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SYSTEMS ENGINEERING CAPSTONE PROJECT REPORT

MISSILE DEFENSE IN THE 21ST CENTURY ACQUISITION ENVIRONMENT: EXPLORING A BMD-CAPABLE LCS MISSION PACKAGE

by

Team LCS
Cohort 311-121O

September 2013

Thesis Advisor: John Green
Co-Advisor: Paul Shebalin

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Of particular concern are the threats presented by aggressor short- and medium-range ballistic missiles. These weapons, capable of carrying weaponized chemical or biological payloads, are small, mobile, and difficult to track. Aegis, the premiere sea-based ballistic missile defense (BMD) system of the U.S. Navy, is a high-demand, cost-limited resource that cannot be mobilized to defend all potential target zones. A smaller, more mobile solution is necessary to afford foreign U.S. interests adequate protection. This paper details a systems engineering approach to assess the emergent ballistic missile threat, synthesize solution options to meet littoral region capability needs, and conduct comparative analyses to downselect a conceptual BMD system that meets stakeholder needs.

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MISSILE DEFENSE IN THE 21ST CENTURY ACQUISITION ENVIRONMENT: EXPLORING A BMD-CAPABLE LCS MISSION PACKAGE

Cohort 311-121O/Team LCS

Cayle Bradley
Darren Ly
Dennis Gamban
Hermanzo Moreno
Matthew Podawiltz
Adam Wilk

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Lead editor: Adam Wilk

Reviewed by:

John Green
Capstone Project Advisor

Paul Shebalin
Project Advisor

Accepted by:
Cliff Whitcomb
Systems Engineering Department

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ABSTRACT

In the aftermath of the Cold War, proliferation of late-20th-century Soviet and NATO offensive weaponry has provided many countries and groups around the globe with the ability to challenge the defensive infrastructure of neighboring states. With the collapse of the Soviet Union, the struggle between two great superpowers to gain and maintain access to regions of strategic interest has been eclipsed by the emergence of new threats—corrupt regimes, warlords, and terrorists who now have the capability to attack civilian populations, destabilize regional governments, and threaten United States and allied strategic interests.

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LIST OF ACRONYMS AND ABBREVIATIONS

A2/AD	Anti-Access/Area Denial
ALTBMD	Active Layered Theater Ballistic Missile Defense
AMDR	Air and Missile Defense Radar
ASW	Anti-Submarine Warfare
ASuW	Anti-Surface Warfare
BMD	Ballistic Missile Defense
CIWS	Close-In Weapons System
CMS	Combat Management System
CNO	Chief of Naval Operations
COMBATSS	COMponent BAsed Total Ship System
CONOPS	Concept of Operations
COTS	Commercial Off-The-Shelf
CRS	Congressional Research Service
DoD	Department of Defense
DOE	Design of Experiments
DRM	Design Reference Mission
EOR	Engage on Remote
EPAA	European Phased Adaptive Approach
ICD	Integrated Capabilities Document
LCS	Littoral Combat Ship
LOR	Launch on Remote

LOS	Line of Sight
KPP	Key Performance Parameter
MCM	Mine Countermeasures
MDA	Missile Defense Agency
MOE	Measure of Effectiveness
MOP	Measure of Performance
MOS	Measure of Suitability
NATO	Northern Atlantic Treaty Organization
NAVSEA	Naval Sea Systems Command
OPNAV	Office of Naval Operations
O&S	Operations and Support
PAC	Patriot Advanced Capability
PEO	Program Executive Office
PRA	Probability of Raid Annihilation
RDT&E	Research, Development, Test and Engineering
SBIRS	Space Based Infrared System
SoS	System of Systems
TBBM	Theater Based Ballistic Missile
THAAD	Terminal High Altitude Area Defense
RCS	Radar Cross Section
USN	United States Navy

EXECUTIVE SUMMARY

In the aftermath of the Cold War, proliferation of late-20th-century Soviet and NATO offensive weaponry has provided many countries and groups around the globe the ability to challenge the defensive infrastructure of neighboring states. With the collapse of the Soviet Union, the struggle between two great superpowers to gain and maintain access to regions of strategic interest has been eclipsed by the emergence of new threats—corrupt regimes, warlords, and terrorists now having the capability to attack civilian populations, destabilize regional governments, and threaten United States and Allied strategic interests.

Of particular concern are the threats presented by aggressor short- and medium-range ballistic missile attacks. The weapons, capable of carrying weaponized chemical or biological payloads, are small, mobile, and difficult to track. The premiere sea-based ballistic missile defense (BMD) system of the U.S. Navy, Aegis, is a high-demand, high-operational-cost limited resource, and cannot be mobilized to defend all potential target zones. According to the United Nations' report on Environment and Development "more than half the world's population lives within 60 km of the shoreline, and this could rise to three quarters by the year 2020" (United Nations, 1992). Given this rising population increase in the littoral coastline regions, smaller, more mobile, sea-based solution is necessary to afford foreign U.S. interests adequate protection against ballistic missile attack.

This report highlights the key benefits and challenges of a Littoral Combat Ship (LCS) BMD mission package as a flexible, cost-effective approach for fulfilling the BMD mission in littoral regions. Following a systems engineering methodology, the open architecture design unique to the LCS is considered through the initial stages of the system concept development process.

Through requirements analysis, cost and performance thresholds were determined and the LCS sea frame integration metrics were identified. Only publicly sourced

information was used in the analysis, which necessitated use of a comparative approach to assign mission performance success measures. Specifically, the assumption that the Aegis platform meets the U.S. Navy requirement for BMD was used as the key performance criteria in assessment of candidate mission package configurations in fulfilling the BMD mission need.

To support synthesis and assessment of candidate BMD mission packages, a high-level look at the threat possibilities lead to the development of a design reference mission (DRM) where the threat country launches a combination of scud and ballistic missiles from three different locations, all within 800 km of the asset. A design of experiments was conducted using a range of available radars, fire control systems, and engagement systems. Using public domain characteristic data for these elements, BMD effectiveness of each variant is then evaluated by modeling each of the associated components in simulation algorithms, and then subjecting the resulting simulated BMD system variant to the design reference mission-specified, simulated salvo attack. The simulations, run many times, enabled assessment of the likelihood that the variant will be successful in neutralizing a multiple-missile attack, in terms of a "probability of raid annihilation" (P_{RA}).

As a result, the analysis identified several "packages" that could perform as effectively as the Aegis system in the design reference mission (DRM). Also, the analysis determined that two Littoral Combat Ships positioned near an asset, each equipped with 16 terminal high-altitude area defense (THAAD) launchers and missiles, using the currently installed TRS-3D or Sea GIRAFFE radars, could intercept an incoming salvo of short range ballistic missiles and scud missiles as effectively as one Aegis equipped destroyer.

An analysis of alternatives, that included system costs, is performed; this further reduces the number of possible solutions to one "mission package" of BMD system components that meet the performance threshold and LCS sea frame limitations. To provide insights over a range of cost and performance points, two additional variants are proposed.

In retrospect, this capstone project provided new insights regarding the viability of the LCS in performing regional BMD missions. In this role, the LCS would defend tactical and strategic assets form short range ballistic missiles and scud missiles. The LCS is not expected to perform midcourse detection and engagement of medium and long range ballistic missiles from a sea based platform, as the installed power and volume exceeds the capabilities of the LCS. This mission role is expected to remain exclusively with Aegis-equipped platforms for the foreseeable future. Nonetheless, further investigation into the use of the LCS in a BMD mission role is recommended, as the inventory of BMD-capable ships remains limited and will likely be stretched thinner over the next decade while the LCS inventory grows.

LIST OF REFERENCES

United Nations. (1992, June). *Protection of the oceans, all kinds of seas, including enclosed and semi-enclosed seas, and coastal areas and the protection, rational use and development of their resources.* Report of the United Nations Conference On Environment & Development, Rio de Janeiro, Brazil.

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I. INTRODUCTION

The end of the Cold War has brought the dissolution of the Soviet Union. Its once powerful military has shattered long-held paradigms on how conflicts in the 20th century were to be fought. The threat of Soviet military expansion has now been eclipsed by the emerging threats presented by unstable nations and non-state actors with political agendas not aligned with the interests of the United States and its allies. These new groups, with their access to Cold War-era Soviet and NATO armaments, continue to establish a military presence; their ability to launch and conduct armed regional conflicts has increased the risk of destabilizing and denying access to regions of strategic and tactical importance across the globe.

With the majority of the world's population located in coastal or near-coastal areas, these emerging threats are particularly concerning in the littoral regions. The increased likelihood as aggressor-launched attacks, ranging from ground and small watercraft assaults to short- and intermediate-range ballistic missile strikes have increased the urgency to support maritime defense missions such as anti-piracy, anti-terrorism, and port security.

This shift in views toward future conflicts has had several significant implications. American naval assets, whose Cold War mission included containment of Soviet military expansion efforts, were designed for the open ocean operational environment, i.e., blue-water. With the shift in focus to regional maritime security, Cold War-era naval assets were found to be inadequately suited for operation in the shallower coastal waters, i.e., the littorals. Independent analyses supported the notion that the U.S. Navy (USN) could not effectively operate in littoral environments. The USN fleet was simply too big to operate in these environments; while many foreign navies had a class of ship in the 3,000 ton displacement range, the USN did not have a widely deployed platform smaller than the 4,200 ton Oliver Hazard Perry class guided missile frigate. In addition, access to these regional areas of interest could be denied by the host countries as many countries (even allies) were opposed to allowing larger, nuclear-powered surface combatants into territorial waters.

Considering the high cost of construction of large surface combatants, and even higher operation and maintenance costs, the U.S. Navy proposed the fielding of a new, smaller platform that could quickly adapt to a multitude of global threats. However, given that there were so many potential mission areas under the new role envisioned by the U.S. Navy, it became quickly apparent that the only way a single platform could perform such a role is by incorporating an open architecture allowing for modular "mission modules" that could be rapidly exchanged to reconfigure the ship's primary mission (PMS 420, 2012).

Many mission packages (reconfigurable mission modules combined with the ships core and auxiliary capabilities) were investigated by the USN and the defense industrial base, but only three were commissioned with the initial "Flight-0" Littoral Combat Ship (LCS); Anti-Surface Warfare (ASuW), Anti-Submarine Warfare (ASW), and Mine-Countermeasure (MCM) (United States Navy, 2012).

While these first flight Navy programs address a number of threats to maritime security, the current mission packages do not address the threat of theater based ballistic missile attacks. As mentioned, the proliferation of Cold War era armaments has not only increased the risk of attacks upon littoral region assets by land-borne or sea-borne aggressors; it has also increased aggressor access to short and intermediate range ballistic missiles such that ballistic missile attacks are now recognized as a viable threat to these assets. This paper discusses an exploration into the viability of the LCS in serving a littoral region ballistic missile defense (BMD) mission role, and proposes a concept-level LCS-based BMD mission package, developed using a systems engineering approach.

II. BACKGROUND

A. LCS BACKGROUND

At the International Seapower Symposium at the U.S. Naval War College on October 17, 2007, the Chief of Naval Operations introduced a document titled *A Cooperative Strategy for the 21st Century Seapower*. This document defined the United States Navy's newest maritime strategy by outlining six functional naval capabilities (United States Navy);

- Forward presence
- Deterrence
- Sea control
- Power projection
- Maritime security
- Humanitarian assistance/disaster response

A Cooperative Strategy for the 21st Century Seapower is a follow-on to the legacy Sea Power 21 vision. Sea Power 21 was released in October 2003 in an effort to make the Navy "more flexible and agile to effectively meet future threats" (Chief of Naval Operations, 2003). The strategy focuses on three independent projections of power; Sea Shield, Sea Strike, and Sea Basing respectively aiming to project Global Defensive Assurance, Precise and Persistent Offensive Power, and Joint Operational Independence.

The Littoral Combat Ship was the first true development effort to adhere to the model presented by the Sea Power 21 vision. An independent report presented in 2002 by the Naval Postgraduate School exemplifies the LCS as a model of the Sea Power 21 initiative. The study shows that LCS's reconfigurable mission module capability of the LCS enables both the power projection and logistics missions contributing to the Sea Power 21 concepts (Naval Postgraduate School).

However, a decade later, after two littoral combat ships have been commissioned, the outlook has changed significantly. Whereas the original CONOPS envisioned LCS as a replacement for aging frigates, minesweepers and patrol boats, within the Fleet, operational assessment quickly concludes that capability restrictions prevents the LCS from fulfilling most of the fleet missions envisioned in Sea Power 21 and required by *A Cooperative Strategy for 21st Century Seapower*.

Furthermore, Navy leadership was not eager to reduce the size of the fleet or compromise on the individual capabilities awarded by the classes of ship that the LCS was slated to replace. Cost over-runs, capability gaps, and unpopular perception throughout the fleet have been the subject of criticism and increased scrutiny of the LCS program with both Congress and the acquisition community. However, it is important to note that the acquisition community (NAVSEA) has publically feuded with congressional leadership and independent testing organizations over some of the negative findings concerning the LCS's perceived cost and performance.

Operational testing quickly showed that the LCS excelled in some mission areas, while failing to successfully perform some of the core mission areas in their concept of operations. When compared to the six elements of the Cooperative Strategy for the 21st Century Seapower, the LCS was found competent in the areas of deterrence, maritime security, and humanitarian assistance/disaster response. However, it was deemed incapable of possessing forward presence, sea control, or power projection requirements.

The Vice Chief of Naval Operations, ADM Mark Ferguson ordered a review assessment of LCS to include war gaming scenarios and other aspects of operational analysis. The output report (hereby known as the OPNAV report) was released by RDML Samuel Perez. While the OPNAV report is classified, secondary sources cite issues including the concept of operations, manning shortages, maintenance and training concerns, modularity and mission module issues, and commonality problems between the two LCS variants" (Cavas, 2012).

The OPNAV report continues to address shortfalls with the mission module concept, highlighting concerns regarding the manning, logistics, and sustainment of the reconfigurable mission module concept. Other sources have cited flaws with the LCS's mission module system integration and inability to meet established requirements (Eckstein, 2013). Conversely, this claim has been publically refuted by the PEO LCS organization and has been a frustration to acquisition officials (PMS 420, 2012).

In short, the OPNAV report, as well as additional, independent observations, state that the LCS cannot perform to its intended mission requirements due to its extended length of time required to reconfigure mission packages, its lack of power projection, control, and forward presence, and its shortcomings in managing the complexities of OCONUS deployment and support.

B. EMERGING A2/AD PROBLEM

In the 2012 DoD Strategic Guidance, the president identified Anti-Access/Area Denial (A2/AD) as a chief concern in maintaining global security (Defense, 2012). The nature of many of the oil ports and shipping waterways is such that a small force could effectively shut down all incoming and outgoing sea traffic using rudimentary, inexpensive, and widely available weapons, such as mines and scud missiles.

The existing mission modules and the sea frame of the LCS were designed toward performance of counter A2/AD missions with an initial focus on Mine Countermeasures (MCM) and Littoral Antisubmarine Warfare (ASW). These mission packages were intended to filled capability gaps as U.S. frigates and MCM ships were retired, as mentioned in the previous section. But as current and potential adversaries acquire and expand A2/AD capabilities to include concentrated missile attacks, a missile defense mission capability must be introduced. U.S. strategic and tactical assets, such as bases, ports, and international waterways in the littoral regions are becoming increasingly vulnerable to this threat.

