launching and recovering aircraft and controlling both UAV and USV systems. Also included in the functionality figures is the assignment of system component to complete the specific function and explained in more detail in follow-on sections of this thesis.

C. PHYSICAL ARCHITECTURE

The physical architecture identifies the action performers for the system. DODAF architecture breaks the physical architecture between system nodes or human operators performing operational activities and components or the physical items performing system functions.

1. Operational Nodes

Each OA requires an operator, referred to as a node, designated to perform the specified activity. Figure 21 identifies the 10 required nodes for the system. This does not mean the system only requires 10 operators to function. While not explicitly shown in the figure, the "operator" includes multiple operators on multiple platforms. For example, the weapons operator includes the pilot pulling the trigger in an aircraft and the tactical action officer staffing the combat information center on a ship. In addition to identifying the required nodes, Figure 21 also shows the needlines between the nodes or what each node needs from another to perform its assigned OA. These needlines directly relate back to the inputs and outputs of the architected operational activities, reinforcing the architectural completeness.

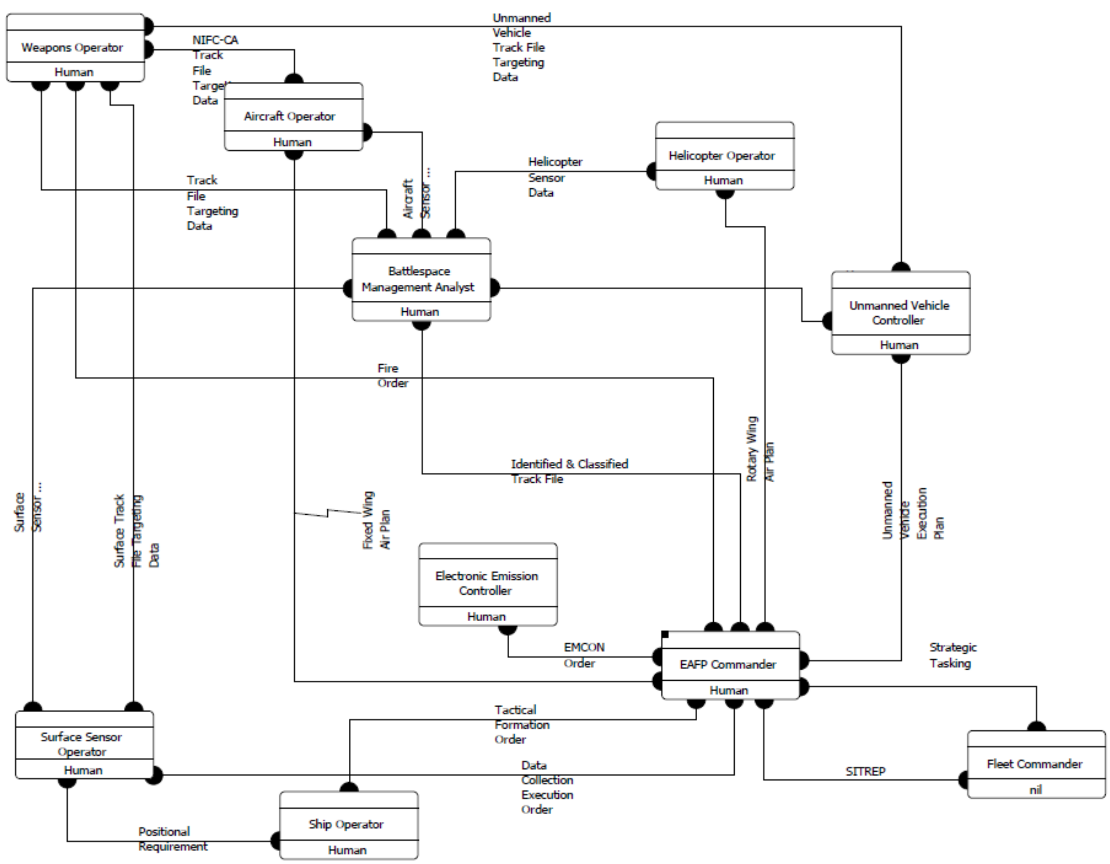


Figure 21. System Nodes

2. System Components

Identifying the required functions, the system needs to perform assists the architect in creating the components in the system to execute these functions. Figure 22 identifies the high-level system components from which the author decomposed further into individual sub-system components displayed in Appendix C, Figure 47 through Figure 53. Like the architecting of the operational nodes, the systems can contain multiple systems within one system. For example, the ship system component can include one ship that contains all the required components or multiple ships that may contain some or all the architected components. Logic dictates that certain components are necessary for each ship system such as propulsion while isolating, launching, and recovering aircraft applies to one ship system.

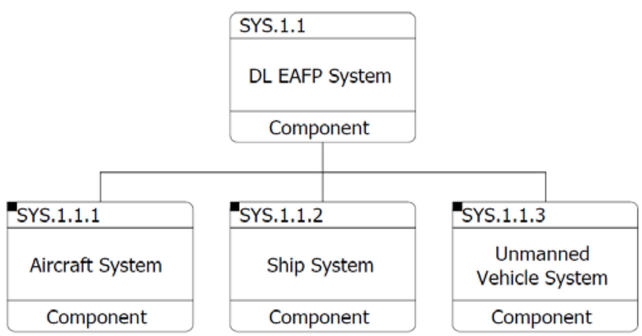


Figure 22. EAFP System Components

An LHA acting as a light aircraft carrier can launch and recover both fixed wing and rotary wing aircraft. Ongoing research and development of the USV, Sea Hunter, and UAV Tern provide examples of UVS to include as systems and allocate to this architecture. In addition, LCS and DDGs currently deploy the MQ-8 Fire Scout to provide active and passive sensor coverage.

Beyond sharing a hierarchal relationship, each system component connects to each other to pass information or material. Figure 23 outlines the interfaces for the major system components in Figure 22. For completeness and to ensure the architectural elements relate directly, the inputs and outputs identified in the system functions are the same as the interfaces shown.

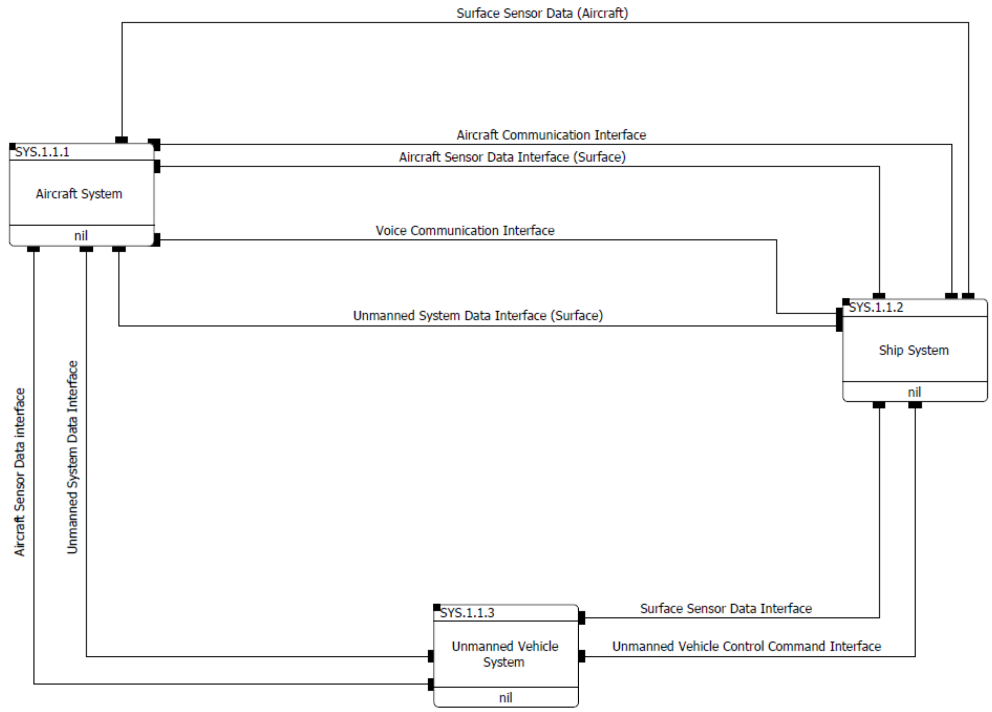


Figure 23. EAFP System Interfaces System Architecture Analysis

The developed architecture follows the system approach outlined in Figure 6. The initial problem statement and stakeholder concerns form the basis of the system requirements. The requirements then drive the functions and components to complete those requirements. While the EAFP LHA architecture meets the requirements identified, it represents just one system solution to the stakeholder's capability gap. Architecting a DL, SAG as earlier researchers accomplished also addresses stakeholder concerns and meets all identified requirements for a surface warfare mission.

In the next chapter, architected functions and components become the basis for a model-based system engineering simulation, helping identify the most critical variables in the system as well as the trade space between different EAFP system configurations.

IV. ARCHITECTURE ANALYSIS

The LHA architecture developed in this thesis employs the tactic of DL through DMO utilizing all available naval assets to solve the surface warfare, sea control problem and better address stakeholder concerns. However, simply adding more to solve the problem is not necessarily the optimized solution. The addition of an LHA into a SAG increases operational capabilities but places additional unexpected designed risks on the LHA through new hostile encounters. Simulating an EAFP against adversary threats provides quantitative data to assess an EAFP's effectiveness and the tradeoffs that exist.

A. MODELING SCENARIO

Discussed in Chapter II, Operational Scenario, section of this thesis a traditional SAG exhibited vulnerability from a layered defense of aircraft and surface ships. NPS Professor Kline provided the following unclassified scenario to his NPS, Joint Capability Analysis class. Fleet commander tasked an LHA, EAFP, consisting of an LHA, DDG, CG, and LCS, to penetrate and control a SLOC within the Chinese first island chain, displayed in Figure 24. Intel indicates recent bomber, aircraft identified in later tables as type one aircraft, and fighter activity, identified as type two aircraft, on nearby islands and air reconnaissance identified an adversary SAG within the last 48 hours. The number of aircrafts, missiles, and ships is unknown. Intelligence knows that bomber aircraft carry ASCMs capable of greater speed while fighter aircraft can only launch slower speed ASCMs.

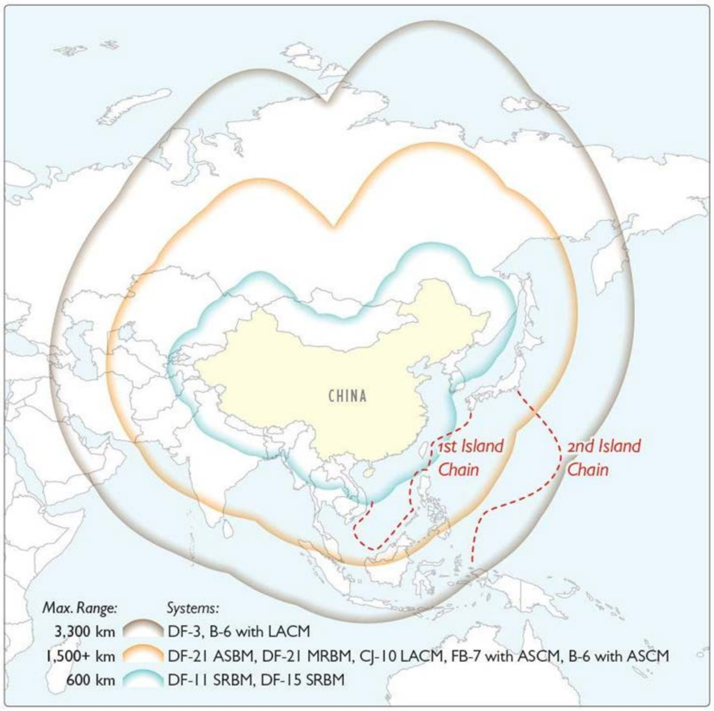


Figure 24. Chinese A2/AD Regions. Source: Leonardo (2015).