1. Potential Threats

The A2/AD missile threat was assessed for several potential adversaries ranging from the topical look at capabilities currently possessed by North Korea to hypothetical possibilities in Yemen. For the purpose of this project, the scope was bounded to consider the ballistic and scud missile threats not already covered by missile defense systems. An assumption was made that countries having long range and intercontinental missiles would continue to have committed defenses, such as the European Phase Adaptive Approach or the U.S.'s Ground-Based Midcourse Interceptor system.

In examining the A2/AD environment and, more broadly, the possible capability gaps in missile defense, a common, likely scenario would be that civil conflicts result in an unpredictable missile threat. This would be especially harmful in areas where U.S. and allied ballistic missile defense capabilities do not fully cover, which include Libya and Syria.

A review of the inventories of the most likely countries indicated that an inventory of 50 to 60 missiles having ranges between 200 and 800 km would be likely, and that these countries may have half as many launchers (Abby Doll, 2012). Table 1 shows missile inventories of Syria and Libya. Although many other countries could present this threat, a Design Reference Mission based on these inventories provides realistic values for designing to a particular measure of effectiveness.

Syrian Missile Inventory		
Missile	Range	Missile
SS-21	120 km	18+
Scud-B	300 km	38+
Scud-C	500 km	
Scud-D	700 km	
Libyan Missile Inventory		
Missile	Range	Missile
Al Fatah	200 km	45+
Scud-B	300 km	

Table 1: Threat Missiles

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III. PROBLEM STATEMENT

A. BMD BACKGROUND AND CAPABILITY GAP

Weapons proliferation has been a long-standing concern for the United States Government, even prior to the collapse of the Soviet Union. In order to finance an ongoing campaign and protect allied interests, both the U.S. and USSR provided weaponry to neighboring nations in return for monetary or strategic compensation. Unfortunately, this has led to the present day situation where many unstable nations, as well as non-state actors, have access to advance weaponry. Terrorist organizations, regime opposition groups, and regional war lords have demonstrated their willingness to use these weapons on their enemies, or even on innocent civilian population centers.

Given that these weapons, while advanced, are many generations behind the state of the art capabilities that our nation's military is best equipped to counter, there are many capability gaps in the U.S. response strategy. One of the largest threats exists in the short to medium range ballistic missiles operated by many middle-eastern, African, and east-Asian countries. These weapons, while rarely nuclear capable, can contain explosive, chemical, radiological, or biological compounds. However, given the wide-spread nature of these threats and their relative inaccessibility, response tactics are limited. Furthermore, the diversion of defense-capable assets often puts the U.S. at risk for additional threats.

B. LITTORAL BMD CHALLENGE

Considering that over 50% of the world's population lives within 60 kilometers of the shoreline, it is easy to believe that many of the abovementioned threats are near the littorals. As mentioned earlier, the U.S. has a recognized capability gap in the littoral regions, including the inability to easily intercept locally targeted ballistic missile threats. In order to protect the U.S. and allied interests in the littoral regions, it is commonly agreed upon that a littoral-capable ballistic missile defense platform is needed to ensure global maritime security.

Operating in the littoral environment requires special consideration to geographical constraints and increased air and sea traffic. Radar clutter, resulting from commercial air and sea traffic, affect detection and classification times and ultimately limit the number of engagements a system can have on an incoming threat. Furthermore, geographical features of the landmass can block radar and prevent even the possibility of early detection. A sea based ballistic missile defense system design must tackle these challenges to be effective in littoral combat.

1. Problem Statement

With the advancement and expansion of Anti-Access/Area Denial (A2/AD) capabilities of current and potential adversaries, strategic assets (e.g., bases, ports, littoral regions) of the U.S. are becoming increasingly vulnerable to threats, especially concentrated missile attacks, that will either deny access to or limit ability to conduct operations from them. This, combined with the resource-constrained challenges faced by the armed forces, may ultimately compromise the United States' ability to project power and protect its interests in contested regions.

2. Capability Need Statement

To counter the increasing threat posed by the expansion of adversary A2/AD capabilities, an improved and economical BMD capability is needed to protect U.S./allied regional strategic assets against concentrated missile attacks which play a key role in adversary A2/AD strategy.

IV. OBJECTIVES

A. CAPSTONE PROJECT OBJECTIVES

The capstone assignment was to identify a capability need that the LCS could perform effectively, and design a concept mission package to meet that need. Theater Ballistic Missile Defense was identified as the capability need. The design objective was to develop an LCS mission package concept capable of protecting regional strategic assets from concentrated missile attacks. The Systems Engineering methodology was used to derive the functional requirements, develop the concept, and assess the design's feasibility.

B. STAKEHOLDER ANALYSIS

The ballistic missile defense mission affects a large range of stakeholders. A high level assessment was done to understand the scope of these affects and to also identify where design requirements and guidance should come from.

In the beginning of this capstone project, several stakeholders within NAVSEA and the Program Executive Offices (PEO) were surveyed to understand the demand and to get some direction. Ultimately, the capability need was derived from the Defense Strategic Guidance and several Congressional Research Service reports. Further direction was provided by the Naval Postgraduate School capstone advisors and LCS requirements were pulled from the Interface Control Document. Table 2 ties stakeholders with their roles with respect to the BMD capable LCS.

Stakeholder	Role	Interest
NAVSEA PEO LCS PMS 501 Littoral Combat Ship Program Office PMS 420 LCS Mission Modules Program Office	Planning/architecture	Delivery of system meeting capability need
DoD Secretary of Defense Missile Defense Agency	System acquisition	Acquisition of system(s) meeting capability needs
U.S. Navy Chief of Naval Operations Combatant Commanders	System operation	Operating/maintaining /sustaining system
Shipbuilders /Contractors Lockheed Martin General Dynamics	Develop/build/deliver	Deliver mission-capable system within budget / schedule
Allied/Coalition Forces	BMD presence/partner	Mutual protection of strategic and tactical assets
Host Nations	Host presence of BMD assets	Ensure solution(s) can be implemented without escalating concerns of neighboring countries or other interests
Taxpayers	Funding support of project	Funds are efficiently spent to provide capabilities needed to protect U.S. /allied interests

Table 2: High-Level Stakeholder Analysis

C. MISSION OBJECTIVES

1. Primitive Needs

In a 2009 Congressional Research Service (CRS) report titled *Sea-Based Ballistic Missile Defense – Background and Issues for Congress* it was reported there are over 5900 ballistic missiles outside the U.S., NATO, Russian Federation, and Peoples Republic of China (O'Rourke). Short and medium range ballistic missiles make up 99% of the aforementioned inventory. The findings suggest that many lesser-developed countries are in possession of these weapons; the majority of which are in areas not covered by any ballistic missile defense systems. Asset availability and geopolitical constraints make staging defense systems for all possible threats infeasible.

Currently, the U.S. Navy has 26 Aegis BMD systems and six more are planned to be in service by FY17. The 2020 European Phased Adaptive Approach (EPAA) commitment will require 4–5 Aegis equipped ships on station around Europe. As the Ticonderoga Class cruisers are retired over the coming years and as demand for ballistic missile defense increases, the Aegis equipped destroyer could be stretched too thin to respond to missile threats in underdeveloped areas of the globe.

According to the FY13 Shipbuilding Plan, 55 Littoral Combatant Ships will be operational by 2026 (Operations, 2012). The open architecture design of the LCS sea frame allows the ship to be fitted with mission package components required for the mission demand. Packages for Surface Warfare, Antisubmarine Warfare, and Mine Warfare are currently being fielded. A BMD mission package is needed to meet future ballistic missile threats and fill gaps in ballistic missile defense coverage.

2. System Design Objectives

The design objective of this project was to apply the Systems Engineering methodology to develop a BMD LCS mission package concept. Design metrics and measures of effectiveness were established by characterizing the present day performance measures using publicly available information to rank system components and determine those most suited to fill the capability need. The final deliverable is this report describing a BMD mission package concept that leverages current and future assets to provide a cost-effective, scalable, and flexible BMD system for defending strategic and tactical assets in littoral regions of interest.

D. DESIGN REFERENCE MISSION

To reiterate, the purpose of this project was to develop a solution that could be rapidly deployed in response to threats to high value assets in more underdeveloped countries that are armed with short range ballistic missiles and scud missiles. It was determined that 50 to 60 missiles having ranges between 200 and 800 km would be likely, and that a salvo of 24 missiles launched at a single asset would be feasible. These metrics were used to establish the Design Reference Mission. From a sea based platform, defending a land based asset from a missile threat further inland is done more effectively within closer proximity to the asset. This puts the platform in the littoral environment.

1. Projected Operational Environment

Ballistic missile defense of an asset requires the system to operate close enough to allow sufficient intercept opportunities of missiles coming from any direction. From a sea based platform, this often demands that the system be deep within the littoral waters of the asset's host country and sometimes within the littorals of the threat country. Several regions have been identified, based on recent events, as having higher likelihoods of needing ballistic missile defense. These were described previously in the Capability-Need Assessment, and further in the Mission Execution Scenario section of the DRM. The environmental conditions and threats prominent in these regions (and specifically the littoral waters) are listed below.

- Environmental Conditions
    - Littoral Waters
        - Geographical constraints lead to limited battle space, congestion, and clutter resulting in reduced reaction time to incoming threats.
        - Higher sea states demand higher sensor fidelity and active tracking to discriminate contacts on the surface and in the air.
    - Targeted Regions
        - Temperatures range from below 0° F near the Korean Peninsula to over 100° F in the Middle East.
        - The geography is sometimes flat, but other times it is mountainous, limiting detection time and thus reducing response time.
- Threat/Target Details
    - Threat Characterization
        - The strategic assets identified in the capability-need analysis are those that are not currently under the defense umbrella of some other defense system, or those with insufficient coverage. The threat regions are typically using shorter range ballistic missiles with 1000 kg warheads. These are up to 12 km in length and 1 m in width. Table 3 shows the flight characteristics these missile types.
    - Threat Tactics
        - Quantity
            - Research into potential threats posed by weapons capabilities of foreign countries found that a maximum inventory of 60 missiles is likely and a maximum salvo launch of 24 ballistic missiles could be realized.

- Direction
    - If the threat country recognized that the sea-based defense system was the only defense system in place, then that country would try to launch from a location, or several locations that would minimized the system's coverage.
- Range
    - As described in previous sections, the threat country would likely possess short range ballistic missiles that have a range between 100 and 800 km. Table 3 shows the flight characteristics of the prospective missiles (Bardanis, 2004).

Range (km)	**Flight Time (s)**	**Max Speed (km/s)**	**Apogee (km)**	**Boost Time (s)**	**Burnout Range (km)**	**Burnout Altitude (km)**
200	198.0	1.27	50	21.73	27.70	21.33
400	280.0	1.80	100	29.63	38.54	29.65
600	342.9	2.20	150	37.37	49.38	37.97
800	396.0	2.55	200	44.95	60.22	46.29

Table 3: Threat Missile Flight Characteristics

a. Mission Execution Scenario 1

In the DRM, civil conflicts in a neutral country threaten U.S. assets near Benghazi, Libya. Intel indicates that the radicals possess short range ballistic missiles and scud missiles and intend to use them. The U.S. positions sea based BMD systems to defend U.S. assets. Libyan radicals launch 24 ballistic missiles simultaneously from three different launch sites ranging from 180 km to 700 km. U.S. forces engage incoming missiles (Figure 1).

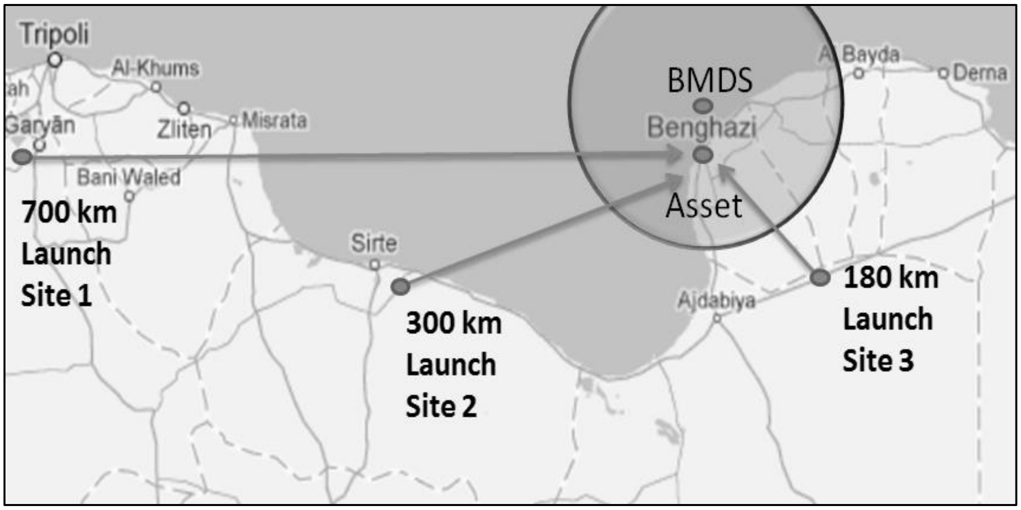

Figure 1: Design Reference Scenario

The operational concept starts with positioning the BMDS equipped Littoral Combat Ship(s) to an optimal location to defend the strategic or tactical asset. In the event multiple systems are deployed, they will exchange information as needed. Then a somewhat conventional detect to engage cycle begins. The BMDS scans the air space, tracks contacts, detects missiles, controls the engagement, and intercepts the missile. Figure 2 shows this sequence.

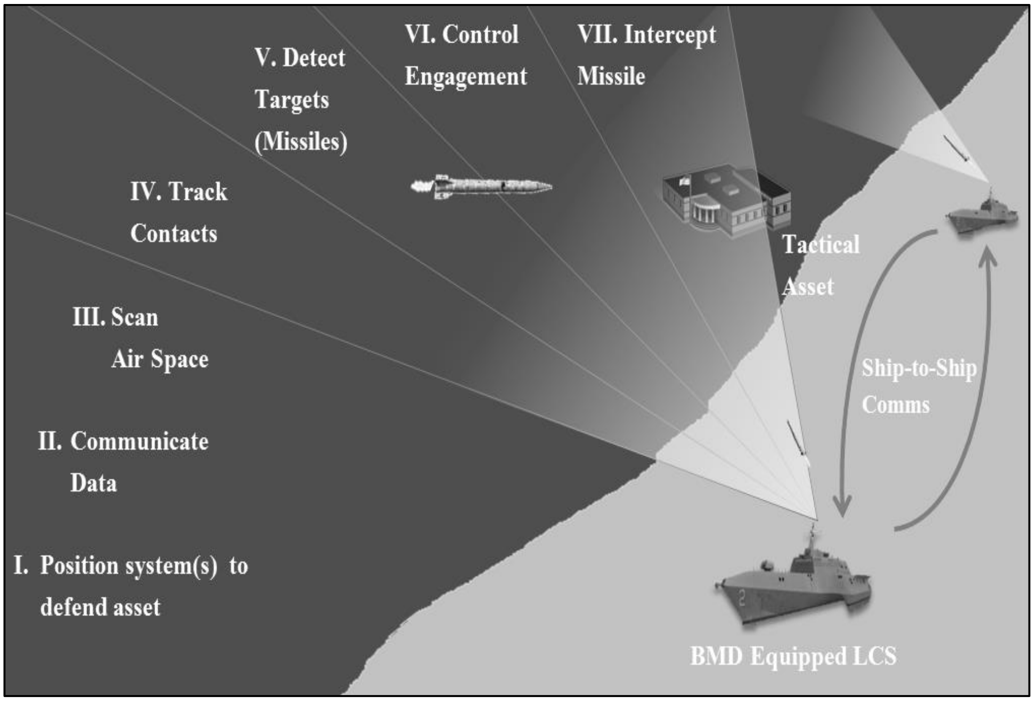

Figure 2: Operational Sequence

V. REQUIREMENTS DEFINITION

A. APPROACH

In the initial approach to determining ballistic missile defense success metrics, public sources, such as the MDA website, were explored. A focus was placed on finding performance requirements for the Aegis and the Patriot air defense systems. Missile and defense system characteristics were compiled, but none of the sources provided any specific level of performance requirements.