The author developed an ExtendSim discrete model employing the EAFP architecture outlined in Chapter III, System Architecture, within this scenario environment. Table 2 summarizes the unclassified, continuous range of values for blue weapon and sensor capabilities and Table 3 summarizes the continuous range for red force's quantity, start range, detection range, and speed. For this model, the start range is the range red can detect blue forces while detection range is the range at which blue will begin detecting the red unit.

Table 2. Blue Weapon and Sensor Properties. Adapted from Davis (2017).

Blue Force Weapon Properties	Low	High
SM6PHit	0.5	0.95
SM6PK	0.7	0.9
SM6MinRange (nm)	8	12
SM6MaxRange (nm)	200	250
SM6Cycle Time (s)	0.9	2.2
SM6Speed (nm/s)	0.6	0.7
SM2PHit	0.5	0.8
SM2PK	0.6	0.8
SM2MinRange (nm)	3	5
SM2MaxRange (nm)	70	85
SM2Cycle Time (s)	0.9	1.2
SM2Speed (nm/s)	0.6	0.7
CIWSPk	0.05	0.2
CIWSMaxRange (nm)	0.9	1.1
5inchMaxRange(nm)	4.5	5.5
5inMinRange(nm)	1.8	2.2
5inSpeed(nm/s)	0.78	0.81
5inPk	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
RAMMaxRange(nm)	8	9
RAMMinRange(nm)	0.9	1.2
RAMSpeed(nm/s)	0.35	0.5
RAMPk	0.25	0.35
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
DDG SPY Radar Pd	0.88	0.98
DDG SPY Surface Pd	0.65	0.75
CG SPY Radar Pd	0.83	0.93
CG Surface Pd	0.6	0.7
LCS 3D Radar Pd	0.6	0.7
LCS Surface Radar Pd	0.15	0.25
LHA Air/Surface Radar Pd	0.7	0.8
JSF Air/Surface Pd	0.89	0.98

Table 3. Red Quantity and Performance Parameters. Adapted from Davis (2017).

#ASCM(Fast)	2	6
#ASCM(Slow)	2	3
#Aircraft1	5	10
#Aircraft2	5	10
#Ship	4	8
ASCM(Slow)Detect(nm)	5	120
ASCM(Fast) Detect(nm)	5	100
ACFT1 Detect(nm)	90	110
ACFT2 Detect(nm)	30	50
ShipDetect(nm)	25	35
ASCM(Fast)Speed(nm/s)	0.485	0.655
ASCM(Slow)Speed(nm/s)	0.12	0.18
ACFT1 Speed(nm/s)	0.15	0.165
ACFT2 Speed(nm/s)	0.25	0.35
ShipSpeed(nm/s)	0.005	0.01
ASCM(Fast)Start(nm)	80	120
ASCM(Slow)Start(nm)	70	90
ACFT1 Start(nm)	110	170
ACFT2 Start(nm)	90	110
Ship Start(nm)	5	40

Table 4 outlines the blue or red force variables changed within the simulation to model the operating environment more realistically. The variable, NIFC-CA, is a categorical value representing whether or not the EAFP employs NIFC. Not employing NIFC is equivalent to the capabilities of a SAG. EMCON Condition specifies the percentage that blue force sensors radiate. At zero, the EAFP is fully radiating all sensors while at the highest threshold minimal radiation emits from the force package limiting both blue and red forces' capabilities to detect. Prior to launching missiles, the force package must exit EMCON if not employing NIFC at a certain time delay. Instead of modeling red's sensors individually, a single probability of detection simplifies the model. Finally, if using NIFC, the distance at which the JSF establishes a combat air patrol (CAP) is varied. This variable pushes the detection range further out permitting earlier detection of red and more engagement opportunities.

Table 4. Simulation Variables

NIFC-CA	0	1	
EMCON Condition (%)	0	.8	
EMCON Delay (s)	5	10	30
RedPd	0.5	0.8	
CAP Location (nm)	25	50	75

B. MODEL DESCRIPTION AND ASSUMPTIONS

1. Red Aircraft Performance and Detection

The model assumes a set number of red air and surface threats at the beginning of the simulation with no known location of the blue EAFP. During the model run, red bomber and fighter aircraft linearly proceed on the same attack axis, attempting to locate blue forces all with the same detection probability. If one red aircraft locates the EAFP, the simulation assumes they radio to the rest of the red forces the location allowing all remaining red forces to employ weapons on blue.

If red aircraft reach the missile start range for its respective ordinance type and red force knows the blue force location, the aircraft launch all ASCMs and immediately exit the simulation, meaning blue cannot attack retreating red forces despite being in sensor detection range or missile engagement range. If red aircraft did not locate the blue EAFP at the missile start range they cease looking and immediately exit the model as a truce unit (cannot kill and blue cannot kill them).

2. Red Surface Action Group Performance

The Red SAG does not actively search for the EAFP and only engages if red aircraft determine the location of the blue EAFP. If the EAFP has not located and destroyed the red SAG prior to all enemy aircraft retreating, the SAG retreats as well ending the simulation run.

3. Blue Expanded Adaptive Force Package Performance and Detection

Simultaneous to red searching for the EAFP, the EAFP attempts to locate red forces both surface and airborne. While the model treats the EAFP as a point source, the EAFP must locate each red threat prior to engaging it. The model assumes each blue force unit shares a common network with each blue force sensor detection aggregated into a probability of detection for a given red threat. The probability of detection also includes a scaling factor to account for the size and speed of a given threat as well as an EMCON modifier to reduce detection probability when EMCON level is higher (assumes fewer sensors radiating).

$$Pd_{overall} = (1-((1-Pd_a)(1-Pd_b)...(1-Pd_n))*(1-EMCON\%)*ScaleFactor \qquad (1)$$

The EAFP can offensively engage red aircraft prior the weapon release (eliminating any missiles onboard) and surface ships. The model assumes the EAFP engages red surface threats with harpoon missiles. Once the aircraft release their missiles, the EAFP must locate the missiles and shoot them down prior to the missiles impacting. The EAFP also needs to find and destroy any remaining red surface combatants prior to them impacting the EAFP.

The model counts only the number of hits and does not assess damage to the target. A blue hit also does not degrade the unit’s capability within the model (i.e., a hit on a CG does not eliminate SM-6 capabilities during a simulation run).

C. MEASURES OF EFFECTIVENESS AND PERFORMANCE

The evaluation criteria used to assess the EAFP within the scenario includes blue force lethality and blue force vulnerability. These measures of effectiveness (MOEs) directly relate back to stakeholder requirements and represent the most important traits an EAFP must possess. Measures of performance (MOPs) capture specific, measurable data to support its MOE.

1. Measure of Effectiveness One: Blue Lethality

One of DL's primary requirements is lethality. The EAFP does not sit and wait to defend but must be on the offensive to destroy red forces while holding a SLOC. Within the model, three MOPs evaluate the effectiveness of a SAG or EAFP, and are directly related to the MOE of Blue Lethality: percent of red forces offensively killed (aircraft or ships), percent of red retreat (both red and blue unable to find the other), and percent of leakers (threat aircraft releasing missiles). A higher percentage for offensive kills is optimal. A lower value for percent of leakers is optimal. Red retreat records the red aircraft that blue does not destroy but also the percent of red aircraft that do not find the blue force package. A higher percentage of red retreat, while not optimal for blue forces, indicates a virtual attrition of red forces, where red forces utilize aircraft for search rather than offensive projection. This may be beneficial for other blue forces as the purpose of DL is to stretch red's forces and overload their offensive and defensive system capability.

2. Measure of Effectiveness Two: Blue Vulnerability

Vulnerability, a subset of survivability, is how well a system resists hits from attack. For this the model, three primary MOPs evaluate the system's vulnerability: percent of red defensively killed, percent of red units impacting blue (hits), number of hits total. When red units reach their engagement envelop and launch a missile blue must defend against the incoming threat. From the total number of missiles launched, the number of missiles blue destroys and the number of missiles that hit blue represent the percent of red defensively killed and percent of hits, respectively. Number of hits records the hits on blue regardless of the number of missiles originally launched. A secondary MOP is number of hits to the LHA. This metric addresses and attempts to quantify the relationship between the lethality and vulnerability when adding the LHA to the EAFP. Intuitively, the author expected lethality to increase when conducting NIFC with an EAFP, but concerned with the potential risk to this high value unit.

D. DESIGN OF EXPERIMENTS

Due to the number of variables of interest to this analysis, traditional factorial designs are not appropriate. In order to minimize the number of simulation runs required with minimal impact to the assumptions associated with the regression techniques that will be employed to analyze the output data, the model used the nearly orthogonal/balanced designs generated in Vieira (2012). Vieira 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 associated design enabled examination of the 57 continuous variables and the three discrete variables of interest to this analysis using only 512 design points with minimal correlation between those input variables. To demonstrate the appropriateness of the design, Table 5 presents the correlation between 10 of the input variables (note that zero correlation is preferred). No variables had greater than a .061 correlation. Replicating the 512 design points 10 times created the inputs to the model generating 5120 trials.

Table 5. Correlation Matrix Independent Variables

	SM6 PHit	SM6 Pk	SM6 Min Range	SM6 Max Range	SM6 Cycle Time	SM6 Speed	SM2 PHit	SM2 Pk	SM2 Min Range	SM2 Max Range
SM6 PHit	1.000	-0.001	0.003	0.001	-0.007	0.004	-0.002	-0.008	0.003	-0.003
SM6 Pk	-0.001	1.000	-0.002	-0.003	0.001	-0.004	0.002	0.004	0.004	0.000
SM6 Min Range	0.003	-0.002	1.000	0.007	-0.006	-0.009	0.013	-0.002	-0.008	0.003
SM6 Max Range	0.001	-0.003	0.007	1.000	-0.001	-0.001	0.001	0.005	-0.001	-0.001
SM6 Cycle Time	-0.007	0.001	-0.006	-0.001	1.000	0.006	-0.003	0.000	0.000	0.002
SM6 Speed	0.004	-0.004	-0.009	-0.001	0.006	1.000	0.000	0.000	0.001	-0.001
SM2 PHit	-0.002	0.002	0.013	0.001	-0.003	0.000	1.000	-0.002	0.000	0.000
SM2 Pk	-0.008	0.004	-0.002	0.005	0.000	0.000	-0.002	1.000	0.001	0.002
SM2 Min Range	0.003	0.004	-0.008	-0.001	0.000	0.001	0.000	0.001	1.000	0.000
SM2 Max Range	-0.003	0.000	0.003	-0.001	0.002	-0.001	0.000	0.002	0.000	1.000

E. RESULTS AND ANALYSIS

The methodology for analyzing the results focuses on general descriptive statics and analysis of variance (ANOVA) primary effects. Note that the analysis intentionally omitted higher order effects and interaction effects. The result of excluding interactions and higher order effects results in an overall lower R^2 than if these were included but analysis indicated that the top contributing factors remained the same despite adding higher orders of analysis. The most significant result from the analysis showed NIFC and the utilization of JSF aircraft aboard an LHA represents the greatest difference between a SAG and an EAFP. Table 6 and Table 7 summarize the mean performance for each MOP/MOE segmenting the data between a SAG and LHA EAFP.