The approach then shifted to a more analogous assessment in which the Aegis and Patriot Advanced Capability systems were simulated in the Design Reference Mission, and the measure of effectiveness of those systems was the design requirement of the LCS BMD system. The approach required two high level steps.

1. Determine how effectively the existing solution(s) can perform the DRM (Aegis and PAC3)
2. Determine what is required of the LCS to perform the DRM at least as effectively

1. System Considerations

The feasibility of this LCS BMD package concept leaned heavily on several considerations and assumptions. A description of how the capability need for a BMD mission package was determined was given in previous sections, but the bottom line is that it is not practical to dedicate a large share of the Aegis platforms capability to "asset protection" when only a fraction of capability is needed. In a time when LCS platforms are abundant (as projected), the Navy should leverage these lower-cost solutions to provide Littoral Region BMD scaled to specific, smaller scale protection requirements.

2. Key Assumptions

A few key assumptions were necessary to move forward with the system design. First, as expressed in the Approach section, the sea based Aegis system represents the best capability to date, and meets the Navy's requirements for ballistic missile defense on a sea based platform.

Next, the Navy will continue to build the LCS; 55 ships are planned to be in service by 2026. The modular architecture of the LCS allows the Navy to fit components for the mission in demand.

Last, publicly sourced information is sufficient for proving the concept at this stage. Because this concept design study is a feasibility analysis, published data was used in characterizing the system; therefore, the performance characteristics are not of the highest fidelity. The quantitative requirements that will be used in the design were derived from performance metrics of the Aegis and PAC3 systems in the simulated DRM.

B. HIGH-LEVEL REQUIREMENTS

1. Project Requirements

The customer-defined requirement, or capstone assignment, was to identify a capability need (mission) that the Littoral Combat Ship could perform effectively, and design a concept mission package to meet that need.

2. Derived Requirements

The LCS mission package design shall increase layered BMD capability to enable cost-effective, rapidly established protection of an expanded range of littoral-area strategic and tactical assets from conventional and unconventional ballistic missile attacks.

a. Cost

The BMD equipped LCS shall cost considerably less than the seagoing Aegis solution price of ~$2B per unit (Office of Management and Budget, 2013). The cost goal used for this analysis is at least two BMD capable LCS platforms can be procured for the cost of a single Aegis-BMD destroyer.

Again, an assumption was made that the Aegis system meets the performance requirements of the sea based BMD solution. In future threat projections, if it was determined with a high certainty that the Ballistic Missile (BM) threat on strategic and tactical assets has the highest priority, then the force structure plan might be modified to meet this demand. If the Aegis solution was the most cost effective, then the LCS solution could become obsolete, largely because the Aegis is a multipurpose system. Therefore, for the LCS solution to be considered, the cost should be considerably less than the seagoing Aegis solution.

b. Technical

The BMD systems modules shall integrate with the Littoral Combat Ship architecture. The open architecture design of the LCS is such that mission packages can be easily and quickly installed to meet the mission demands. The LCS Interface Control Document (ICD) identifies the requirements for mission module integration. Deviations from the ICD negate the open architecture concept. For this solution to be mission package, it must meet the requirements given in the ICD. This document is distribution limited, so for this study, broad ranges of values are used. An assessment of weight or center of gravity was not performed, but future efforts should address the weight requirements at each mission module station.

(1) Space: The current monohull variant of the LCS has two weapons module stations, and the trimaran has three, each with about 50 cubic meters of useable volume. Internal to the ship are ten support module stations each with about 36 cubic meters.

(2) Power: The available power on the LCS sea frame at any single mission module station is less than 50 kW. However, studies have been performed that suggest that 1 MW of power could be installed easily and as much as 10 MW may be possible using portable generators

c. Performance

The solution, when properly deployed, will provide BMD capability at least as effectively as the sea based Aegis system when measured against the salvo and conditions of the DRM. These metrics are described in the simulations section of this report.

VI. SYSTEMS ENGINEERING PROCESS

A. TAILORED SYSTEMS ENGINEERING PROCESS

To guide the BMDS systems engineering effort a tailored Vee model was used, based on the Forsberg and Mooz Systems Engineering Entity Vee (Forsberg & Mooz, 2005) (Figure 3). With project time constrained to a span of three academic quarters and limited dedicated resources, the project scope was bounded to developing and proposing an LCS-based BMD system concept only. i.e., primary focus was on synthesizing and proposing a cost effective, force-structure aligned concept solution that would fulfill BMD capability needs in littoral waters.

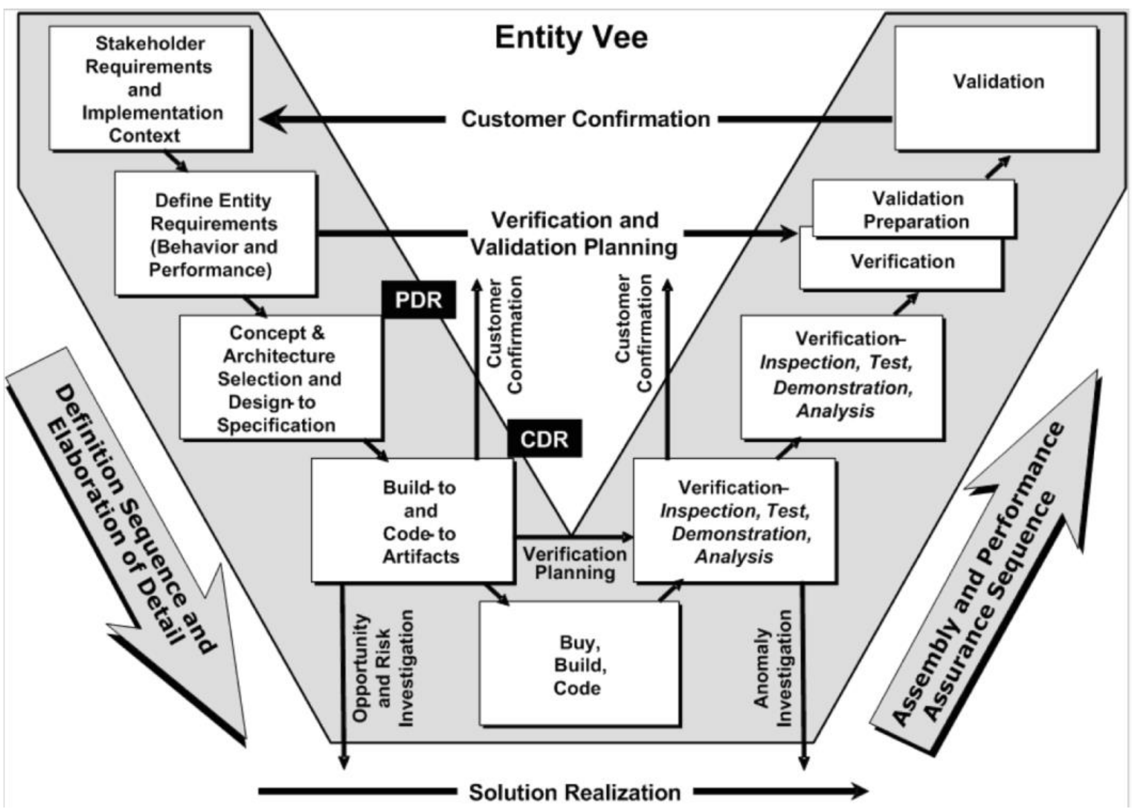

Figure 3: Entity Vee Model (From Forsberg & Mooz, 2005)

The systems engineering process focused on activities in the upper left corner of the Vee model, which emphasizes the front-end phases of the systems engineering life cycle, including requirements development, functional analysis and decomposition which lead to the definition of the architectures and concept design. The resulting process used, which reflects the key BMD system project activities, is depicted in Figure 4.

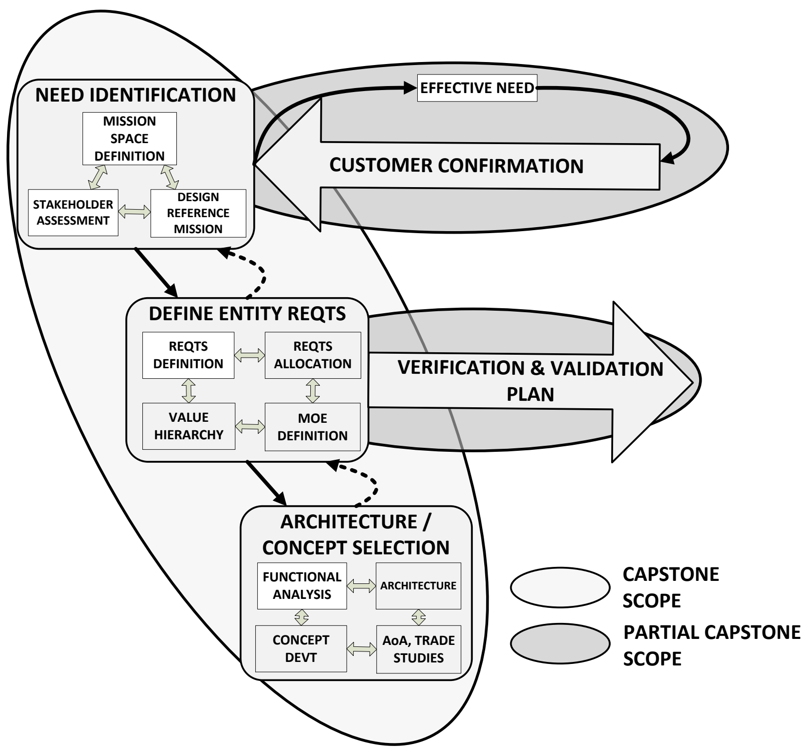

Figure 4: BDMS Concept Development Tailored Vee Model

B. SYSTEM CONTEXT MODEL

The context model for the proposed LCS-based BMD system is shown in Appendix A. Context Model for LCS BMD System. This system is envisioned to operate within a larger system of systems, which may include other Aegis, Command and

Control (C2) or other coalition BMD assets operating within the theater. The key interacting systems include the following:

1. Sensors

Detection of an incoming ballistic missile can be accomplished via a variety of means ranging from very simple approaches, e.g., an observer equipped with binoculars or night-vision goggles, to more sophisticated methods, including radar and satellites e.g., the space-based infrared system (SBIRS). For maximum BMD system effectiveness, detection of incoming ballistic missiles as early as possible will be needed to maximize the amount of time the system will have to react to the incoming missile, system reaction time to track, determine course of action, and intercept the missile before it is able to reach its intended target to inflict damage and/or casualties. This will require leverage of use of more sophisticated sensors which can readily be integrated into the overall system to enable prompt notification of potential missile threats.

2. Combat Management System (CMS)

On a naval combat ship, the CMS facilitates the collaboration of human (crew) and non-human actors (CMS system, sensors, and actuators) to perform three of the ship’s main functions, including C2, war fighting, and planning. Dr. Skowronek and Mr. Van’t Hag note that,

> The Naval CMS systems’ main capabilities encompass awareness of situation around the ship (or a group of ships: a naval force) using sensors, recognition of threats against the ship or force and response to those threats using actuators such as missile and gun systems. Other capabilities of a Naval CMS include those frequently called Command Support capabilities, and which in general are concerned with preparation of the ship’s mission. They also include the preparation and supervision of execution of diverse plans, as well as reception and interpretation of communication from external parties (other vessels or shore-based parties). (Van’t Hag & Skowronek, 23–24 September 2002)

As such, execution of the BMD mission on the LCS-based system is expected to be facilitated by the LCS CMS.

3. Interceptors

Neutralization of ballistic missile threats is expected to be accomplished primarily by anti-ballistic missiles, either LCS-based or otherwise-based, designed specifically to counter BM threats. While there are other methods or technologies available e.g., Close-In Weapon System (CIWS), directed-energy weapons, cursory assessments indicate that these solutions do not appear viable due to constraints including effective range and supportability (i.e., power requirements).

4. Support Infrastructure

Support BMD system include all elements needed to enable setup, operation, and maintenance and repair to ensure the system can fulfill its mission throughout its life cycle. Elements include, all transportation systems to deliver and transport the system to, from, and around the theater of operation, all personnel required to sustain the system, as well as all infrastructure needed for system operation. In the context of the LCS-based BMD system, much of the support tasks will be facilitated by the LCS sea frame and crew.

VII. REQUIREMENTS DEVELOPMENT

A. MEASURES OF EFFECTIVENESS (MOE)

The functional decomposition for the DRM mission set was used to derive MOEs for the LCS BMD solution. The intent of determining MOEs for this analysis was to bind the problem space for subsequent system engineering design synthesis. Table 4 is a list of MOE for the LCS BMD Mission Package and breaks the MOE into two categories of Measures of Performance (MoP) and Measures of Suitability (MoS) (Prothero, 2010).

MOE	Notes/Justification	MoP	MoS
Operation Availability	Ability to maintain BMD capability given DRM environment	☐	☒
Operational Reliability (R)	Characteristics that promote successful operation within DRM operating environment e.g. Mean Time Between Failure (MTBF)	☐	☒
Maintenance Down Time (MDT)	The total time the system needs to be taken down for corrective or preventative/predictive maintenance.	☐	☒
Number of Operators	The total personnel required to be deployed on the LCS to operate BMD Mission Package	☐	☒
System Cost	The Life-Cycle Cost for the LCS BMD Mission Package	☐	☒
System Size	The ability for the system to fit within the LCS modular framework or otherwise aboard	☐	☒
Probability Of Raid Annihilation (P_{ra})	The probability that the DRM ballistic Missile salvo is neutralized	☒	☐
Probability of Detection	Probability that a missile of DRM parameters is detected	☒	☐
Range of Detection	Range that that a missile of DRM parameters is detected	☒	☐
Probability of Track	Probability that a missile of DRM parameters is Tracked	☒	☐
Range of Track	Range that that a missile of DRM parameters is Tracked	☒	☐
Probability of Kill (P_K)	Probability that a missile of DRM parameters is destroyed if engaged	☒	☐
Range of Engage	Range that ballistic missiles can be engaged	☒	☐

Table 4: Measures of Effectiveness

B. KEY PERFORMANCE PARAMETERS (KPP)

The attributes of system performance that shape the LCS BMD capability within the DRM operating environment are the KPPs, listed in Table 5. The KPP were developed based on modeling and simulation work or information provided by similar systems.