Table 6. Summary Statistics SAG

Variable	Mean
%Red Offensive Kills	0.04
%Red Defensive Kills	0.92
%Red Retreat	0.04
%Red Hits	0.04
%Leakers	0.91
#Hits	3.19

Table 7. Summary Statistics EAFP

Variable	Mean
%Red Offensive Kills	0.16
%Red Defensive Kills	0.92
%Red Retreat	0.04
%Red Hits	0.03
%Leakers	0.76
#Hits	2.29

Reviewing the tables two MOPs standout, the percentage of red offensive kills (red aircraft destroyed) and the number of hits (red missiles impacting blue) sustained on average. With JSF CAPs patrolling for enemy aircraft and allowing remote targeting, the offensive capability quadrupled. Because of this offensive improvement, blue forces reduced red forces' opportunity to deploy ASCMs and as a result, an EAFP sustained on average one fewer hit per trial.

1. Measure of Effectiveness One: Blue Lethality

a. Offensive Kill Percentage

Regression analysis showed NIFC, CAP location, and ASCM (Fast) Range as the dominant variables in modeling blue lethality. Figure 25 highlights the top five variables predicting the percentage of red units offensively killed. The Summary of Fit statistics are included to provide additional detail regarding the quality of the model fit and the LogWorth values are included to provide additional detail regarding the relative importance of the input variables.

Source	LogWorth	PValue
NIFC	390.850	0.00000
CAP Location	250.998	0.00000
ASCM(Fast)Range	94.322	0.00000
ACFT1Detect	35.466	0.00000
ACFT1Range	24.088	0.00000

Summary of Fit	
RSquare	0.444403
RSquare Adj	0.44386
Root Mean Square Error	0.09011
Mean of Response	0.102292
Observations (or Sum Wgts)	5120

Figure 25. Partial Effect Summary for Offensive Red Kills

Using factor isolation to remove NIFC (the most dominant term) and subsequently the difference between an EAFP and SAG, allows segmented analysis and assists in determining the variables with the most significant impact on offensive kill percentage. Figure 26 highlights the result of this analysis with the top 10 variables identified following a stepwise regression. Blue forces need time to progress through the find, fix, track, target, engage sequence with the dominant independent variables including range (start or detection) and speed both tied to time for both a SAG and EAFP.

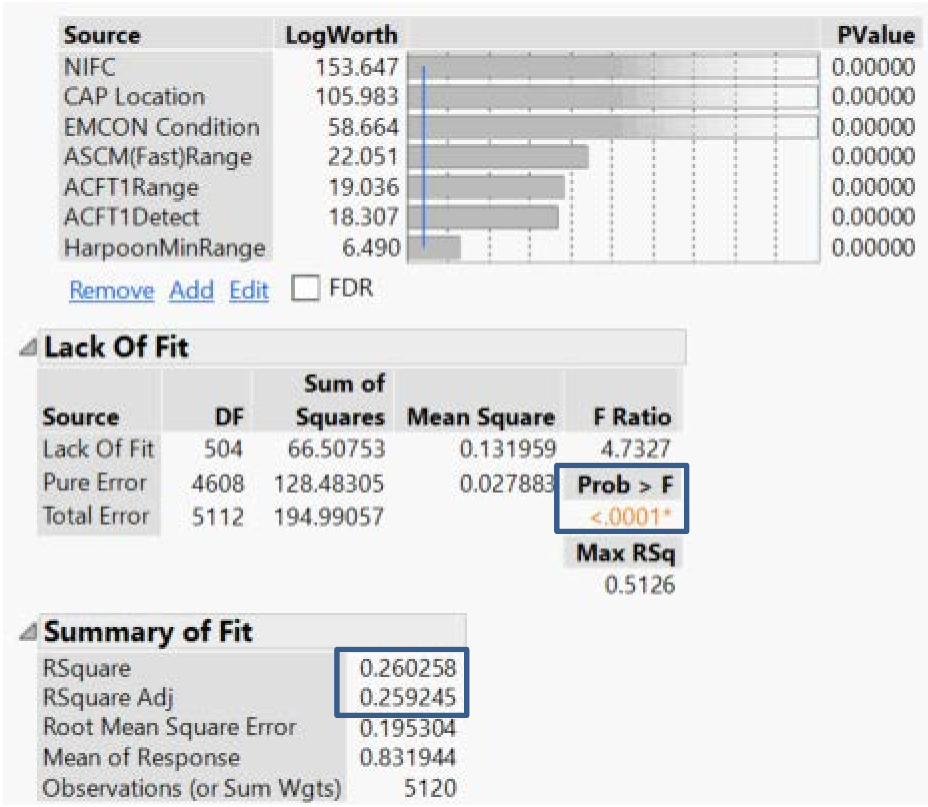
Source	LogWorth	PValue
CAP Location	389.634	0.00000
ASCM(Fast)Range	58.838	0.00000
ACFT2Detect	31.661	0.00000
ACFT1Range	24.272	0.00000
ACFT1Detect	20.774	0.00000
EMCON Condition	15.997	0.00000
ASCM(Slow)Range	15.183	0.00000
ShipDetect	7.196	0.00000
5inPk	4.534	0.00003
ESSMPk	3.970	0.00011

Source	LogWorth	PValue
ASCM(Fast)Range	174.178	0.00000
ACFT1Detect	67.540	0.00000
ACFT1Range	44.803	0.00000
ASCM(Fast)Speed	7.399	0.00000
#ACFT1	5.045	0.00001
ASCM(Slow)Range	4.377	0.00004
5inMaxRange	4.338	0.00005
ShipSpeed	4.320	0.00005
ASCM(Slow)Speed	4.083	0.00008
HarpoonPk	2.613	0.00244

Figure 26. Partial Effects Comparison EAFP/NIFC (left) and SAG/No-NIFC (right)

b. Red Aircraft and Ship Leakers

Figure 27 shows the results from a regression analysis on the number of leakers. Like the offensive kill percentage, the employment of NIFC and EMCON, as well as the CAP Location impact the number of red aircraft leakers most substantially. Unfortunately, the R-Square value associated with the model is rather low (as highlighted in Figure 27), accordingly this model affords no further recommendations regarding the number of red leakers.



Source	LogWorth	PValue
NIFC	153.647	0.00000
CAP Location	105.983	0.00000
EMCON Condition	58.664	0.00000
ASCM(Fast)Range	22.051	0.00000
ACFT1Range	19.036	0.00000
ACFT1Detect	18.307	0.00000
HarpoonMinRange	6.490	0.00000

Remove Add Edit FDR

Lack Of Fit

Source	DF	Sum of Squares	Mean Square	F Ratio
Lack Of Fit	504	66.50753	0.131959	4.7327
Pure Error	4608	128.48305	0.027883	Prob > F
Total Error	5112	194.99057		<.0001*
				Max RSq
				0.5126

Summary of Fit

RSquare	0.260258
RSquare Adj	0.259245
Root Mean Square Error	0.195304
Mean of Response	0.831944
Observations (or Sum Wgts)	5120

Figure 27. Partial Effect Summary Red Aircraft Leakers

c. Red Retreat

Red retreating represents a win and lose situation for blue forces. The objective of DL is to detect and destroy red forces and remove them from the current fight and future fights. As a result, when red retreats, it represents a failure for both red and blue. For an EAFP, a red retreat though is a successful-failure, as the red forces searching for the EAFP cannot execute a mission against another blue force. Figure 28 displays the top five variables contributing to red retreat. These variables possess a low R^2 value of .076 meaning modeling those variables only explains seven percent of the variability in red retreat. However, even when adding all the variables for the model the R^2 value only increases to .09 indicated that an alternative type of analysis might be more appropriate.

Source	LogWorth		PValue
EMCON Condition	74.286		0.00000
ASCM(Fast)Range	6.897		0.00000
ACFT1Range	5.245		0.00001
#ACFT2	4.437		0.00004
HarpoonMinRange	3.038		0.00092

Summary of Fit

RSquare	0.076429
RSquare Adj	0.075526
Root Mean Square Error	0.140798
Mean of Response	0.040454
Observations (or Sum Wgts)	5120

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	5	8.38962	1.67792	84.6403
Error	5114	101.38086	0.01982	**Prob > F**
C. Total	5119	109.77048		<.0001*

Figure 28. Partial Effects Summary Red Retreat

While traditional regression did not result in any actionable conclusions, partition tree analysis did result in insights. Figure 29 partitions retreat data based on the most significant independent variable, EMCON condition, to determine if a split exists where a greater percentage of red units retreat. From this partition, at an EMCON condition greater than .7, where almost no electromagnetic radiation occurs from blue forces, the mean increases from .03 to .14. At the split indicated, a greater concentration of trials resulted in higher red retreat percentages.

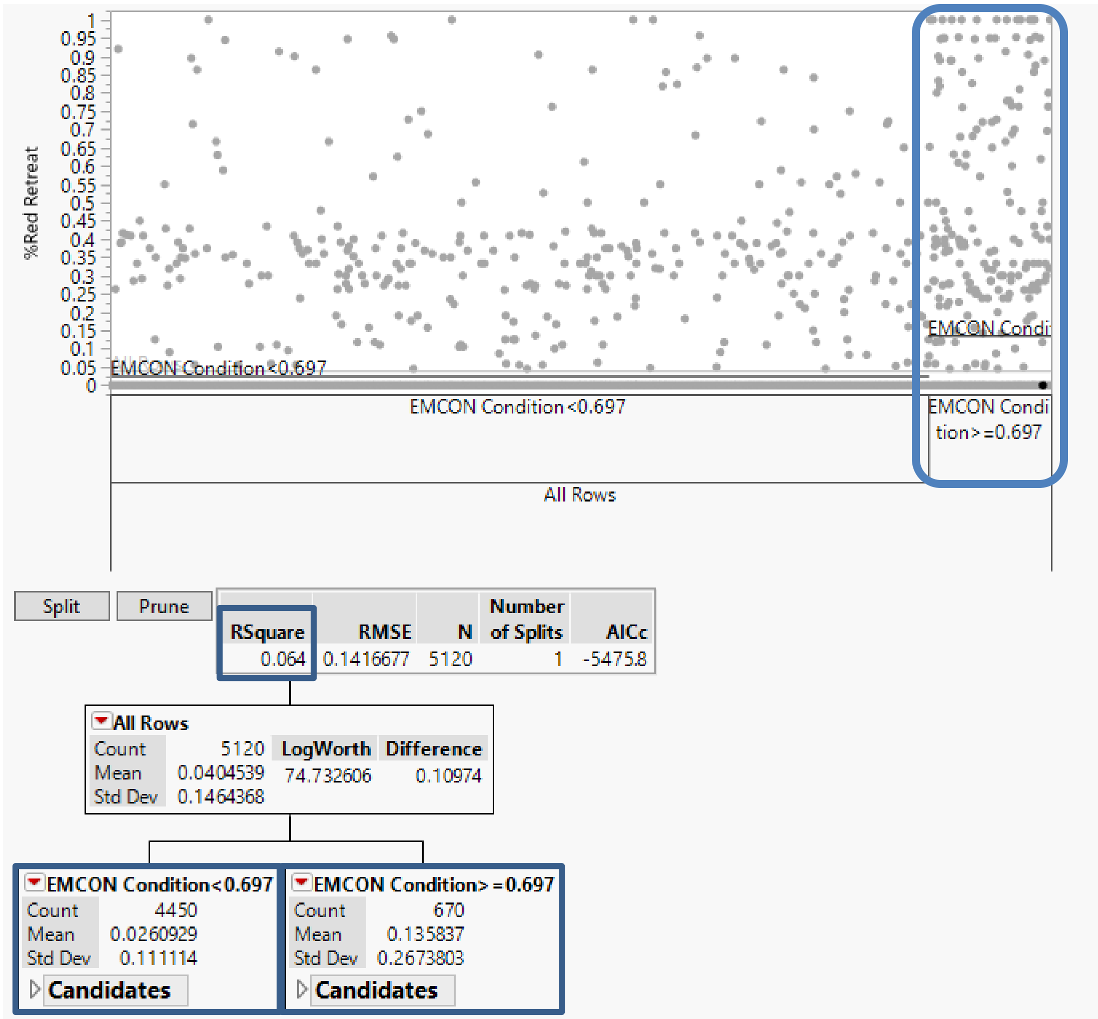


Figure 29. Partition Plot Red Retreat

An alternative way to analyze red retreat is through a segmented analysis, removing all the trials where zero red units retreated (either blue destroyed them all or red discovered the blue force package). Figure 30 displays the results of this analysis. The R^2 value increases to .36 with a considerable number of factor variables influencing probability of detection (including NIFC which enables a higher EMCON level for blue) significant to the fitted model.