KPP	Threshold	Objective
Operational Availability (A_0)	0.90	0.95
Probability Of Raid Annihilation (P_{ra})	0.55	0.75
Probability of Detection	0.90	0.96
Range of Detection	180 km	300 km
Probability of Track	0.90	0.96
Range of Track	180 km	300 km
Probability of Kill (P_K)	0.80	0.96
Range of Engage	25 km	100 km

Table 5: Key Performance Parameters

BMD system requirements were developed in step using Model Based SE Methods. After gathering all the system needs and requirements from the stakeholders as well as simulation, brainstorming sessions were held to align requirement content considered essential to system development. Subsequent analyses enabled final downselect and elimination of requirements considered unnecessary. Next, requirements were into Functional and Non-Functional groupings at the upper level of the system requirements taxonomy. The end result was a listing of requirements structured via a CORE model (Figure 5).

C. REQUIREMENTS DECOMPOSITION

The Functional requirements of the BMD System were sub-categorized into:

1.1 Input Requirements – command input from the user or control and command.

1.2 Output Requirements – should generate system or mission information e.g., battle damage assessment.

1.3 Interface Requirements – the system artifacts should function within the operational environment.

1.4 BMDS Function Requirements – describe the system functionality.

Correspondingly, Non-Functional Requirements were sub-categorized into:

2.1 Suitability Requirements – operational and maintenance intervals should support mission needs.

2.2 Physical Requirements – system size, weight, center of gravity, etc., shall be defined.

2.3 Technology Requirements – system shall be able to upgrade to newer technology in the future.

2.4 Standards and Protocol Requirements – system shall prescribe to current operational doctrine and constraints.

2.5 Cost Requirements – system shall be within the expected cost.

2.6 Schedule Requirements – system shall be delivered within the mandated timeframe.

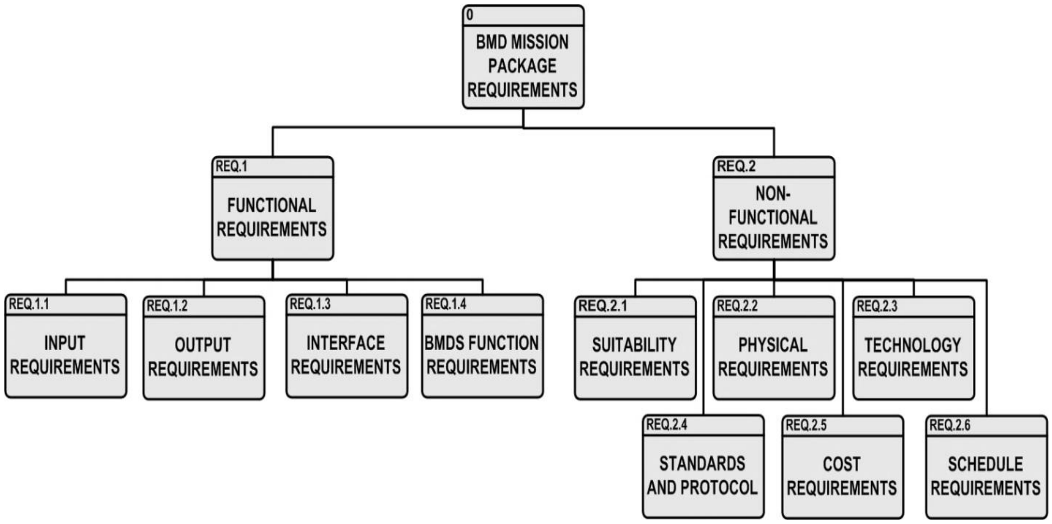

Figure 5: High level of requirements model

For further analysis, each sub-category was decomposed into sets of lower-tier functions. For instance, the functional requirements were decomposed into; Scanning, Tracking, Detection, Control and Threat Intercept Requirements (Figure 6). This process was repeated for all high level requirements. From this view point, every requirement will turn into a system or sub-system function and integrated together later. A detailed list of all requirements can be found in Appendix E. System Requirements.

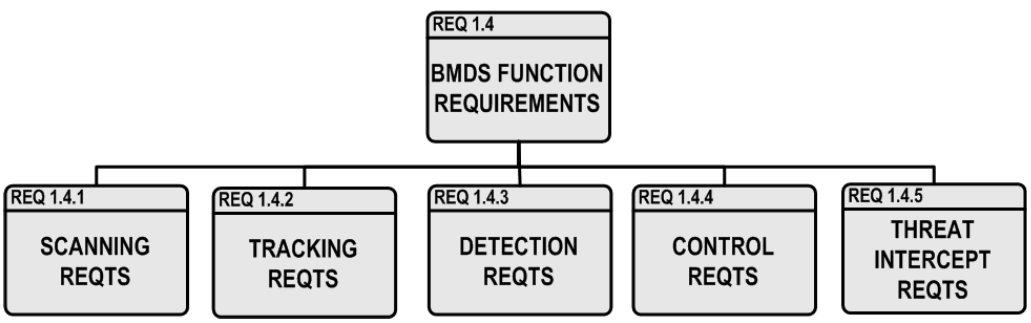

Figure 6: BMDS Function Requirements Decomposition

VIII. SYSTEM ARCHITECTURE

With system requirements defined, development of the BMD system architectures began. Synthesis of the architectures was accomplished in steps, starting with use of the system functional requirements, system operational concept, and system context model to synthesize the high level functional architecture of the BMDS. This high-level structure was then decomposed into sets of lower-tier sub functions, and the resulting functional hierarchy was then transformed into the BMDS functional architecture and subsequent candidate BMDS physical architectures to be evaluated in the project Analysis of Alternatives. Specific details regarding the development of the BMDS functional and physical architectures are provided in the subsequent sections.

Since the focus of this project is to propose an LCS-based BMD mission package concept, the functional and physical architectures have been developed only to the levels of granularity needed to support concept development.

A. FUNCTIONAL ARCHITECTURE DEVELOPMENT

1. Functional Decomposition

The BMDS functional architecture, which expresses specifically *what* the BMD system does in performing its mission, started with a first-order decomposition of the top level function, perform ballistic missile defense, into the key activities conducted by the system. The BMD system functional requirements, operational concept, and system context model were considered to decompose the top-level system functional context (Figure 7) into the following five “key” functions.

1.0 Scan – Continuously monitor the air space for any changes that may indicate an incoming BM.

2.0 Track – Continuously monitor and status potential BM threats.

3.0 Detect – Evaluate and classify potential BM threats.

4.0 Control – Determine course(s) of action.

5.0 Engage – Schedule and deploy weapon(s) to neutralize the threat

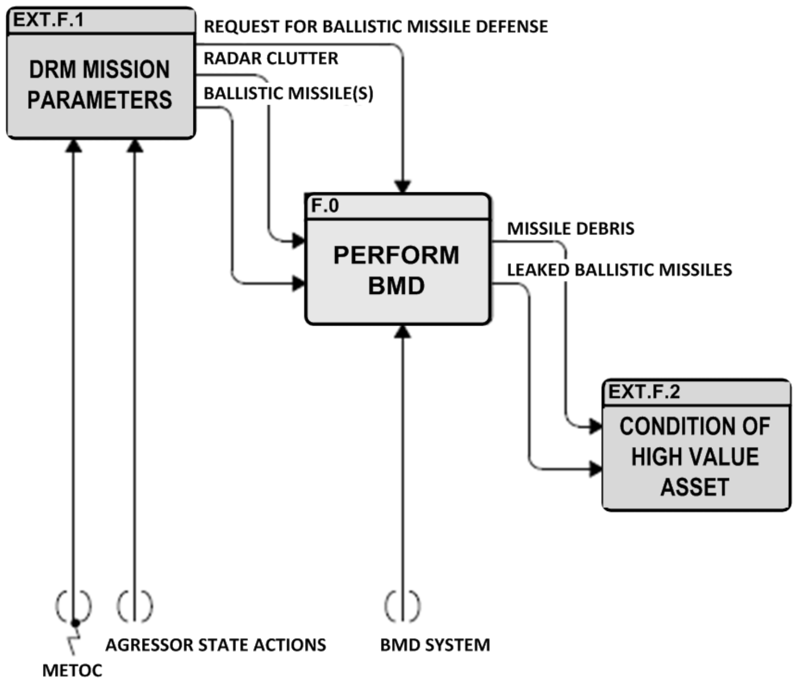

Figure 7: BMD System Functional Context – Top Level

Using the first-level functional hierarchy, decomposition of each of the key functions was then performed to further define the lower level activities required. The resulting hierarchy from the first and second order functional decomposition is provided in Figure 8.

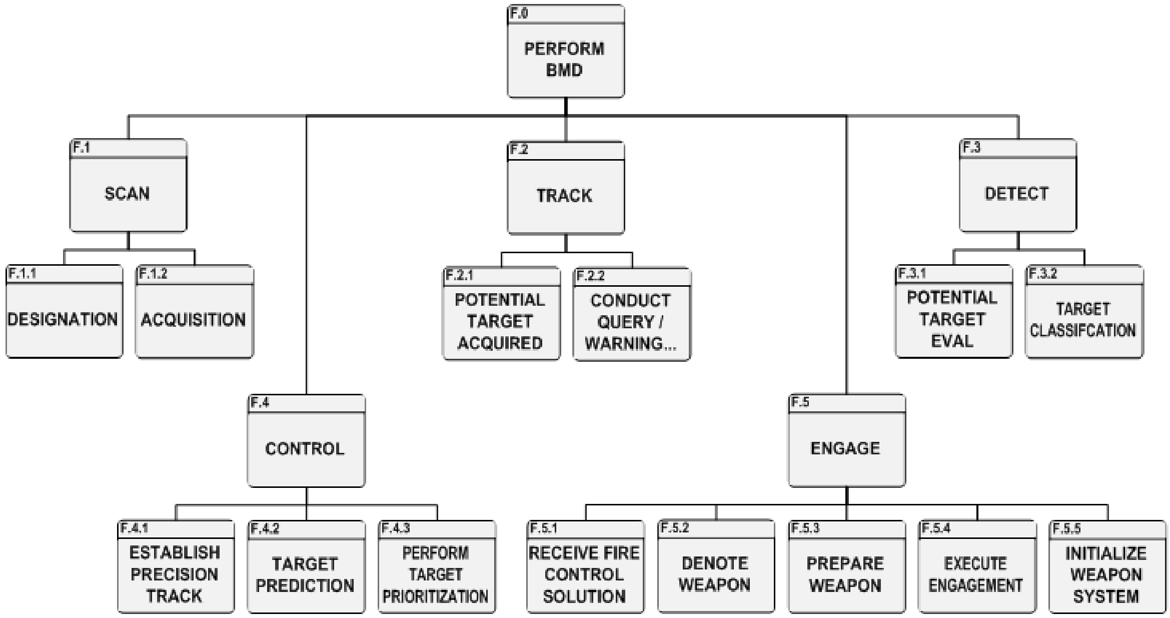

Figure 8: BMD System Functional Hierarchy Architecture

With the key and sub-level functions identified from the functional decomposition, relationships between the functions were established to yield the functional architecture. With the first level decomposition, a first level functional architecture was established by defining the interactive relationships existing between the 5 key functions. The resulting functional architecture, expressed in IDEF0 format in Figure 9, shows the relationships between the key functions in terms of inputs, outputs, controls, and mechanisms. This process is continued at the next level of the hierarchy with establishment of the relationships of the lower level functions (Figure 10 and Figure 11).