Source	LogWorth	PValue
NIFC	11.575	0.00000
EMCON Condition	10.238	0.00000
CAP Location	5.564	0.00000
ACSM(Fast)Detect	4.417	0.00004
ACFT1Range	4.041	0.00009
ASCM(Fast)Speed	3.168	0.00068
#ACFT1	3.149	0.00071
Red Pd	2.878	0.00132
ASCM(Fast)Range	2.813	0.00154
ASCM(Slow)Detect	2.486	0.00326
5inMaxRange	2.439	0.00364
DDGSurfPd	2.241	0.00574
ESSMMinRange	1.671	0.02135
#ASCM(FAST)	1.657	0.02202
5inPk	1.564	0.02727
RAMMinRange	1.546	0.02841
CGSpyPd	1.160	0.06924
LHAPd	1.149	0.07092
CGSurfPd	1.097	0.07991
5inSpeed	1.095	0.08039
RAMMaxRange	0.981	0.10445
EMCON Delay	0.947	0.11292
ShipSpeed	0.905	0.12449
ESSMPk	0.903	0.12496
ACFT2Detect	0.836	0.14600
#ACFT2	0.717	0.19202

Summary of Fit

RSquare	0.366052
RSquare Adj	0.331131
Root Mean Square Error	0.207887
Mean of Response	0.415078
Observations (or Sum Wgts)	499

Analysis of Variance

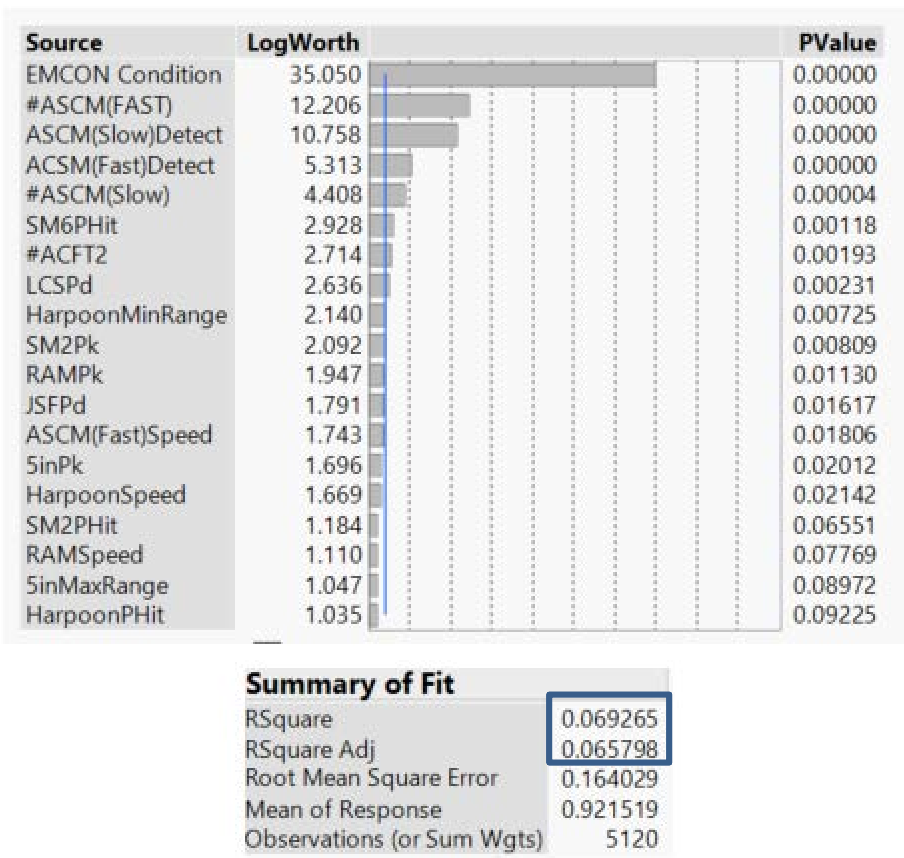
Source	DF	Sum of Squares	Mean Square	F Ratio
Model	26	11.778334	0.453013	10.4823
Error	472	20.398361	0.043217	**Prob > F**
C. Total	498	32.176696		<.0001*

Figure 30. Red Retreat Segmented Partition (Red Retreat Greater than Zero Percent)

2. Measure of Effectiveness Two: Blue Vulnerability

a. Defensive Kill Percentage

Defensive kill percentage included the percentage of ASCM destroyed as well as remaining enemy SAG units. Running a stepwise regression model using a forward step p-value threshold analysis resulted in the identification of the independent variables displayed in Figure 31. Interestingly, the most significant variable, EMCON condition, does not readily apply to a defensive posture. Once blue forces identify incoming threats, the blue force breaks EMCON to ensure all sensors are available to defend the ship. The low R^2 suggests this model does not adequately represent defensive kill percentage MOP.



Source	LogWorth	PValue
EMCON Condition	35.050	0.00000
#ASCM(FAST)	12.206	0.00000
ASCM(Slow)Detect	10.758	0.00000
ACSM(Fast)Detect	5.313	0.00000
#ASCM(Slow)	4.408	0.00004
SM6PHit	2.928	0.00118
#ACFT2	2.714	0.00193
LCSPd	2.636	0.00231
HarpoonMinRange	2.140	0.00725
SM2Pk	2.092	0.00809
RAMPk	1.947	0.01130
JSFPd	1.791	0.01617
ASCM(Fast)Speed	1.743	0.01806
5inPk	1.696	0.02012
HarpoonSpeed	1.669	0.02142
SM2PHit	1.184	0.06551
RAMSpeed	1.110	0.07769
5inMaxRange	1.047	0.08972
HarpoonPHit	1.035	0.09225

Summary of Fit

RSquare	0.069265
RSquare Adj	0.065798
Root Mean Square Error	0.164029
Mean of Response	0.921519
Observations (or Sum Wgts)	5120

Figure 31. Partial Effect Summary Percent of Defensive Kills

Like percentage of leakers, eliminating trials, which included zero percent defensive kills (red units offensively killed or retreated), segments the data, identifying the variables, which most impact the percent of defensive kills. Figure 32 displays this analysis. The R^2 value increases to a level that the model is acceptable. The identified independent variables remain almost unchanged, but the analysis removes EMCON condition, which implies it had a significant impact on trials in which there were zero percent defensive kills. The model identifies blue weapon kill probability of kill, number of red missiles, and detection range as the significant independent variables.

Source	LogWorth	PValue
#ASCM(FAST)	90.756	0.00000
#ACFT2	65.132	0.00000
ASCM(Slow)Detect	65.115	0.00000
#ASCM(Slow)	46.226	0.00000
ACSM(Fast)Detect	29.066	0.00000
SM6PHit	24.856	0.00000
RAMPk	17.669	0.00000
NIFC	11.510	0.00000
#ACFT1	11.128	0.00000
SM2Pk	8.135	0.00000
ASCM(Fast)Speed	7.099	0.00000
ShipDetect	6.328	0.00000
HarpoonMaxRange	5.792	0.00000
RAMMaxRange	5.152	0.00001
HarpoonPk	4.464	0.00003
Red Pd	4.457	0.00003

Summary of Fit	
RSquare	0.270687
RSquare Adj	0.268334
Root Mean Square Error	0.05637
Mean of Response	0.948187
Observations (or Sum Wgts)	4976

Figure 32. Segmented Partial Effects Summary (Percent of Defensive Kills Greater than Zero)

b. Number of Red Hits

If blue is unable to kill incoming red forces the result is a hit. Modeling the number of hits through a forward, stepwise, p-value threshold analysis identified the critical independent variables with the number of red forces best predicting the number of hits on blue, shown in Figure 33. Again, the analysis identified detection range and NIFC as significant to the model.

Source	LogWorth	PValue
#ASCM(FAST)	90.756	0.00000
#ACFT2	65.132	0.00000
ASCM(Slow)Detect	65.115	0.00000
#ASCM(Slow)	46.226	0.00000
ACSM(Fast)Detect	29.066	0.00000
SM6PHit	24.856	0.00000
RAMPk	17.669	0.00000
NIFC	11.510	0.00000
#ACFT1	11.128	0.00000
SM2Pk	8.135	0.00000
ASCM(Fast)Speed	7.099	0.00000
ShipDetect	6.328	0.00000
HarpoonMaxRange	5.792	0.00000
RAMMaxRange	5.152	0.00001
HarpoonPk	4.464	0.00003
Red Pd	4.457	0.00003

Summary of Fit	
RSquare	0.270687
RSquare Adj	0.268334
Root Mean Square Error	0.05637
Mean of Response	0.948187
Observations (or Sum Wgts)	4976

Figure 33. Partial Effects Summary Number of Blue Hits

Figure 34 segments the data between an EAFP and SAG. The results of this segmentation show that regardless of the force composition the number of red threats provides the greatest prediction on the number of blue hits.

Source	LogWorth	PValue
#ASCM(FAST)	83.576	0.00000
#ACFT2	47.211	0.00000
#ASCM(Slow)	35.281	0.00000
#ACFT1	33.932	0.00000
SM6PHit	33.094	0.00000
ASCM(Slow)Detect	18.728	0.00000
RAMPk	13.201	0.00000
EMCON Condition	5.947	0.00000
HarpoonMinRange	4.082	0.00008
LCSSurfPd	3.368	0.00043

Source	LogWorth	PValue
#ASCM(FAST)	100.485	0.00000
ACSM(Fast)Detect	49.993	0.00000
#ASCM(Slow)	46.754	0.00000
#ACFT2	42.303	0.00000
#ACFT1	24.474	0.00000
ASCM(Slow)Detect	24.474	0.00000
ACFT1Range	15.092	0.00000
HarpoonPk	7.800	0.00000
RAMMaxRange	6.607	0.00000
LCSSurfPd	4.910	0.00001

Summary of Fit	
RSquare	0.338354
RSquare Adj	0.335856
Root Mean Square Error	2.642518
Mean of Response	2.289474
Observations (or Sum Wgts)	2660

Summary of Fit	
RSquare	0.381635
RSquare Adj	0.37911
Root Mean Square Error	3.614724
Mean of Response	3.185772
Observations (or Sum Wgts)	2460

Figure 34. Partial Effect Comparison EAFP/NIFC (left) and SAG/No-NIFC (right)

3. LHA Risk

A tradeoff exits adding an LHA and its expensive air wing of JSF to a SAG to form an EAFP. Figure 35 quantifies this risk showing frequency of hits on the LHA when the model conducted the NIFC tactic. In 79.02% of the trials, the LHA experienced no hits or in 20.98% of the trials, the LHA experienced at least one hit. At the worse, in one trial, the LHA received 11 hits from red adversaries.