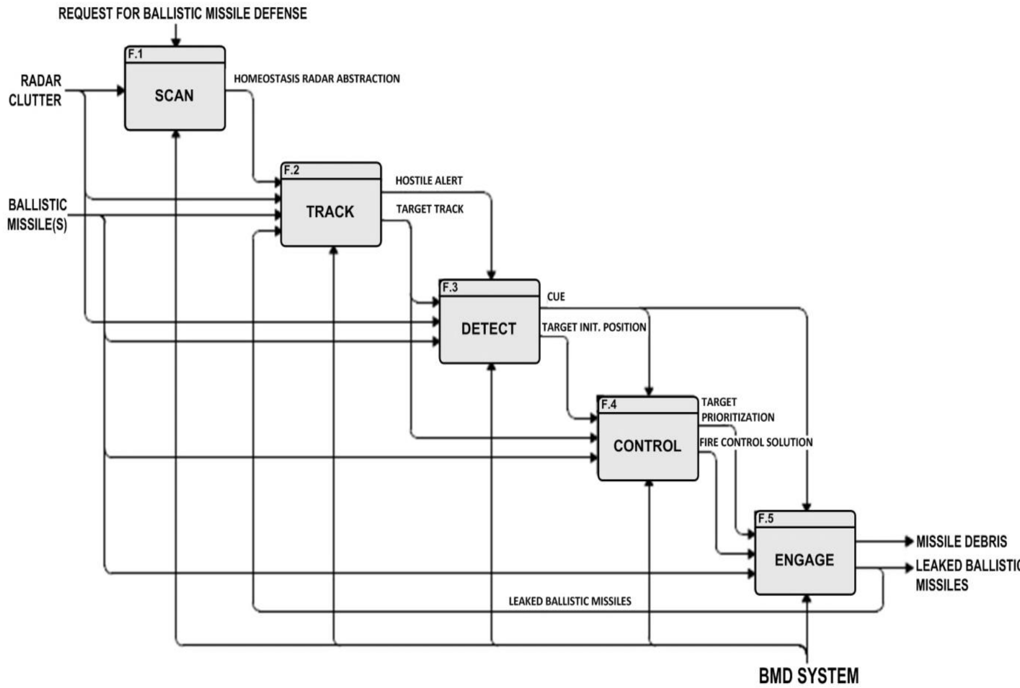

Figure 9: BMD First Level Functional Architecture – IDEF0 Format

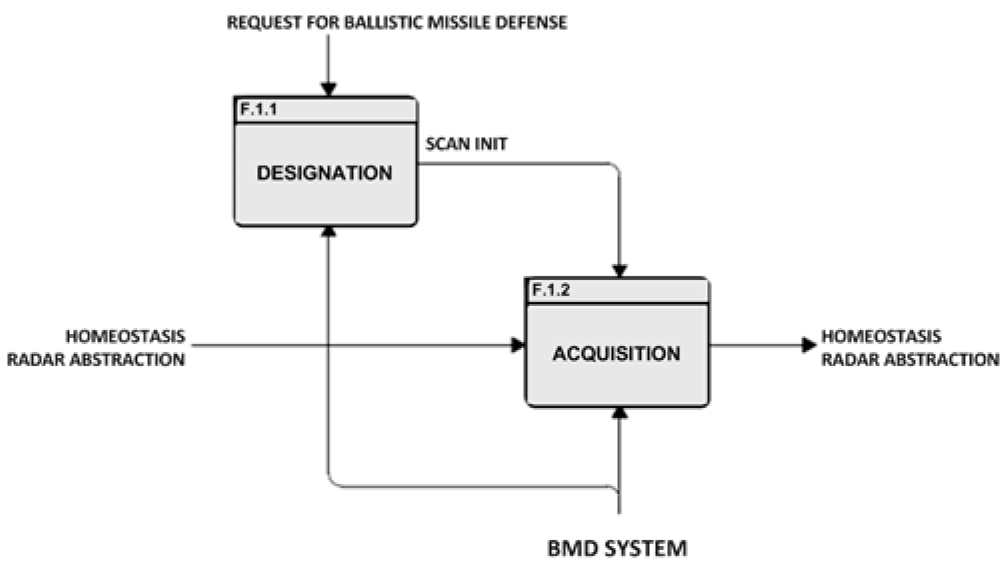

Figure 10: Example Lower Level BMD Functional Architecture Detail

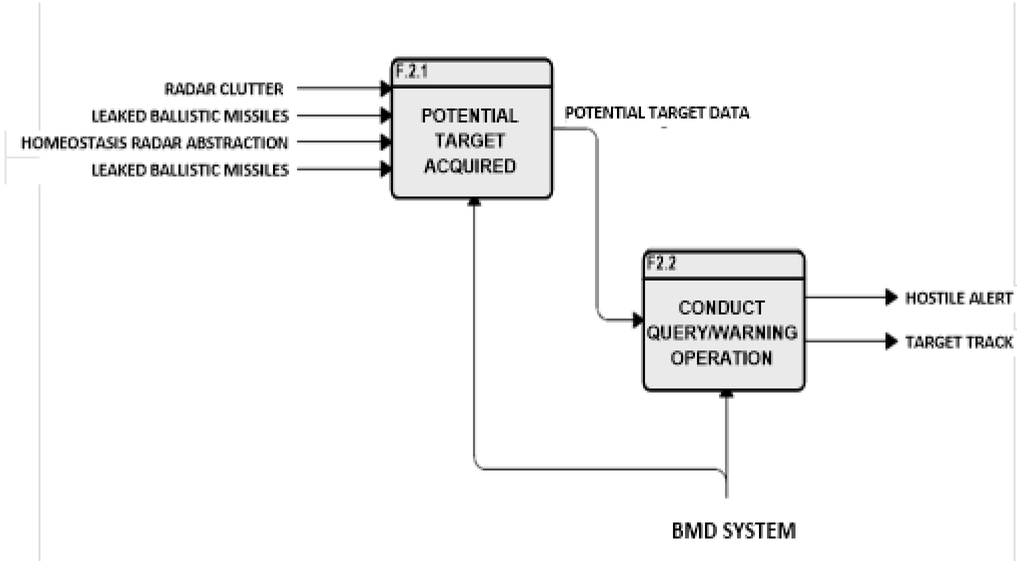

Figure 11: Example Lower Level BMD Functional Architecture Detail

B. PHYSICAL ARCHITECTURE DEVELOPMENT

1. Function Allocation

With the system functions defined, determination of the BMD system physical architecture started with mapping the system functions to the primary system elements previously established and documented (sensors, combat management system, etc.) in the system context model. This mapping is shown as elements in Table 6. Although support of the BMD system is second-order function within the BMD system operation (i.e., it is not a key function during performance of the BMD mission), the support activities are essential in ensuring that all elements of the BMDs are functioning as expected to perform their mission and as such are included here.

System Functions	Sensor Subsystem	CMS	Interceptor Subsystem	Support Infra-structure
Scan	X			
Designation	X			
Acquisition	X			
Track		X		
Query		X		
Warn		X		
Detect		X		
Evaluate Threat		X		
Classify Threat		X		
Control		X		
Establish Precision Track		X		
Target Prediction				
Perform Target Prioritization		X		
Engage			X	
Receive Fire Control Solution			X	
Denote Weapon			X	
Prepare Weapon			X	
Execute Engagement			X	
Initialize Weapon System			X	
Support Infrastructure				X
Provide Resources to BMDS				X

Table 6: System Function Allocation

2. Physical Architecture – Components

In developing the BMD physical architecture, solution components and subsystems were then researched and identified for potential inclusion as solution concept elements. With both functional requirements (e.g., scanning and detecting) and non-functional requirements (e.g., cost, supportability, and integration) in consideration, a cursory list of these components was generated for the sensor system, the CMS, and the interceptor subsystem comprising the BMDS.

With the project objective focused on proposal of an LCS-based BMD mission package, selection of candidate components were biased toward compatibility with the LCS sea frame and its supporting infrastructure.

However, in further developing of an LCS-based BMD system from a system of systems viewpoint it may be possible to also leverage non-LCS based elements, such as satellite feeds or alternate interceptor assets existing in the theater of operations, as part of the physical architecture. The resulting list of LCS-based and non-LCS-based candidate components, along with the high-level considerations used for selection, is summarized in Table 7.

Subsystem	Initial Selection Considerations	Candidates	
		LCS-Based	**Non-LCS-Based**
Sensors	Range Technology Maturity Integration with LCS Sea frame Physical Envelope Power Requirements Compatibility with other BMDS Elements Suitability Cost	SPY-1F Sea GIRAFFE TRS-3D Sea RAM AMDR AN/TPY-2 AN/TPS-80	S1850M SMART-L Iron Dome EL/M-2080 SBIRS SBX AN/TPY-2 AN-MPQ53/65 AMDR AN/TPS-80
Combat Management System	LCS Sea frame Integration Aegis Integration Target Tracking Capacity Engagement Scheduling Technology Maturity Cost	Aegis COMBATSS-21 Sea RAM PAC-3	
Interceptor Subsystem	LCS Sea frame Integration Suitability (ability to intercept BMs) Range Technology Maturity Cost	Rolling Airframe Missile (RAM) COMBATSS-21 Patriot RIM162 ESSM	SM-2 SM-3 SM-6 RIM162 ESSM THAAD Patriot Aster 15 Aster 30 Sea Dart Iron Dome CIWS Directed Energy

Table 7: Candidate Components for LCS BMDS Mission Package

3. Physical Architecture – Types, Variants

With the initial functional mapping complete and candidate system components identified, efforts were then shifted to development of the candidate physical architectures of the LCS-based BMD system. Initial efforts focused on defining BMDS architecture arrangements where all system elements, e.g., sensors, CMS, and interceptors, were located on and integrated with the LCS sea frame. This baseline architecture, denoted as the Type 1 architecture is depicted in Appendix C. Physical Architecture. This figure expresses the physical architecture in terms of the original system context model, elaborated with candidate solution elements for each subsystem. From this basis, a wide range of combinations of sensors, CMS, and interceptors were generated as Type 1 physical architecture variants that were considered in the Analysis of Alternatives.

In developing the candidate architectures, it was acknowledged that with the present constraints of the LCS sea frame, non-LCS-based resources may be needed to compensate for any function or capability gaps that may be discovered as assessment of LCS-only solution progressed. To address potential challenges, a Type 2 architecture, which leverages non-LCS-based elements to augment the LCS-specific capability, was also developed. This Type 2 architecture, which integrates the capability of non-LCS-based sensors (e.g., satellites, other forward-deployed radar) and interceptors, is shown in Appendix C. Physical Architecture

Again, from this basis, a wide range of Type 2 candidate physical architecture variants could be identified for consideration in an Analysis of Alternatives. However, this concept design focused solely on the sea frame constrained solution.

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IX. RISK MANAGEMENT

A risk management process was defined early in the project to systematically classify, assess, and prioritize actions to address risks as they were identified over the course of the project. This process was then implemented to decrease the effects of potential program issues such as increased program cost, delays, defects, and customer dissatisfaction. The risk management architecture used to identify, assess, handle and monitor each of the risks is shown in Figure 12.

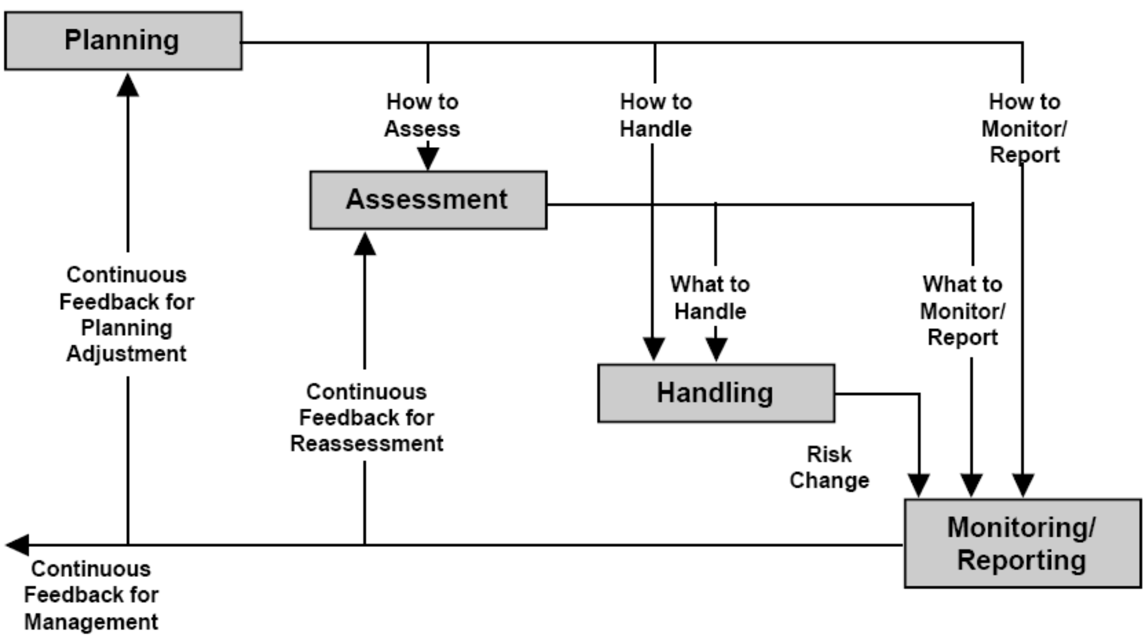


Figure 12: Risk Management Architecture

The planning component of the risk management architecture focuses on assessment of a potential risk, how to handle the risk and how to monitor/report each of the risks. The assessment component focuses on prioritization of the risks and selection of risks to monitor/report. The handling component deals with implementation of controls to mitigate the risks. Lastly, the monitoring/reporting component deals with providing continuous feedback for further planning and adjustment to changing risks or newly discovered risks as the project matured. In the next sections each of the components of the risk management architecture are discussed and show how the risks for the project were developed.

A. RISK IDENTIFICATION AND PLANNING

The initial efforts identified the potential risks of integrating BMDS components on an LCS platform. These risks are those that can potentially prevent the project from achieving the intended mission.

The risk assessment not only focused on the technical risks of system integration but also on the operational and programmatic risks such as cost, schedule, environmental conditions, vulnerabilities, and safety.

Historical, programmatic, and publicly available data, along with the derived system requirements were used to identify the potential risks of the project. Project team meetings were held over the course of the investigation to brainstorm anticipated risks and discuss newly discovered risks based on new information gathered as the project progressed.

The identified risks were categorized as technical, programmatic and operational. Table 8 represents the risks that the project may encounter due to the baseline technical requirements of the project in comparison of the LCS sea frame requirements and the prospects of programmatic limitations such as cost, congressional decisions, and international cooperation.

B. RISK ASSESSMENT

The risks identified in Table 8 were given a qualitative rating on the probability of occurrence and the level of consequence. The risks were then characterized as a product of the risk consequence times the risk probability of occurrence.

The operational risks identified deal with the hazards the LCS may encounter while performing the DRM. Operational risk 1 (O1) identifies that the crew size of the LCS may need to be increased to a level not supported by the LCS in order to successfully perform the DRM. The addition of a BMD capable radar, BMD control console, and missile launch system will require additional crew expertise and manpower to perform the DRM while potentially surpassing the crew size of the other mission packages. Operational risk 2 (O2) identifies concerns regarding the duration of the DRM. The maximum demonstrated at sea duration period for LCS-1 is approximately 21 days. The DRM may require the LCS to be in littoral waters for longer periods in order to monitor potential launches or incoming missiles. Operational risk 3 (O3) deals with the Level I+ survivability rating of the LCS. The Level I+ survivability rating is the lowest rating of a combat ship, meaning the LCS is not survivable in a combat environment. The DRM requires the LCS to hover in littoral waters where it will most likely be immersed in a combat environment. Operational risk 4 (O4) deals with the operational readiness of the LCS due to insufficient configuration management and product road mapping. Due to the schedule constraints of the project, the alternatives chosen for the LCS mission package will be modified COTS equipment limiting the configuration management and product road mapping of the chosen equipment.

The programmatic/project risks identified center on the budget constraints, political roadblocks and the physical limitations the project may encounter. Program risk 1 (P1) is based off the congressional reports (O'Rourke, Sea-Based Ballistic Missile Defense—Background and Issues for Congress, 2009) where the LCS is criticized on mission effectiveness and the potential of reducing the planned fleet of 55. Reduction or even cancellation of the fleet will place the LCS BMD mission package project in jeopardy. The LCS will not be able to support the mission package proposal due to resource constraints. Program risk 2 (P2) deals with cost deviation due to the use of new technology or the modification of COTS items in order for them to integrate onto the LCS frame. Program risk 3 (P3) deals with the integration of BMD capable missiles onto the LCS frame. The BMD missiles require vertical launching systems that usually are ground based or on a larger ship frame, integrating them on to the LCS may cause structural damage to the frame. Program risk 4 (P4) addresses the political risks when operating in the littoral waters of adversaries or friendly/neutral nations. Agreements must be set forward with friendly nations, or the LCS must be able to withstand a combat environment and or political pressures in non-friendly waters.

The technical risks identified deal with the integration and interoperability of equipment and the technical limitations that may be encountered when integrating into the LCS framework. Technical risk 1 (T1) focuses on the technical maturity of the LCS. The LCS is still being vetted as the two variants are still under evaluation. Underperformance of the LCS (not meeting expected requirements) may hinder the LCS in accomplishing the DRM. Technical risk 2 (T2) pertains to the use of higher powered radars for the monitoring, detection and tracking of ballistic missiles. The higher powered radars require higher voltages and current that the LCS framework cannot provide. Technical risk 3 (T3) deals with the integration and interoperability of LCS and the mission package with the BMD systems. Technical risk 4 (T4) describes the issue of using COTS items for the mission package. As mentioned due to schedule constraints COTS items will be used to make up the mission package. The COTS items will require modification that may not be attainable in order to perform the mission. Technical risk 5 (T5) reflects the acquisition of a BMD capable radar. The limited pool of BMD capable COTS radars poses a risk on the feasibility of finding a compatible radar for the LCS sea frame. Technical risk 6 (T6) concerns the systems of systems concept as the LCS will be integrated into the worldwide BMD system, where data sharing will occur among domestic and foreign systems and pose information security risks.

OPERATIONAL RISKS	
O1	The crew size required for BMD operations may increase to a level unsupported by the LCS.
O2	The duration of BMD missions may surpass the at sea capability of the LCS.
O3	The Level I+ survivability capabilities of the LCS limit its ability to handle threats which could affect BMD mission success.
O4	Insufficient Configuration Management and Product road mapping may impede the ability to perform future technology refreshes on time and per budget, impacting operational readiness of the LCS fleet.
PROGRAM/PROJECT RISKS	
P1	Due to budget constraints and the criticism facing the LCS the amount of ships may be reduced and or even canceled putting the project in jeopardy.
P2	Cost deviation risks may be incurred by the design due to the use of new technology (radars, modified missile launchers, BMD communications)
P3	The use of BMD missile launchers on the LCS platform may cause structural damage to the LCS.
P4	LCS platforms in the littoral waters of potential adversaries or friendly nations may be interpreted as a declaration of war or violation of territorial waters.
TECHNICAL RISKS	
T1	The use of the LCS platforms to perform our missions may not be feasible as the technical maturity of the LCS vessel may impact performance. The LCS platform is essentially still being vetted.
T2	Using higher power radars for tracking on the LCS may exceed available power.
T3	Interoperability and integration of the LCS platform with BMD systems may not be fully achieved.
T4	COTS equipment may have to be modified to fit on the LCS platform imposing a technical risk of integration.
T5	Acquisition of a BMD capable radar for scanning, detection and tracking of short to medium range ballistic missiles may not be feasible.
T6	The integration of the LCS platform with foreign BMD systems may incur information security risks.