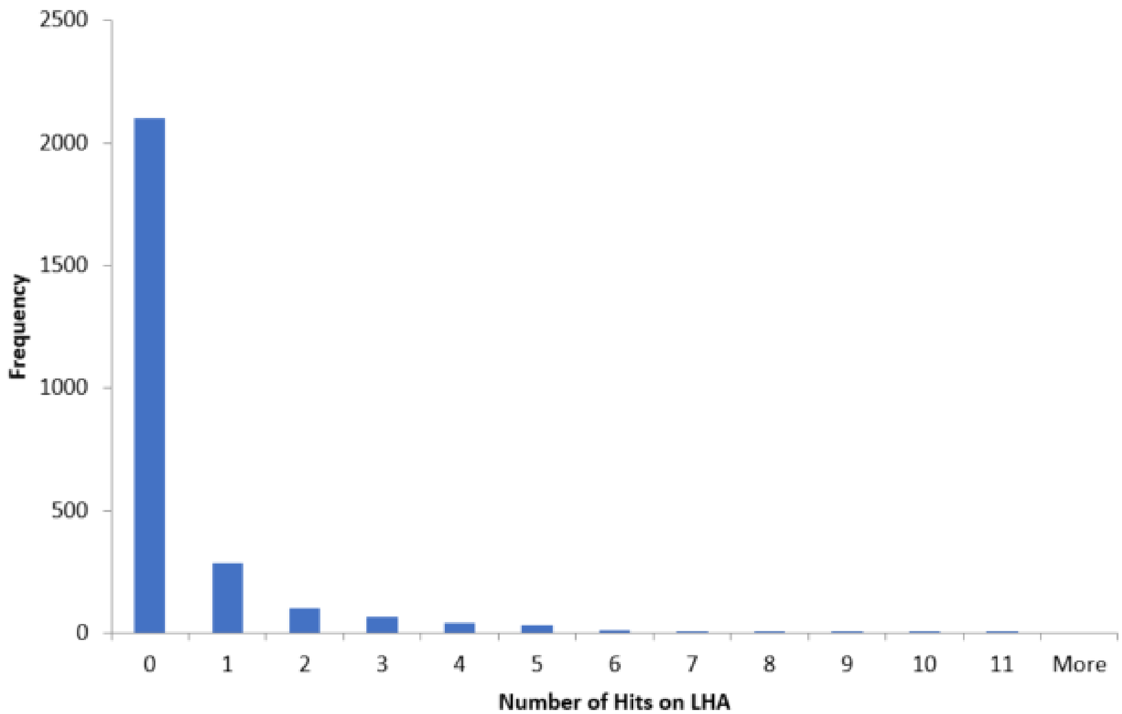


Figure 35. Histogram LHA Hit Frequency

Modeling and simulating the architecture takes the functional breakdown diagrams and contextual diagrams and places the system in a real operating environment. This assists in measurably quantifying the architecture through metrics and provides feedback to designers and stakeholders of the ability of the architected system to meet the initial requirements established. Simulating an EAFP architecture showed increases in offensive capability over a SAG with reduced number of hits during an engagement. Defensive capability remained equivalent between the two force packages. The tradeoff, however, existed in placing the LHA in a risky environment susceptible to enemy fire with the possibility of sustaining hits during an engagement.

During the analysis, NIFC, detection range, and EMCON all significantly impacted the MOPs identified. For future development, stakeholder and architects need to prioritize these system parameters to achieve mission success.

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V. CONCLUSION

A. KEY POINTS

This thesis focused on creating an EAFP integrated architecture combining an LHA and mix of traditional surface combatants utilizing DL tactics under the newly established fleet tactic of DMO. Following the development of the architecture, the author modeled the system in a simulated environment to test the system and its performance against known systems, specifically already deployed SAGs.

Chapter I introduced the problem statement, provided background on current global naval situation and established the reason for research into the tactics of DL and DMO. The chapter also introduced the methodology for research and outlined the questions the thesis intended to answer which included:

- How does DL refine the tactic of DMO, specifically with an LHA EAFP?
- What is the system architecture for an LHA EAFP?
- Through simulation, what are the tradeoff that exist in employing an LHA EAFP into a hostile environment with the intent to control a SLOC?

The methodology this thesis established to answer these questions included a mix of traditional system engineering principles and system architecting utilizing the DODAF system architecture. Following the architecting of the system, one must conduct statistical analysis through a discrete event simulation modeler and statistical software to provide key parameters and quantify tradeoff regions.

Chapter II reviewed previous research on the topic of DL and ways that this research might apply to the focus of this thesis. Additionally, the chapter provided background information on the history of amphibious ships in the United States Navy and the inclusion of the JSF on an LHA and the current capabilities an LHA possesses, specifically its lack of organic offensive capability beyond its carried airwing of JSF. The chapter also included a table of stakeholder concerns establishing the requirements from which to begin architecting the EAFP system. This provided the basis for answering the second research question.

Chapter III answered the first two research questions providing an architected system following the DODAF schema. A breakdown of system requirements highlighted the intersection of DL and DMO and showed that with DMO possessing a “distributed” requirement that DL refined this requirement in combination with other joint, cyber, or international distributed operations. As a result, all the requirements defining DL roll up to form the requirements for DMO. Chapter III also presented the functions, operational activities, components and nodes that make up an LHA EAFP architecture for the given surface warfare CONOP, answering the second research question.

Chapter IV represented the original operational problem of a force package tasked to control a SLOC within an entrenched, multi-layered adversary network of surface and aerial threats. Replicating the architecture from Chapter III within the discrete simulation modeler, ExtendSim, permitted testing of the EAFP system within a realistic operating environment. Testing 65 independent variables in 5120 individual simulations provided data to evaluate an EAFP on its lethality and vulnerability. Analysis of this data showed an EAFP conducting NIFC with a JSF increased offensive lethality and decreased the number of hits sustained in an engagement over a SAG lacking an EAFP. These improvements, however, came at the risk to the LHA with 21% of the trials resulting in at least one hit on the LHA.

B. FUTURE RESEARCH

1. Increased Architectural Levels

The system architecture developed for this thesis includes functions and components two or three levels deep. Future research can further decompose each function, OA, and component to create a more specific architecture, assisting engineers in creating the system and helping stakeholder better understand the capabilities and limitations of the system given their requirements.

2. Classified and Improved Modeling Variables

The ExtendSim model produced utilizes variable values near the current performance characteristics of the current weapons or sensors currently employed on United States naval ships. Inputting actual detection ranges or weapon capabilities will produce a more realistic model and help better simulate an EAFP in a DL environment. Additionally, this will help eliminate independent variables in the model helping to understand the variability in the variables with unknown characteristics or variables that the architect is specifically looking for sensitivity from. One variable, EMCON deactivation time, never appeared as significant in any of the models, a variable this author expected as significant. Further research might center on this variable to establish at what amount of time a crew and ship sensors need to respond to ensure optimality of offensive and defensive kill percentages.

3. Include Anti-ship Ballistic Missiles and JSF Offensive Capability

The author specifically decided to exclude land-based cruise missiles from the model to better simulate blue and red forces searching for each other. A DL mission to control a SLOC likely will place a SAG or EAFP within range of land-based missiles. These long-range missiles can travel supersonic and at low altitudes making the probability of detection harder. The advantage of an EAFP with JSF performing NICF-Counter Air may be more appreciable in terms of reducing the number of hits from these cruise missiles than the air and sea attack simulation in the model for this thesis. Additionally, the model only employed the JSF as an airborne sensor providing no additional capability. As a fifth-generation fighter, these aircraft possess advanced capabilities in air warfare and can thus provide both offensive and defensive weapons making an EAFP more lethal and less vulnerable to hits.

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APPENDIX A. ADDITIONAL OPERATION ACTIVITY VIEWS

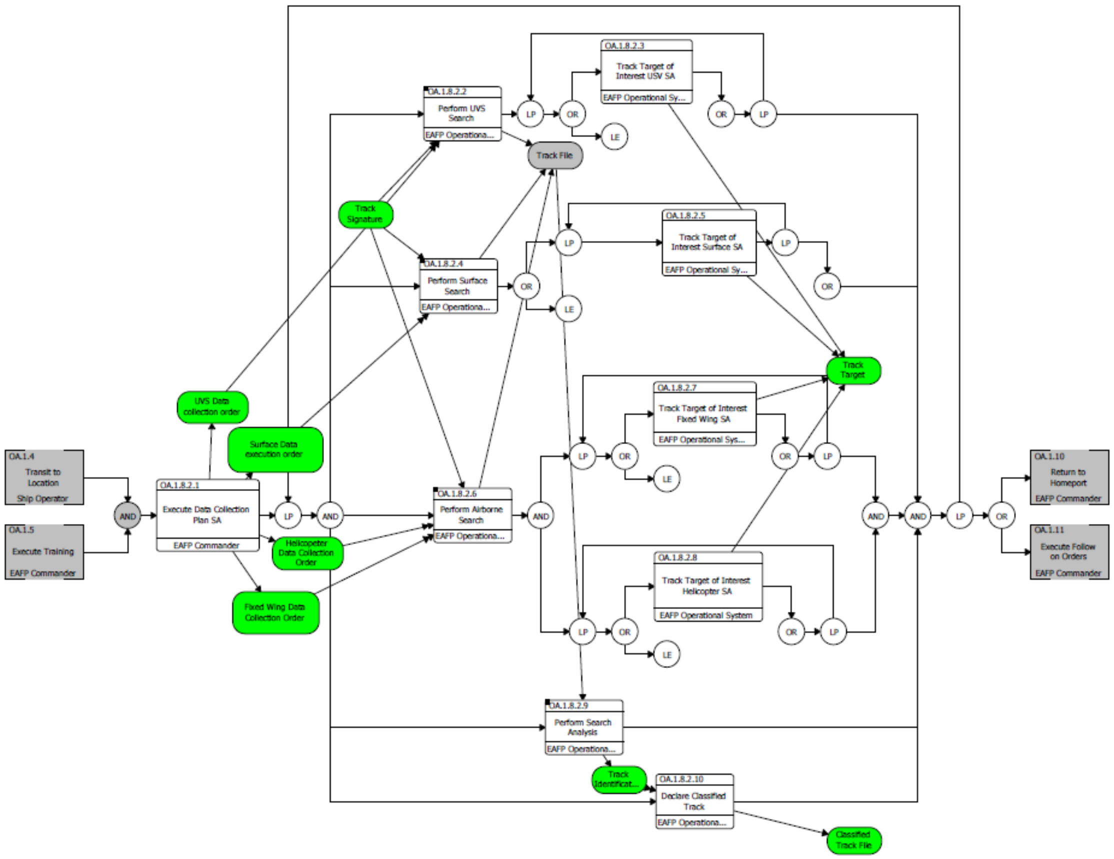

Figure 36. Maintain Battlespace Awareness

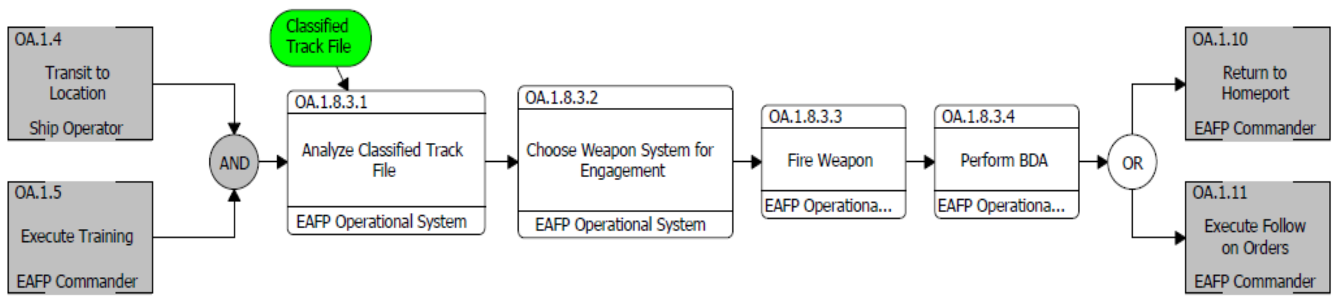

Figure 37. Perform Active Air Defense

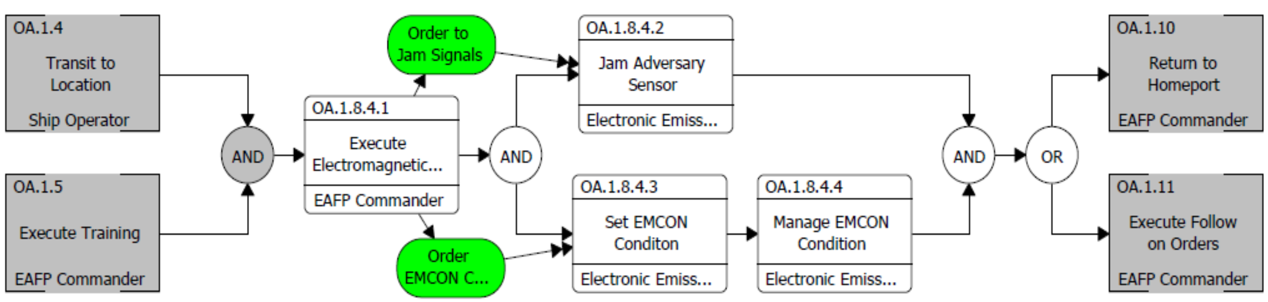

Figure 38. Manage Electronic Warfare

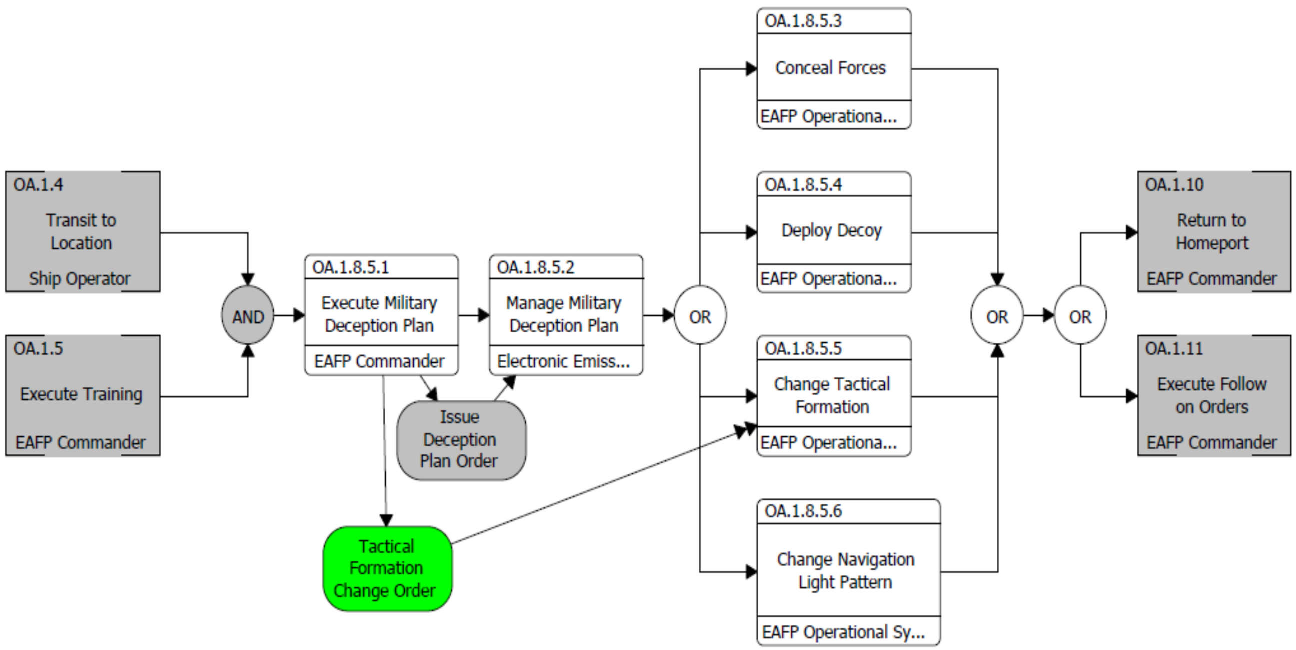

Figure 39. Conduct Military Deception Operations

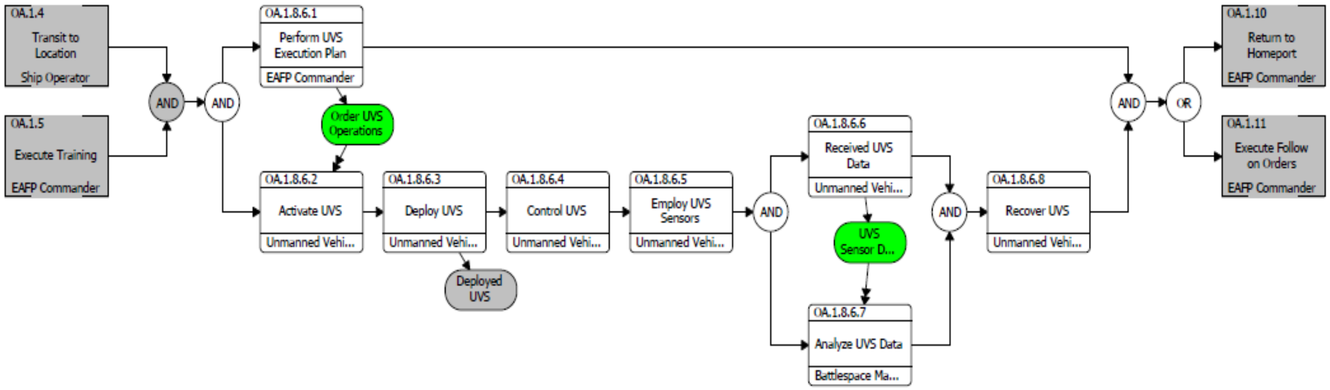

Figure 40. Perform UVS Operations

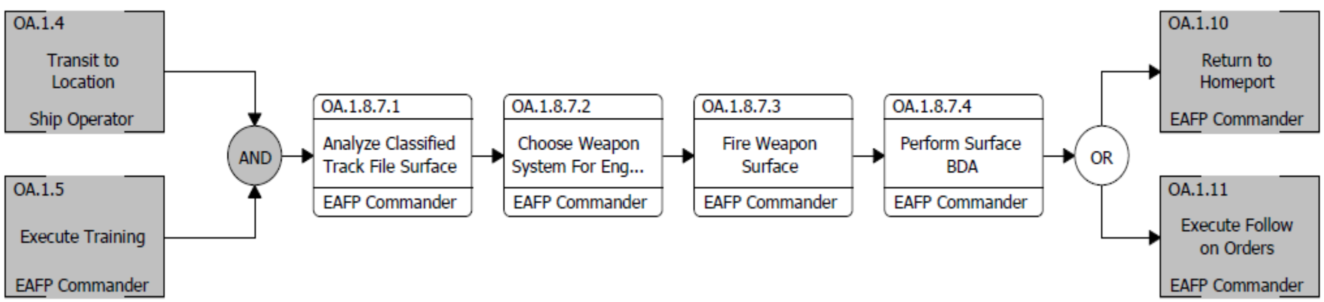