Table 8: Identified Risks

C. RISK CONSEQUENCE

A standardized consequence metric was used for the qualitative scoring of each risk. Risk Consequences categories provided a qualitative measure of the worst possible consequence resulting from design inadequacies, environmental conditions, procedural deficiencies, system, subsystem, or component failure. These qualitative risk consequence metrics are shown in Table 9. The metric was scored with values from one (1) to five (5). A value of one (1) was considered to be of negligible impact and was not determined to be detrimental to the mission objective. A value of five (5) was considered as a catastrophic impact to the mission objective via effects on personnel, project, environmental or systems/equipment. The consequence of each risk was determined using researched data and project team discussions.

Description/ Category	Personnel Injury or Illness Effects	Project Impacts	Environmental Effects	System/ Equipment Effects
Catastrophic 5	Death or permanent disability	Failure to deliver on time and on budget	Irreversible ecological damage and/or violation of official rule	Loss of system or other capital equipment. System fails to meet KPPs
Critical 4	Severe injury or partial disability	Failure to deliver on time or on budget	Reversible ecological damage and/or violation of official rule	Damage of system or other capital equipment. System could fail to meet requirements.
Nominal 3	Minor Injury	Schedule slip	Ecological damage that can be restored with no violation of official rule	Minor damage to system or other equipment
Marginal 2	No Injury	Recoverable schedule slip	Minimal ecological damage with no violation of official rule	Minimal damage to system or other equipment. Maintainability issue
Negligible 1	No Injury	No schedule or budget constraints	No ecological damage or violation of official rule	System exhibits minor nuisance level issue

Table 9: Risk Consequence Metric

D. RISK PROBABILITY

Risk probability level is the likelihood that associated risk will occur during project or system life cycle. The probability of occurrence of each of the identified risks was expressed qualitatively. The qualitative probability metrics was scored with values from one (1) to five (5). Value one (1) represents the probability of occurrence as being improbable with a less than 20% chance of occurrence and value five (5) represents a frequent occurrence with a probability of occurrence equal or greater than 80%. The qualitative probability metrics levels and their characteristics can be seen in Table 10.

The probability of occurrence for each of the risks was estimated through research of public information, historical data of the LCS, stakeholder input and discussion among the project team. Value-oriented comparative technique was used among the available data to estimate the likelihood of the risks occurring.

Description	Level	Metrics Rationale
Frequent	5	Probability of occurrence $\geq .8$ in project or product life cycle
Probable	4	Probability of occurrence $\geq .6$ in project or product life cycle
Occasional	3	Probability of occurrence $\geq .4$ in project or product life cycle
Remote	2	Probability of occurrence $\geq .2$ in project or product life cycle
Improbable	1	Probability of occurrence $\leq .2$ in project or product life cycle

Table 10: Risk Probability Metrics

E. RISK REGISTER

With all the active risks identified and the qualitative rating system established, the risks were tabulated and scored for probability of occurrence and consequence impact. A standard 5 by 5 Assessment Risk Matrix was used to multiply the qualitative risk scores, establish the overall score of each risk, and determine the overall probability of the risk coming to fruition. The active risks where plotted on the Risk Assessment Matrix as seen in Figure 13.

A majority of the risk items identified over the course of the project were assessed as medium-level risks. The medium risk items include: 1) Operational Risk O2 concerning duration of the design reference mission, which may exceed the at sea duration capability of the LCS; 2) Programmatic Risk P1 where the number of LCS ships produced can be reduced and or cancelled affecting mission supportability; and 3) Programmatic Risk P2 which identifies the potential of cost overruns due to the use of new technology implemented in the BMDS capable LCS mission package. The remainder of the medium risk items is shown in Figure 13.

The high risk items identified were Operational Risks O1 and O3. Operational Risk O1 identifies the potential increase in crew size to a level not supported by the LCS platform in order for design reference mission success. Operational Risk O3 discusses the Level 1+ survivability rating of the LCS. The Level 1+ survivability rating is just above the lowest survivability rating for a Navy vessel. The low survivability could potentially impact mission success and the ability to counter threats faced the A2/AD environment.

The identified low risk items were the use of high power radars for tracking on the LCS platform (T2), interoperability and integration of the LCS platform and BMD system (T3), and integration of the LCS platform with foreign BMD system (T6). Technical risks T2 and T3 were quantified as low risk items because of the established BMDS architecture for integration. There are many years of experience among the wide range of international, governmental and private industry on the integration of ballistic missile defense systems. The experience and lessons learned can be leveraged by the LCS project.

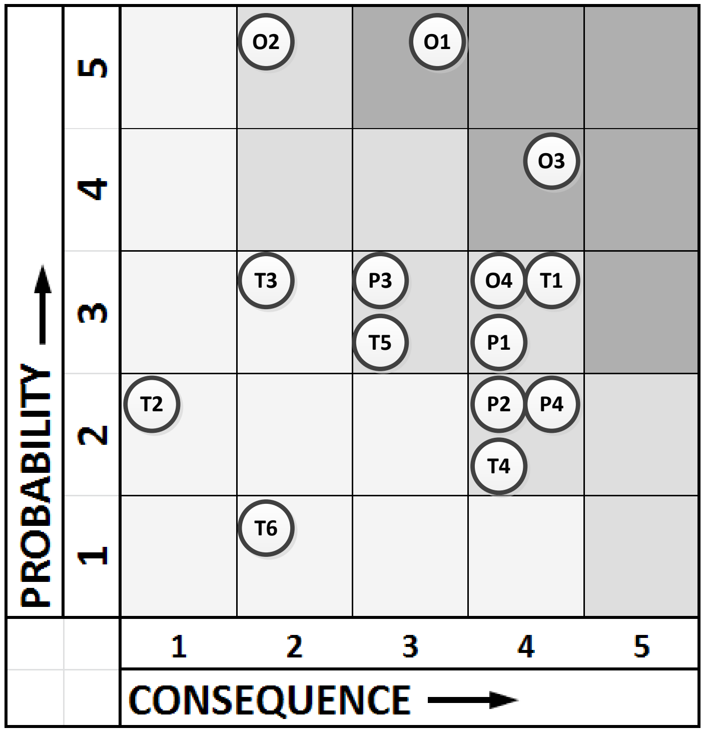


Figure 13: Risk Assessment Diagram

F. RISK HANDLING PLAN

A risk handling plan was developed to evaluate the risks on what options were most viable based on the probability of occurrence and impact. The handling plan was used to mitigate the risks to acceptable levels of project tolerance. For each risk, the following handling options were selected:

- **Control**: Create mitigation and/or contingency plans to handle the risk.
- **Assume:** Mitigation costs are unjustifiable and the impacts bearable to the project, so the risk is ignored.
- **Avoid**: The risk is avoided by redesign or by adopting an alternative approach.
- **Transfer:** Transfer of risk from:
    - Subcontract to supplier.
    - Renegotiate KPP thresholds, requirements, and budget/price.

Although the majority of the identified risks were in the low to medium risk category, they all possess high impact scores as seen in Appendix D. System Design Risks. The realization of any of the risks could hinder the success of the project. In order to mitigate the potential impact of any of the risks, it was determined by the team that all the risks were going to be handled using the control option of the risk handling plan. The control option was used to create mitigation plans to handle each risk.

G. RISK HANDLING PLAN

The identified risks were actively mitigated to eliminate or reduce probability of occurrence and consequence. Simulation techniques were heavily relied upon to predictively assess the ability of each alternative option in meeting mission success when operationally stressed against DRM scenarios. In addition, the systems within these simulations were characterized with best available public domain information and requirements to enable assessment of BMD system of interest in the DRM operational environment as realistically as possible. Throughout the project, several different steps were used to find the most viable mitigation strategy. The evaluation steps were:

- Dual track of alternate solutions and selection as knowledge improved.
- Creative avoidance, redefinition of CONOPS and evolutionary acquisition.
- Plan and re-plan until final mitigation strategy was developed.

For each of the identified risks, a risk mitigation strategy was developed and monitored as the simulation results were gathered and information was collected and reviewed. The risk mitigation strategies for each of the risks along with the qualitative rating, and risk category can be seen in Appendix D. System Design Risks.

The mitigation strategy developed for high risk item O1 is to perform a detailed source analysis and find areas where automation can be maximized while not violating mission effectiveness. An example of such a risk is leveraging existing crew resources as best as possible with the integration of the mission package. For high risk item O2, the mitigation strategy developed is to assess and review survivability of the LCS against BMD threats and the potential combat environment of the DRM. This evaluation relied heavily on the simulation and will be discussed in the modeling and simulation section. The mitigation strategy of the medium and low risk items are provided in Appendix D as mentioned earlier.

X. MODELING AND SIMULATION

An expected performance model is needed to effectively establish system requirements, measure currently fielded solution capabilities, and evaluate proposed system designs. The ExtendSim suite from Imagine That, Inc. was used for its powerful discrete event modeling capability. The modeling and simulation effort was divided into three areas:

1. Evaluation of currently fielded solutions against DRM.
2. Definition of System MOEs.
3. Evaluation of proposed solution performance.

This is an unclassified report. Limited empirical data describing sensor and ballistic missile interception performance is available via the public domain. Using only open source information available, assumptions were made based on the performance of the currently fielded solution. The alternate system options can then be compared to that of the base line fielded options by applicable parameters. For example, it was assumed that the Aegis System would have a certain performance when faced with the challenges of our Design Reference Mission (DRM).

Open source information was used to bolster the accuracy of the allocated subsystem performance (i.e. Probability of Kill). To compare alternative system options against this reference baseline, key parameters that were available open source were heavily utilized. The model outputs, consequently, are only as accurate as the assumptions used and accuracy of the open source information provided therein. Therefore, it is a general understanding that the modeling outputs will not exactly represent real system performance. The process was only intended to allow for an educated comparison of currently fielded solutions against that of proposed alternative LCS based systems. The results could be easily be reevaluated if given access to additional or more accurate information.

To evaluate currently fielded solutions against our proposed DRM, threat analyses that had been performed for similar defense posture were utilized. A Report to Congress called *Theater Missile Defense Architecture - Options for the Asia-Pacific Region* provided the basis for a layered Ballistic Missile approach. (O'Rourke, Sea-Based Ballistic Missile Defense—Background and Issues for Congress, 2009)

A. MODEL DESCRIPTION

The ballistic missile defense mission can be modeled as a series of discrete events. These iterations are a series of Bernoulli Trials. The trial flow can be seen in Figure 14.

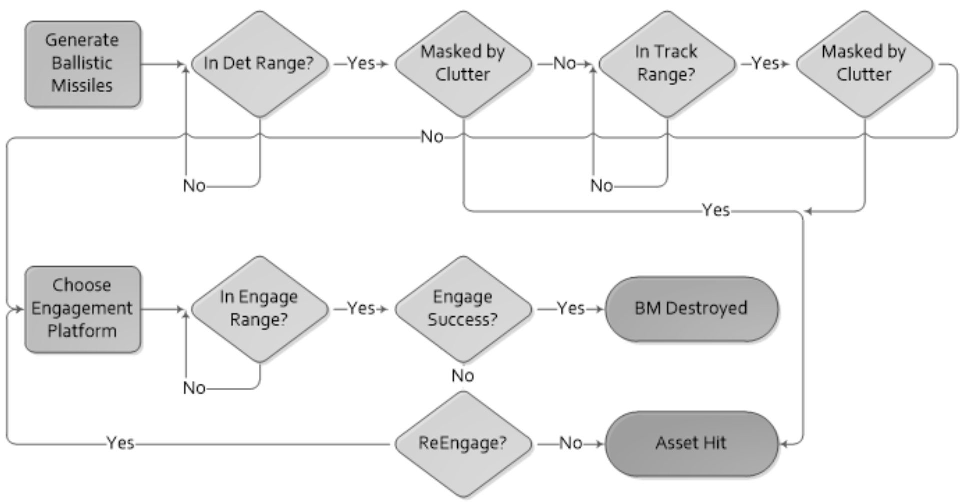


Figure 14: Simulation Process Flow

Within the model, the mathematic position of the detection platform is established using Cartesian coordinates. The threat range to the detection platform is a key input requirement as ballistic missiles followed their flight path to the high value target protected by the BMD system. The following equation was used to solve for ballistic missile range from detection platform.

$$\boldsymbol{Detect_{Effect}} = \sqrt{\begin{matrix}\left(\boldsymbol{Init_{X_{Range}}} - \boldsymbol{Det_{XOffset}} - \left(\boldsymbol{Vel_X} \times (\boldsymbol{Time_{Current}} - \boldsymbol{BM_{Genesis}})\right)\right)^{\mathbf{2}} \\ + \\ \left(\boldsymbol{Initial_{YRange}} - \boldsymbol{Det_{YOffset}} - \left(\boldsymbol{Vel_Y} \times (\boldsymbol{Time_{Current}} - \boldsymbol{BM_{Genesis}})\right)\right)^{\mathbf{2}}\end{matrix}}$$

where:

- $Init_{XRange}$ is the initial x Cartesian range of the ballistic missile.
- $Det_{xOffset}$ is the x offset of detection platform from the high value target.
- Vel_x is the x vector velocity of the ballistic missile.
- $Time_{Curremt}$ is the current simulation time.
- $BM_{Genesis}$ is the simulation time the Ballistic missile is launched.
- $Init_{YRange}$ is the initial y Cartesian range of the ballistic missile.
- $Det_{yOffset}$ is the y offset of detection platform from the high value target.
- Vel_y is the y vector velocity of the ballistic missile.

With the range of the ballistic missile relative to the BMD detection platform known, the maximum detection range was calculated. Little open source information is available for maximum radar detection range for the systems evaluated. John A. Robinson states that the AN/SPY-1D radar "can track golf ball-sized targets at ranges in excess of 165 kilometers" (Robinson, 2004).

Given the radar cross section (RCS) of a golf ball (calculated as a simple metallic sphere), it was determined that this would correspond to a maximum detection range beyond the Launch Site range for a ballistic missile with the RCS of those included in the salvo of the DRM. A decision was made to limit the maximum detection range of the Aegis SPY-1 to the range from the detection platform to the launch sites. With this value established, a mathematical relationship was developed to parametrically compare other radar systems to the SPY-1 radar based on average radar power. The maximum detection range can be seen in Figure 15.

$$R_{Det} = RCS \times (\frac{P_{Tx}}{P_{TAegis}})$$

where:

- RCS equals Radar Cross Section of missile being detected.
- P_{Tx} equals average power transmitted for radar under evaluation.
- P_{TAegis} equals average power transmitted for Aegis AN/SPY-1.

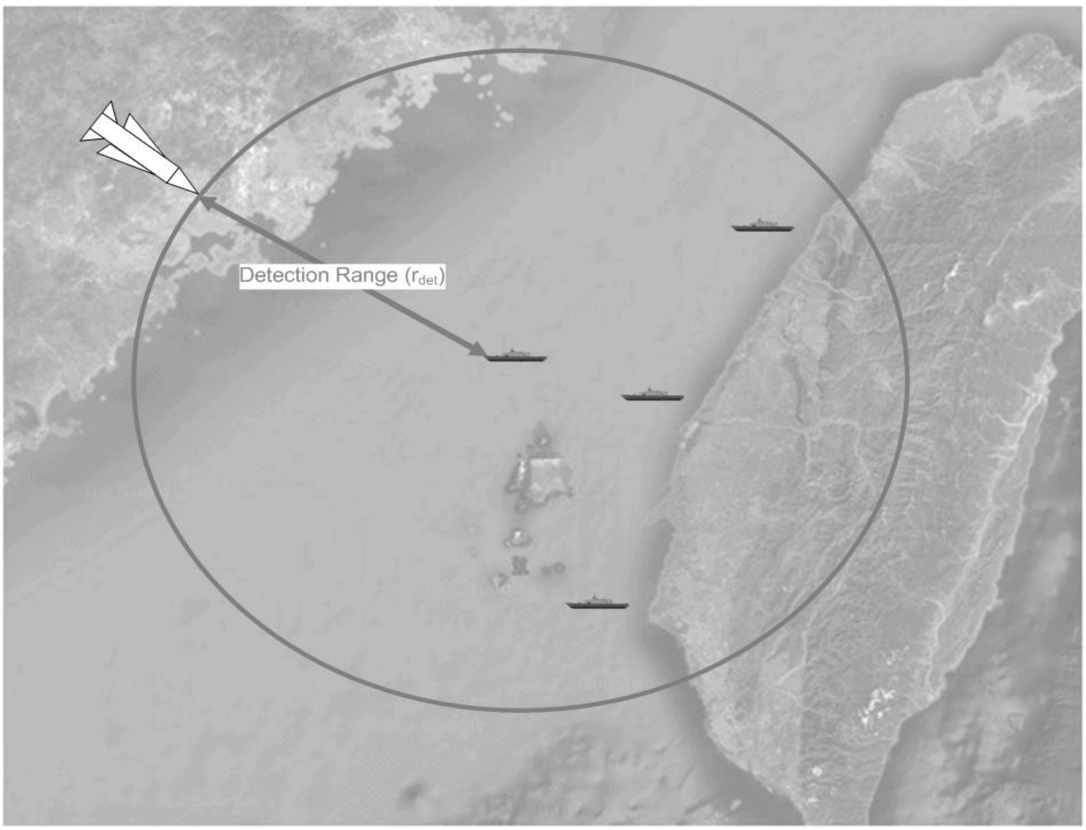


Figure 15: Range Detection (R_{det})

The LCS platform has sea frame constraints that could prevent it from operating as a standalone BMD solution. The model needs the flexibility to account for a System of

Systems approach. To provide this flexibility, the sensors providing the Detection capability needed to be able to be divorced from those providing tracking capability. This would allow detection and tracking to be both geographically and functionally independently located. The $Track_{Effect}$ equation was used to solve for ballistic missile range from the tracking platform.

$$\boldsymbol{Track_{Effect}} = \sqrt{\begin{matrix}\left(\boldsymbol{Init_{X_{Range}}} - \boldsymbol{Track_{XOffset}} - \left(\boldsymbol{Vel_X} \times (\boldsymbol{Time_{Current}} - \boldsymbol{BM_{Genesis}})\right)\right)^{\mathbf{2}} \\ + \\ \left(\boldsymbol{Initial_{YRange}} - \boldsymbol{Track_{YOffset}} - \left(\boldsymbol{Vel_Y} \times (\boldsymbol{Time_{Current}} - \boldsymbol{BM_{Genesis}})\right)\right)^{\mathbf{2}}\end{matrix}}$$

where:

- $Init_{XRange}$ is the initial x Cartesian range of the ballistic missile.
- $Track_{xOffset}$ is the x offset of the tracking platform from the high value target.
- Vel_x is the x vector velocity of the ballistic missile.
- $Time_{Current}$ is the current simulation time.
- $BM_{Genesis}$ is the simulation time the Ballistic missile is launched.
- $Init_{YRange}$ is the initial y Cartesian range of the ballistic missile.
- $Track_{yOffset}$ is the y offset of Track platform from the high value target.
- Vel_y is the y vector velocity of the ballistic missile.

With range of the ballistic missile relative to the BMD tracking platform known, the maximum tracking range is the next calculation required. The same assumptions and comparative formula were used to establish a baseline on the maximum tracking range as were used for maximum detection range. The radar track equation solves for maximum tracking range, which can be seen in Figure 16.

$$R_{Track} = RCS \times (\frac{P_{Tx}}{P_{TAegis}})$$

where:

- RCS equals Radar Cross Section of missile being detected.
- P_{Tx} equals average power transmitted for radar under evaluation.
- $P_{T\,Aegis}$ equals average power transmitted for Aegis AN/SPY-1.

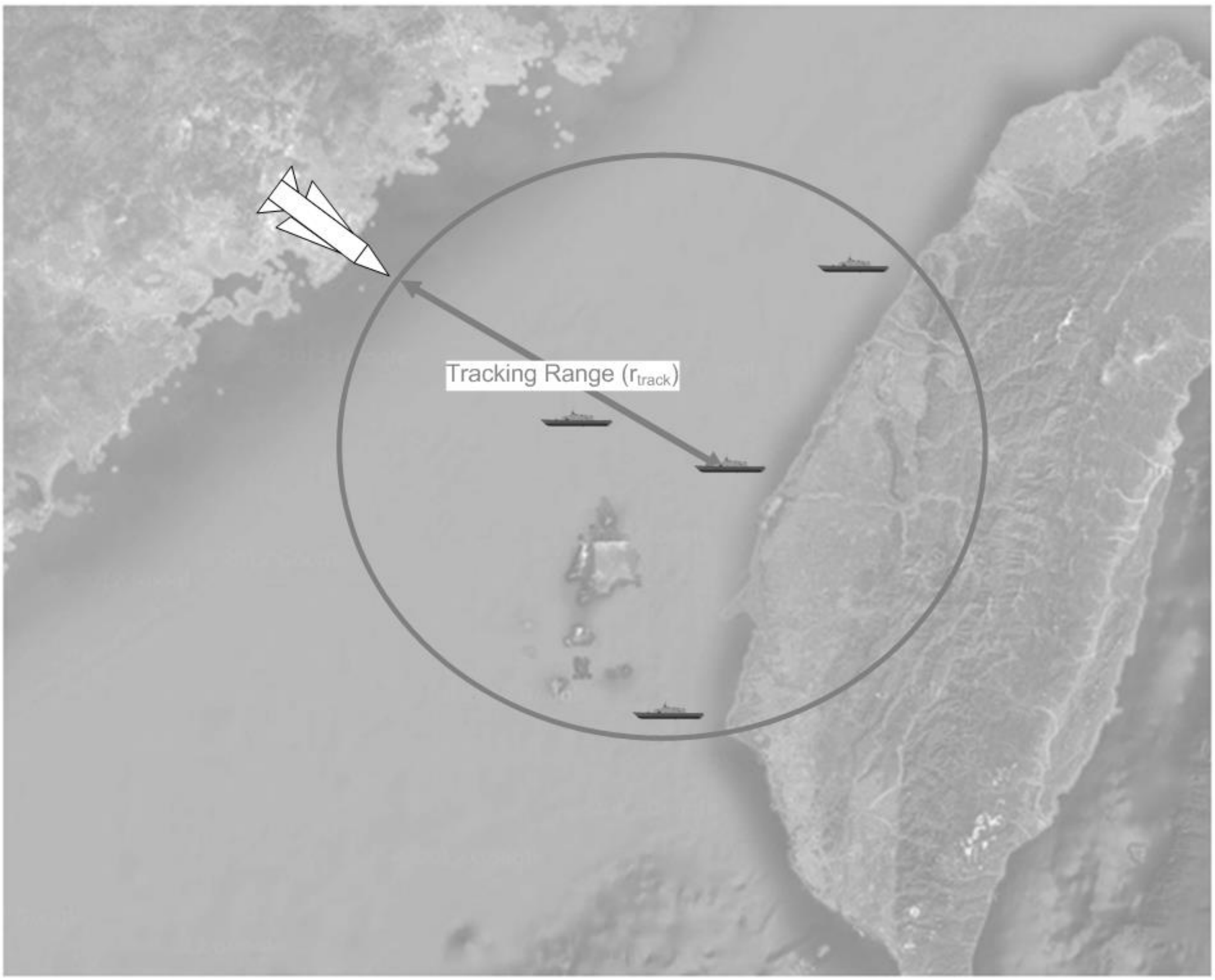


Figure 16: Maximum Tracking Range

B. CLUTTER

Radar returns that interfere with the target signal returns are termed clutter. The geographic and population phenomenon of the world make radar clutter more predominate in the littorals. The following are some of the reasons for higher clutter responses in or near littoral waterways (Sekine, Matsuo, & Mao, 1990):

- Waters interaction with coastlines in the form of waves
- Irregular land masses of coastlines
- Bird/Insect migration and massing
- Meteorological phenomenon
- Settlements
- Air Traffic

The design reference mission was selected based on an area that had representative clutter for the littoral BMD mission. The sea state, wind speed, precipitation, and cloud cover for the DRM region was estimated using data for the Gulf of Sidra (National Oceanographic and Atmospheric Association, 2013). The sea state was estimated on the Douglas Scale to be averaging a sea state 3 (Met Lab UK, 2013).

Meteorological Clutter Parameter	**Average For 5/01/12 thru 5/01/13**
Wave height	.79 Meters
Cloud cover	25% or Mostly clear
Wind speed	11 MPH
Precipitation	13% of Days

Table 11: DRM Meteorological Clutter Parameters

The historic meteorological and oceanographic (METOC) data listed in Table 11 does not have any high radar clutter drivers. The geography of the region primarily consists of desert terrain, which has little radar reflective response. No attempt was made to research bird or insect migration or massing for the region. The region has a high incidence of civilian air traffic with the area surrounding the Gulf of Sidra having 144 airports, 64 of those being paved (CIA World Fact Book, 2012). The large number of airports indicates that discerning ballistic missile targets from civilian and military air traffic will be difficult.

Sekine and Yuhai suggest using a Weibull distribution to model radar clutter. The ExtendSim suite allows a random number set to be generated based on a Weibull distribution. The factors affecting radar clutter were used to parametrically choose a masking point on the stochastic Weibull distribution.

To model clutter a Signal to Clutter (S/C) ratio needed to be established. Open source information on true radar power, transmit gain, and receive gain is not available for most radar systems. The DRM was intended to be a radar stressing environment. Given this stressful environment the S/C was set such that the Aegis AN/SPY-1 radar would fail to detect 7% of incoming ballistic missiles due to clutter. This assumption allowed for a parametric comparison of other radars simulated based on their respective power and band.

Radar power and band provided variables for the masking point that were adjusted to enable modeling of the system. The Aegis AN/SPY-1B variant has a 58 kW average power is operating in the S-band as modeled by the following relationship (Friedman, 2006).

$$\frac{S}{C} = \frac{P_t \, CRL_{bs}}{\sigma^0 A_c}$$

where:

- P_t is the power transmitted.
- CR is clutter reduction techniques.
- L_{bs} is radar beam shape loss.
- σ_0 is clutter reflectivity.
- A_c is clutter reflective area (Curry, 2012).

No access to information on clutter reduction algorithms or radar beam shape is available for this study. In addition to this consideration, an assumption was made that clutter, area and reflectivity remains constant. Subsequently, the equation can be further simplified.

$$\frac{S}{C} = (P_t)/\lambda_p$$

where:

- λ_p is the proportion the wavelength of radar emission.

Sekine and Yuhai state that when compared to the 9.1 cm S-Band wavelength, this proportion can be found using the below relationship and values for common bands are shown in Figure 18: Proportional wavelength reflectivity offset. The relative masking point for the standard Aegis AN/SPY-1 radar is modeled by Figure 17.

$$\lambda_p = \frac{\lambda}{\lambda_s}$$

$$\lambda_s = 9.1\ cm$$

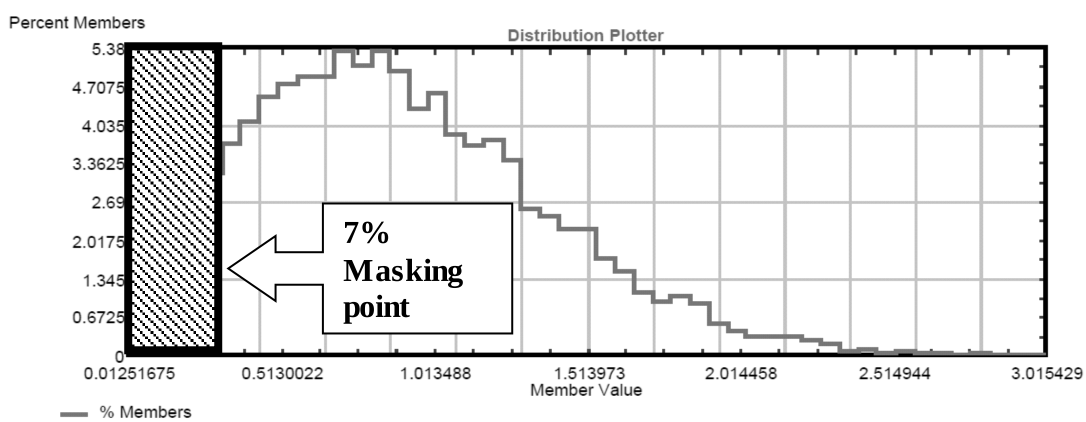


Figure 17: Masking Point for Aegis AN/SPY-1

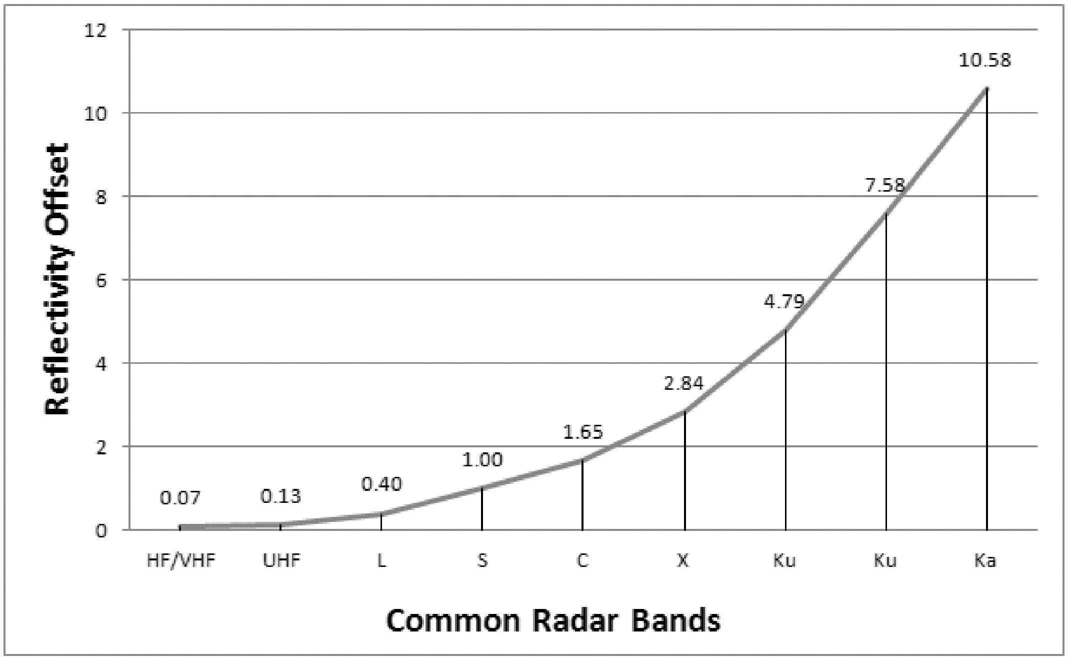


Figure 18: Proportional wavelength reflectivity offset

C. CURRENTLY FIELDED SOLUTION EVALUATION

Despite restricted access to information on the true subsystem and component performance, the model established a means of evaluating proposed system projected performance. The LCS ballistic missile defense platform is required to have performance greater than or equal to that of the ready to deploy solutions available.