Figure 41. Destroy Moving Surface Targets

APPENDIX B. ADDITIONAL ARCHITECTED SYSTEM FUNCTIONS

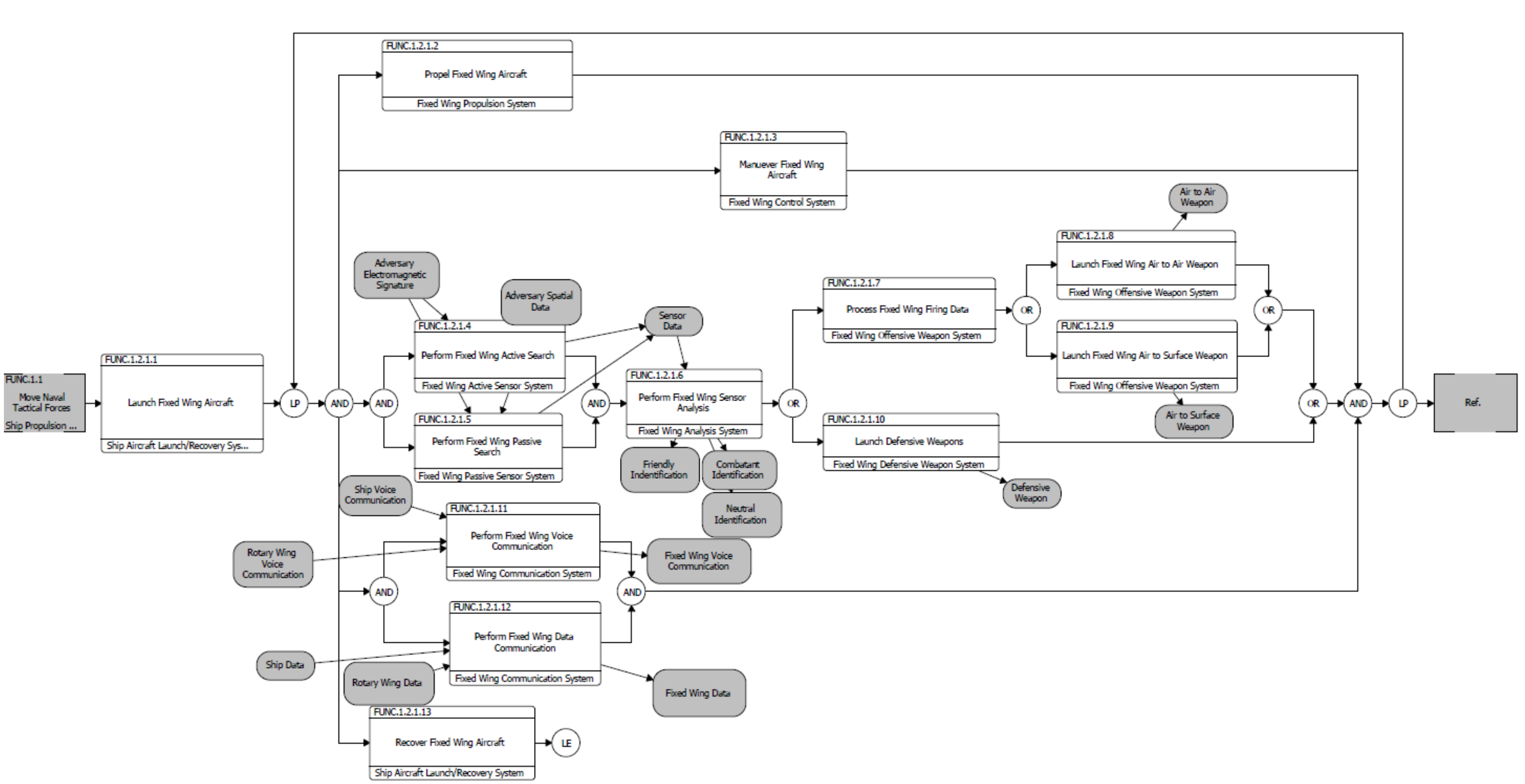

Figure 42. Fixed Wing Functions

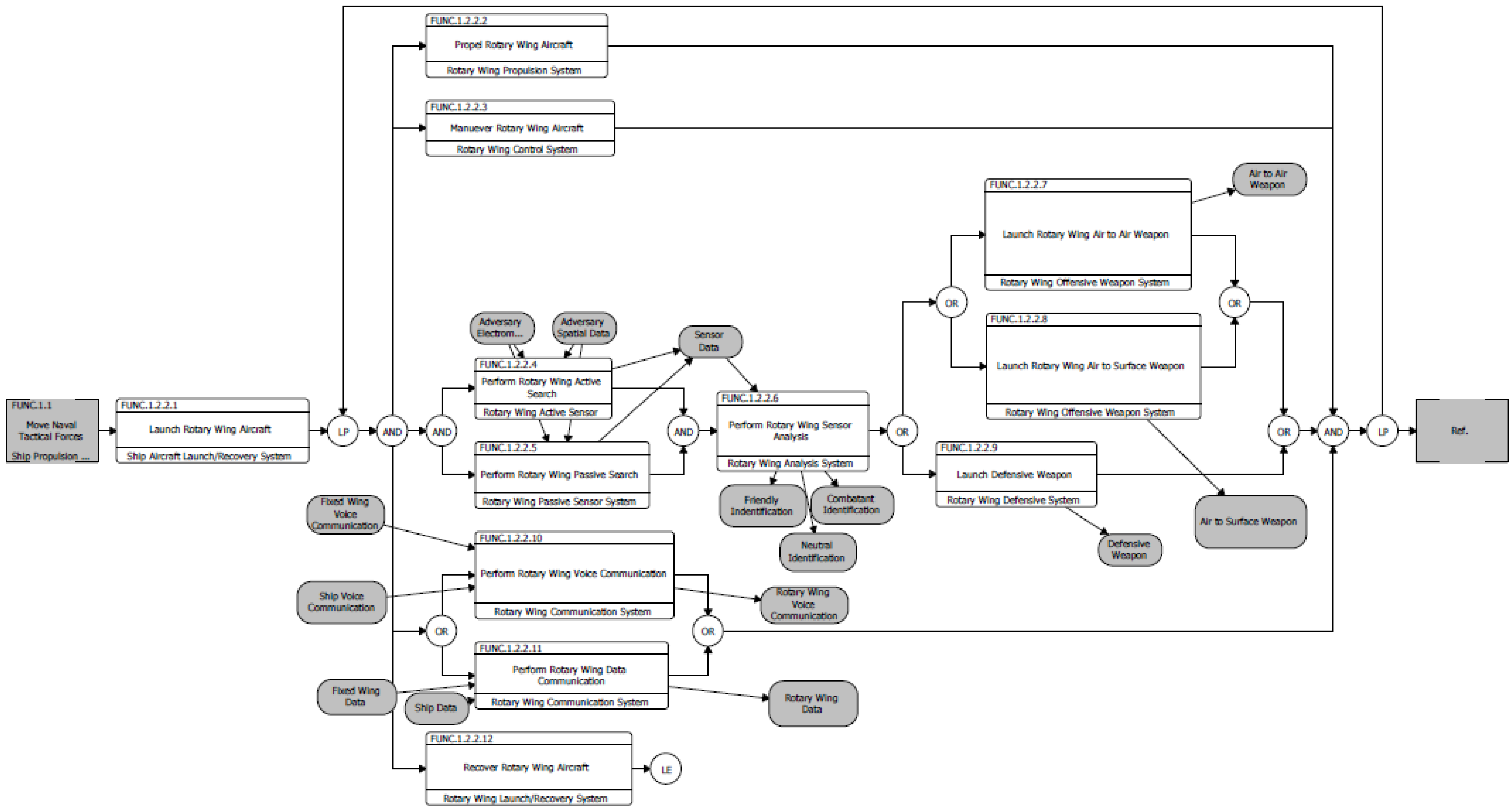

Figure 43. Rotary Wing Functions

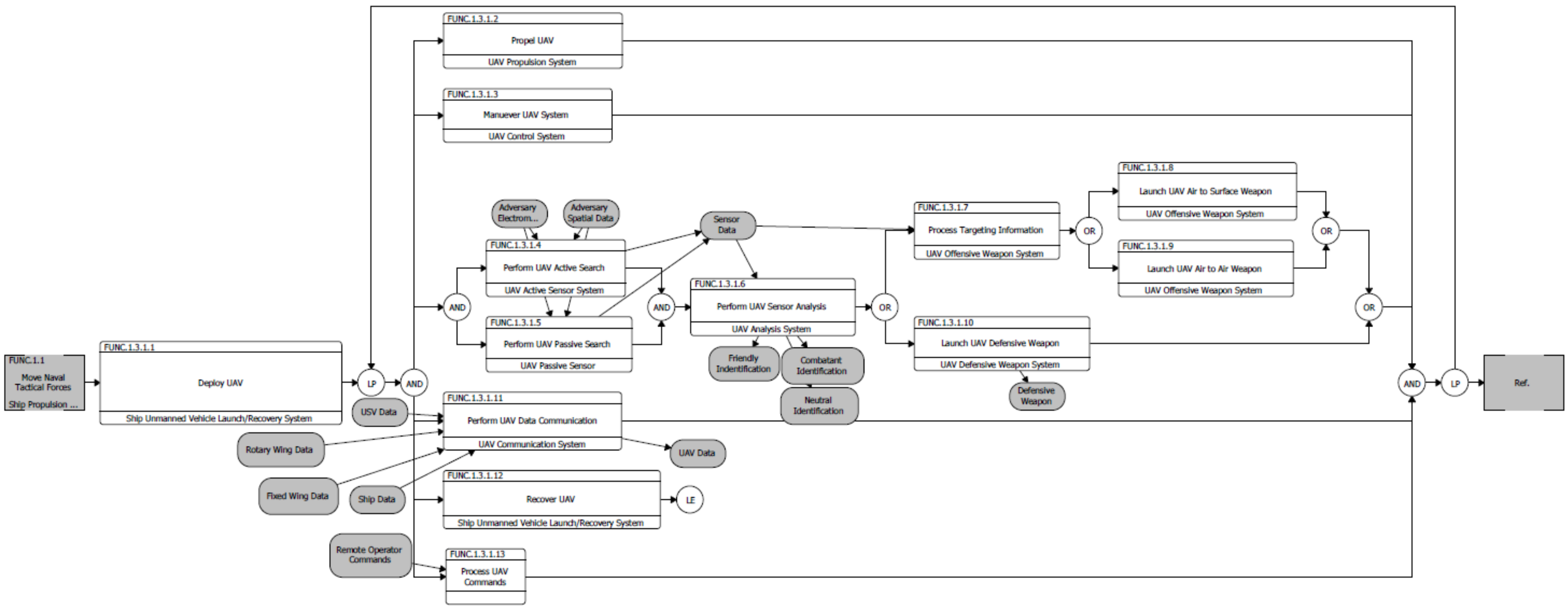

Figure 44. UAV Functions

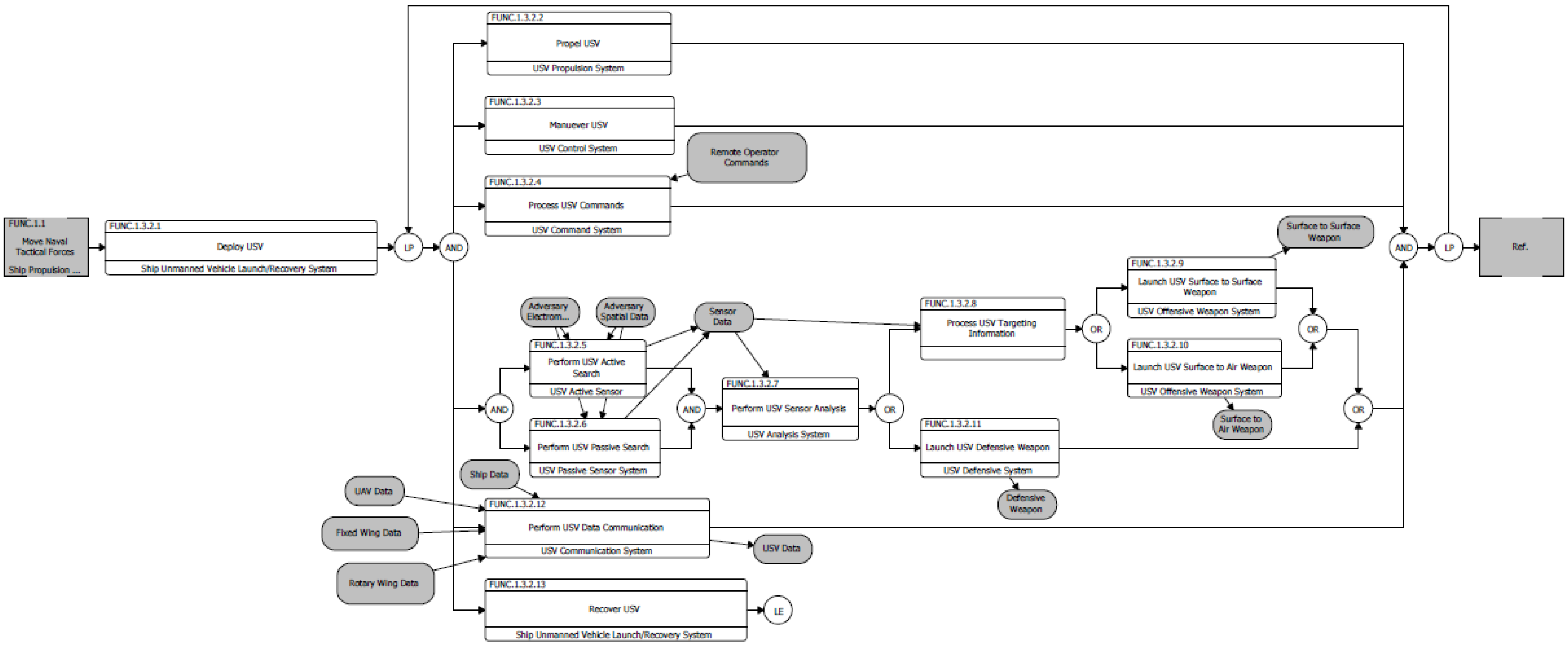

Figure 45. USV Functions

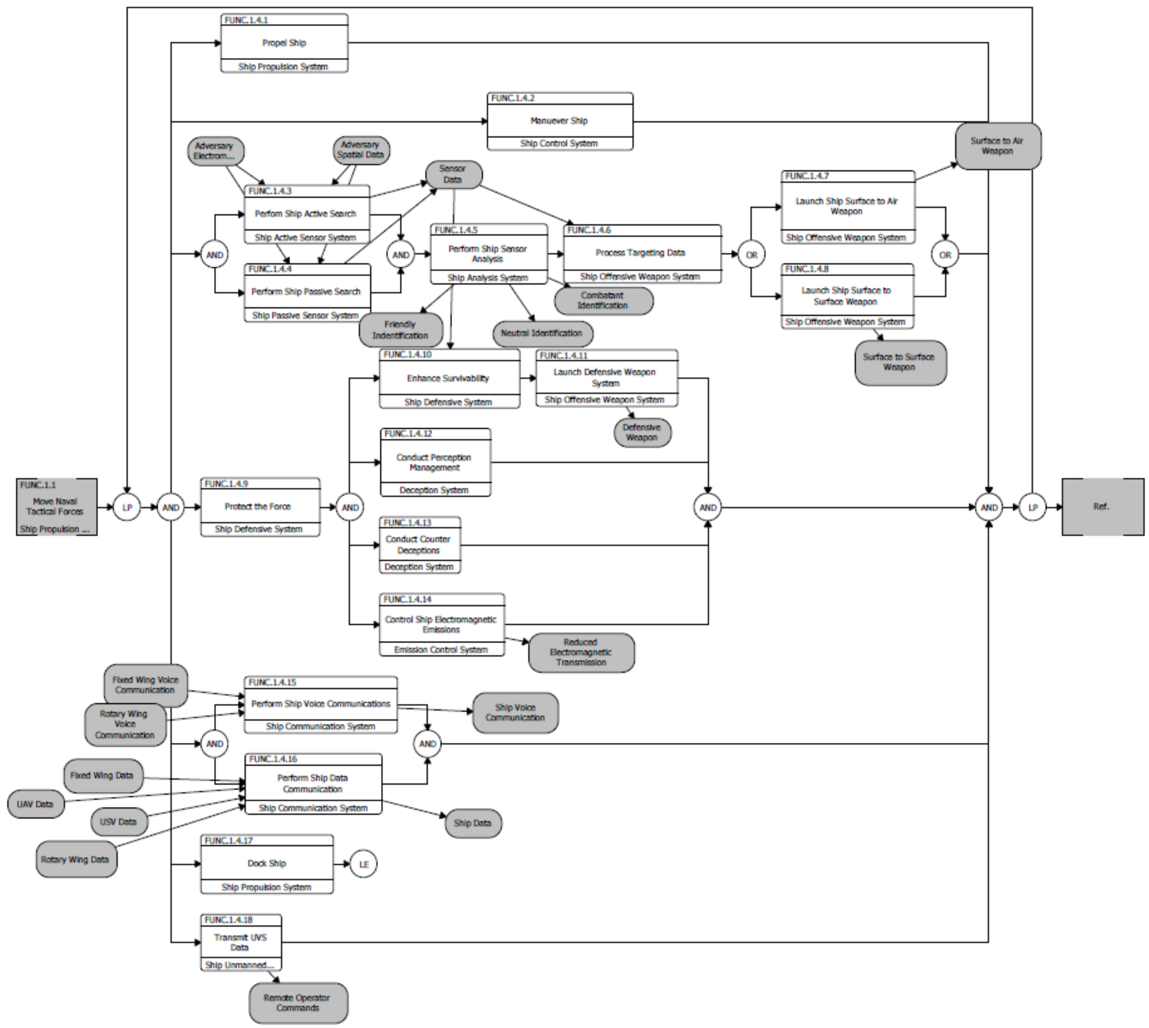

Figure 46. Ship Functions

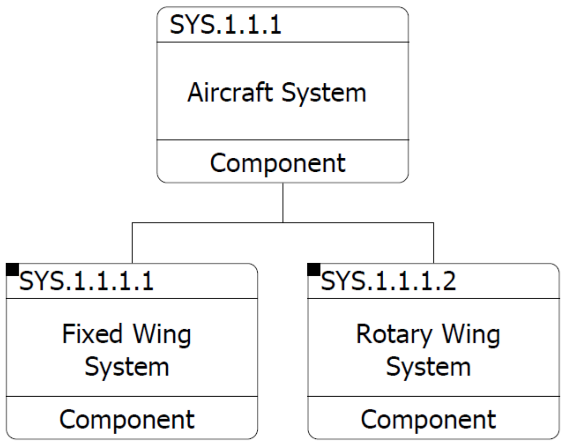

Figure 47. Aircraft System Components

APPENDIX C. ADDITIONAL SYSTEM COMPONENT VIEWS

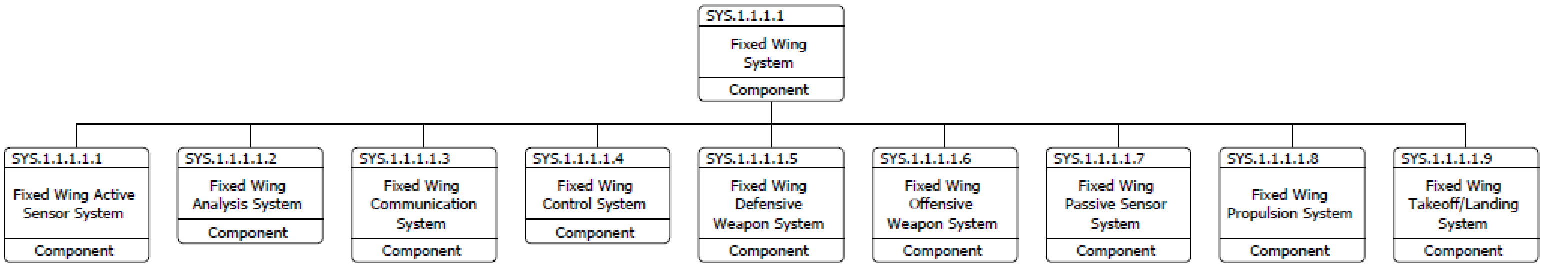

Figure 48. Fixed Wing System Components

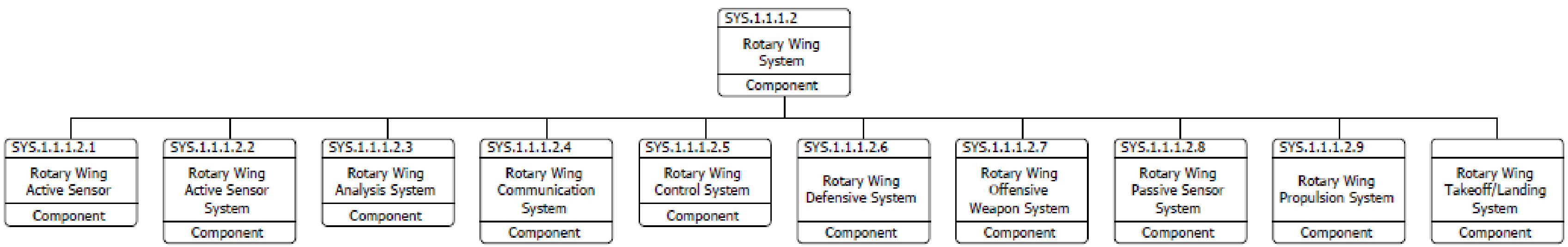

Figure 49. Rotary Wing Vehicle System Components

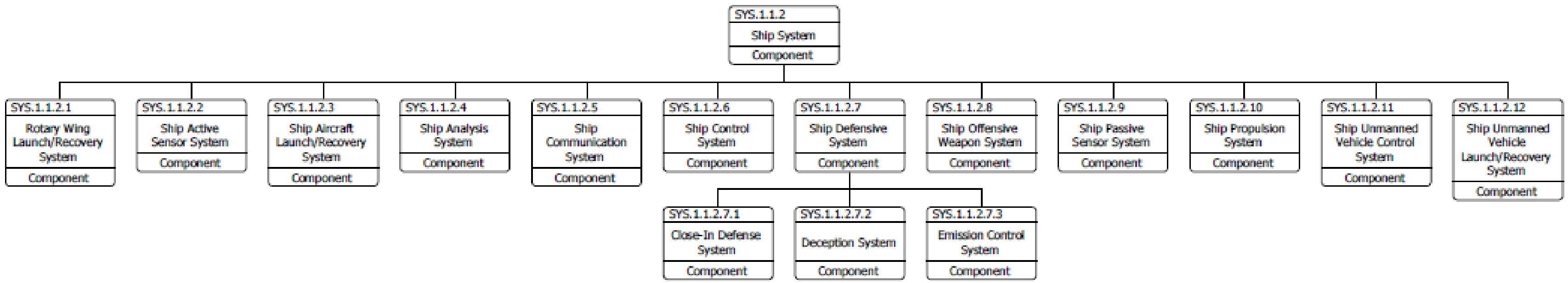

Figure 50. Ship System Components

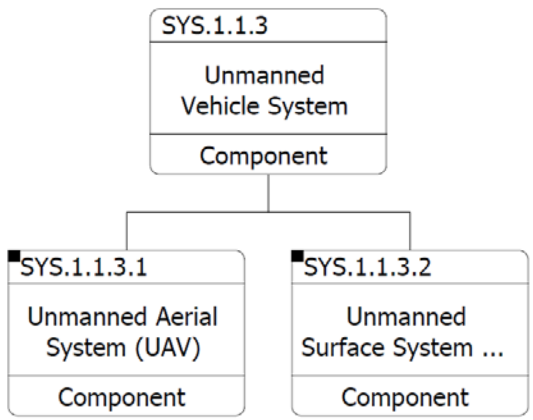

Figure 51. UVS System Components

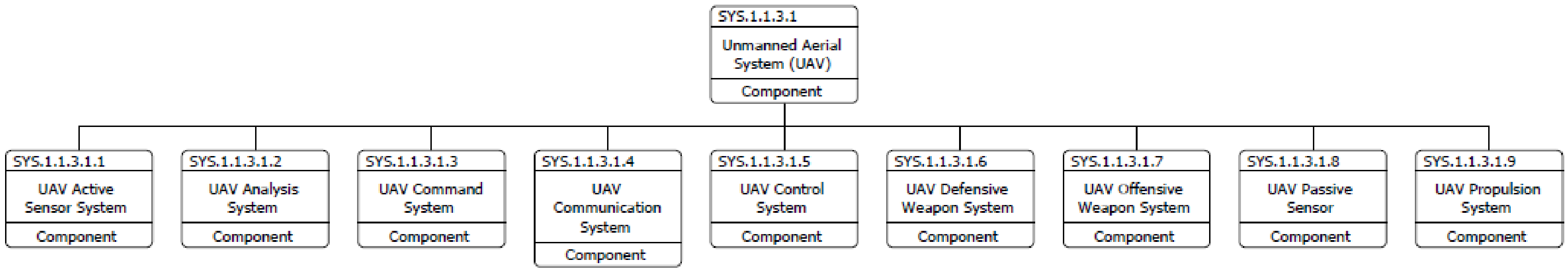

Figure 52. UAV System Components

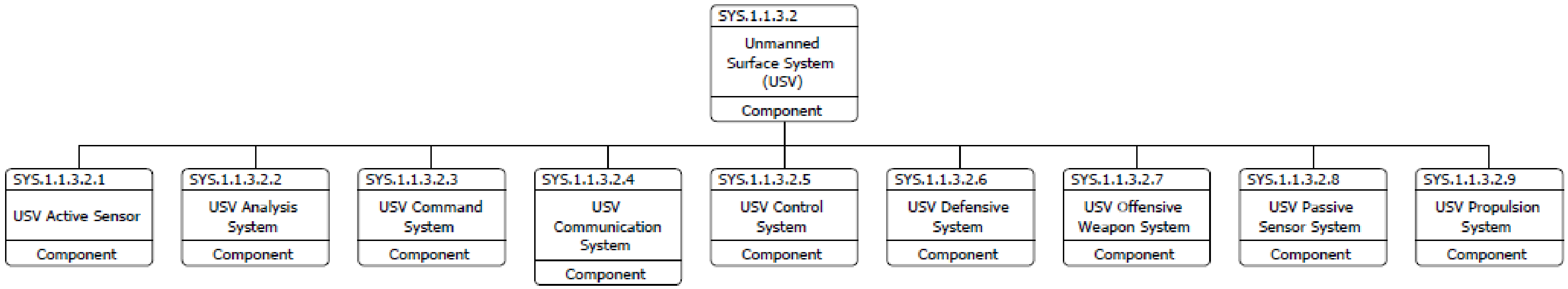

Figure 53. USV System Components

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