The centerpiece of the U.S. ballistic missile defense arsenal is the Aegis warship armed with the Standard Missile 3 (SM-3). This system has been actively been conducting anti-ballistic missile patrols as part of the European Phased Adaptive Approach (EPAA) since its initial operating capability (IOC) in April 2011 (National Defense Industrial Association, 2011).

The Aegis platform is multi-role, and the growth of the BMD mission is impacting its ability to perform its complete mission set (O'Rourke, Sea-Based Ballistic

Missile Defense—Background and Issues for Congress, 2009). Theater based ballistic missiles (TBBMs) account for greater than 90% percentage of the world's overall BM population. The Aegis system uses the SM-3 as its primary interceptor capability; however, the SM-3 does not have a proven capability of intercepting endo-atmospheric traveling missiles. (O'Rourke, 2013)

An LCS based solution needs to address the TBBM problem and perform BMD in the littorals against a BM threat composed of both endo- and exo-atmospheric missiles at least as well as the Aegis platform. As a comparison, modeling and simulation would be used to estimate the performance of the Aegis platform when challenged with the same DRM parameters.

O'Rourke suggests that two Aegis BMD capable ships would make up the CONOPS for the Littoral TBBM defense posture (i.e. Korea). Because of the limitations of the SM-3 against endo-atmospheric targets, O'Rourke recommends that the Aegis be supplemented by either a THAAD system or PAC3 variant. With the current political climate and the general paradigm against committing to a "boots on the ground" solution, a superior response is one that does not require troops of any number to be stationed on a threatened country or region.

The advanced Aegis combat system allows for nearly all resources to be shared; detection, tracking, target illumination, and Launch-on-Remote (LOR) or Engage-on-Remote (EOR) capabilities. This system of systems approach was included in the assumptions used for the simulation. The target illumination and engagement assignments were modeled as a resource pool. A primary platform for these functions was selected based on geographic location relative to the threat, if the resource was busy than an alternative platform was used.

The Aegis/SM-3 BMD capability is frequently tested. MDA advertises that the SM-3 has had 19 successful interceptions in 22 attempts. It has been assumed that the test record represents a reasonable Probability of Kill (P_K) expectation to use for the simulation.

1. Aegis Results

The two Aegis platforms were simulated against the DRM mission for thirty runs. The summary output of the simulation was the number of times that the high value asset trying to be protected is hit. This output is provided in Figure 19.

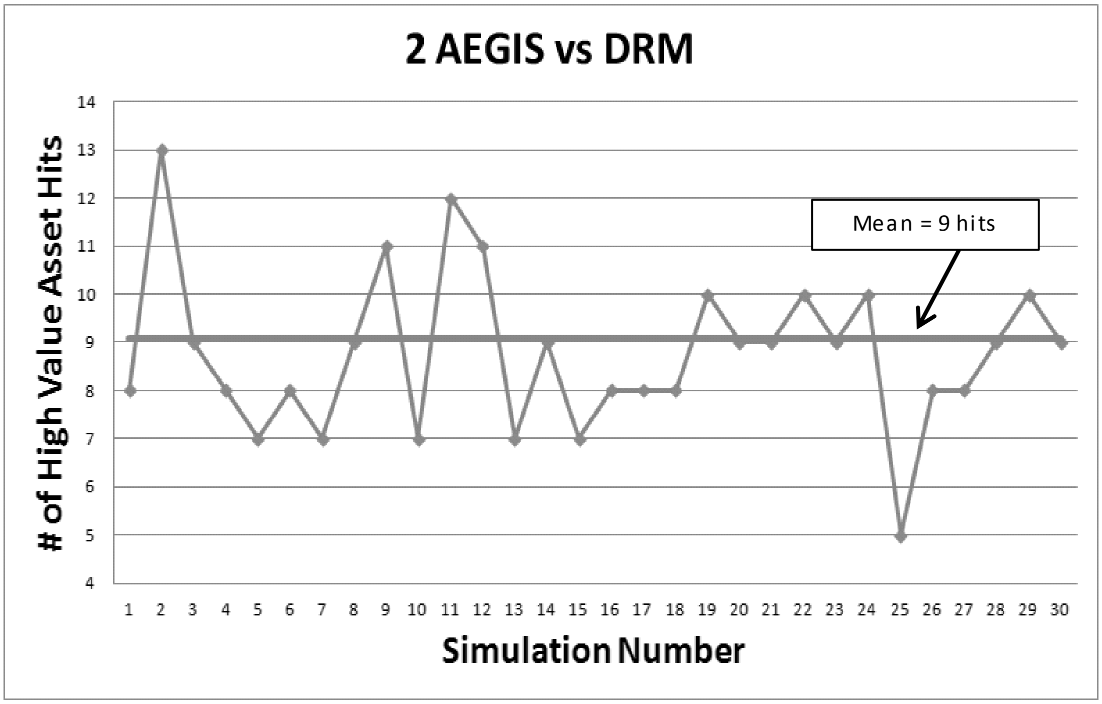


Figure 19: Simulation results for 2 Aegis against DRM

It should be noted that the DRM salvo consisted of 24 total missiles of which 10 had an endo-atmospheric flight path. Without the capability to make endo-atmospheric intercepts the SM-3 will allow all the successful, no early-flight failure or mid-flight failure, to hit the high value target.

The simulation output was converted to probability of raid annihilation (P_{ra}) (Green & Johnson, 2002). P_{ra} was adopted as one of the MOE for the LCS-based solution.

$$P_{ra} = P_{det} \times P_{Control} \times P_{Engage}$$

where:

P_{det}=Probability of Detection.

$P_{Control}$=Probability of Control.

P_{Engage}=Probability of Successful Engagement.

The resulting P_{ra} for the two BMD capable Aegis platforms was 0.55. This formed the basis for the system MOE; in that the LCS shall have a P_{ra} greater than or equal to 0.55.

2. PAC3

To validate the results found with the Aegis results a land-based, shorter range solution was simulated. The Patriot Advanced Capability 3 (PAC3) was chosen as its capabilities had a fair amount of open source information available. Based on the advertised capabilities to intercept either an endo-atmospheric or exo-atmospheric traveling ballistic missile, the PAC3 is anticipated to have a superior P_{ra}. The simulation validated this hypothesis adding additional confidence in the model.

Two PAC3 batteries were modeled and they were geographically situated to maximize effectiveness. They were modeled as independent batteries with only detection data shared. Target illuminators utilization posed a problem as one battery could have a queue while the other was not being utilized.

3. PAC3 Results

The two PAC3 platforms were simulated against the DRM mission for thirty runs. The summary output of the simulation was the number of times that the targeted high-value asset is hit. This output can be seen it Figure 20. The resulting P_{ra} for the two PAC3 batteries was calculated at 0.64.

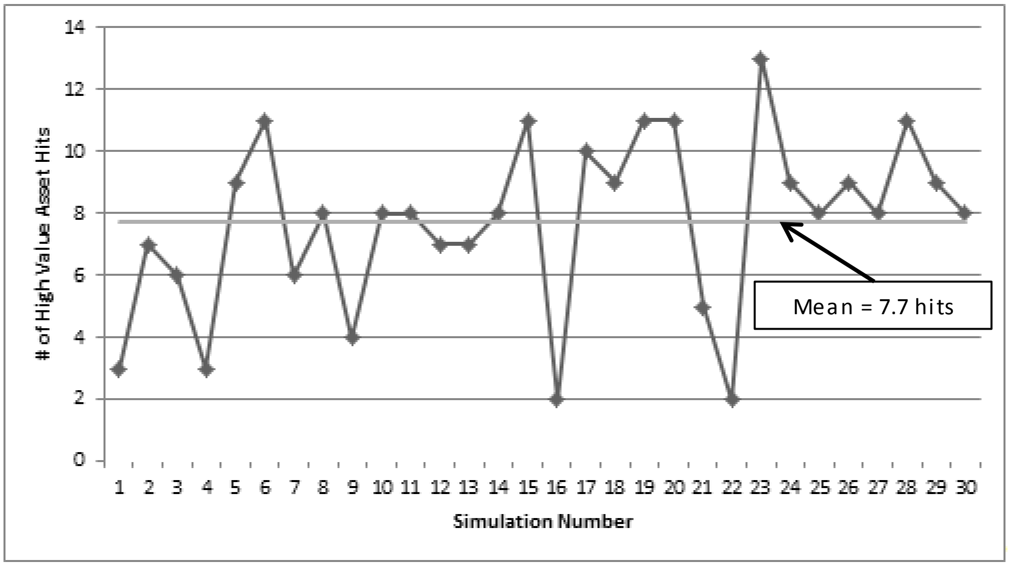


Figure 20: Simulation results for two PAC3 batteries against DRM

4. Layered Defense

In a report to Congress, the DoD suggests use of a layered approach to defend the Republic of Korea, Taiwan, and Japan from aggressor state ballistic missile attacks (Dept. of Defense, 1999). The universal elements recommended between all the defense spaces is the use of a sea based leg for upper tier defense and a land based component for the lower tier.

This multi layered approach is assumed to provide an effective counter for the Theater Missile Defense (TMD). To provide final accreditation to the model this layered approach was simulated. The Aegis ships are hypothesized to intercept the majority of the exo-atmospheric missiles and the PAC3 to intercept the endo-atmospheric missile. The PAC3 would then proceed to intercept the remaining Aegis leaked exo-atmospheric missiles. The platforms were modeled as a system of systems with cooperative engagement capability such that the PAC3 batteries benefited from the superior range of the Aegis SPY-1 radar for detection. As this system resembles those currently being employed as part of the Active Layered Theater Ballistic Missile Defense (ALTBMD) in the European region, the P_{ra} is assumed to indicate an effective scenario (Hendrickson, 2012).

5. Layered Defense Results

The layered defense was simulated against the DRM mission for thirty runs. The output of the summary output of the simulation was the number of times that the high value asset trying to be protected is hit. This output is shown in Figure 21. The resulting P_{ra} for the layered Ballistic defense posture was calculated as 0.94.

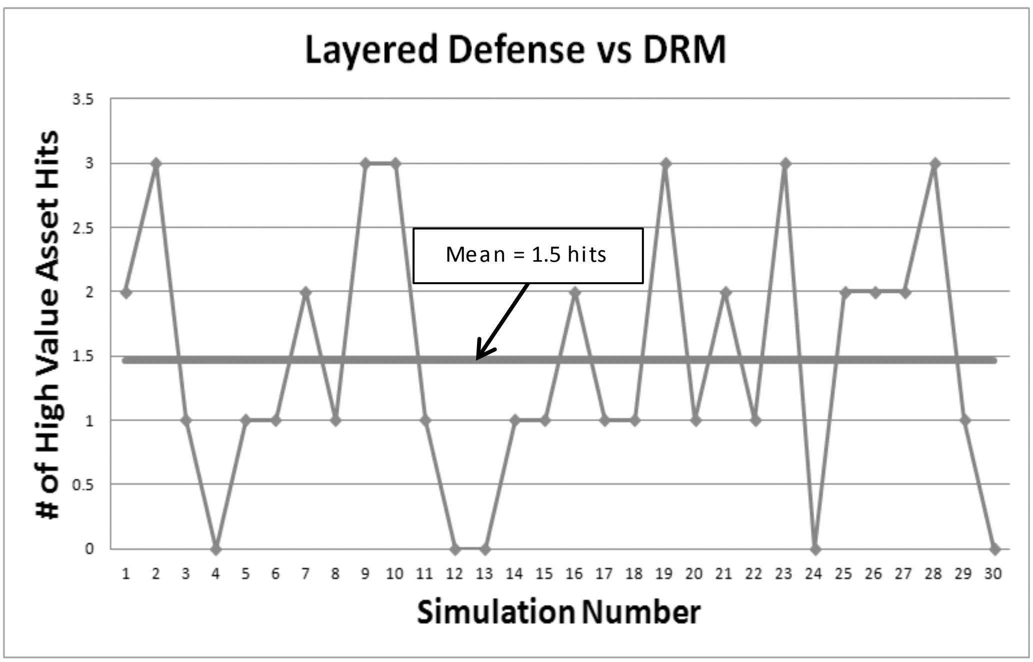


Figure 21: Layered Defense vs. DRM

6. Currently Fielded Solution Evaluation Conclusion

The Department of Defense defines modeling and simulation validation as "the process of determining the degree to which a model or simulation and its associated data are an accurate representation of the real world from the perspective of the intended uses of the model" (DODINST 5000.61). To represent expected real-world conditions, the simulation of currently fielded solutions was modeled and compared against performance assumptions. As previously noted, this is acknowledged not to be the most accurate means of validation; however, this study is constrained to only unclassified open source information.

Given the logical output of the simulation when the currently fielded solutions are challenged by the DRM, the model is considered to be representative to move forward with system design. Table 12 shows the comparison between expected and modeled.

System Simulated	**Expected P_{ra}**	**Simulated P_{ra}**
Two Aegis BMD Capable Platforms	Not great due to inability to engage endo-atmospheric missiles	0.55
Two PAC3 Batteries	Better than Aegis solution because of Endo/Exo-atmospheric capability	0.64
Layered (Aegis + PAC3)	Close to 1	0.94

Table 12: Validation Comparison

7. Design of Experiments

To establish a requirement band for key subsystems of the LCS BMD mission package, a design of experiments (DOE) was used. A series of informal sensitivity simulations were conducted to determine the factors that would be used for the DOE efforts. It was determined that the following would be used for the DOE:

- Range to detect ballistic missiles.
- Capability for both endo and exo-atmospheric intercepts.

- Range to engage.
- Probability of kill.

These four factors were assigned to either a high or low level grouping. These values were assigned based on research of BMD system and anti-air system subsystem/component performance. The associated levels for the four factors are shown in Table 13.

Factor	Low Level	High Level	Variable Designation
Range to Detect	30 km	800 km	X1
Endo/Exo-atmospheric	No	Yes	X2
Range to Engage	5 km	500 km	X3
P_K	0.2 km	0.9 km	X4

Table 13: DOE Factor Levels

A full factorial experiment was considered feasible as there were only 16 discreet permutations. These 16 permutations would establish the corners for the design space and are seen in Table 14. The 16 points were run on the model 30 times each. The output P_{ra} was averaged for the 30 runs to establish a simulated average P_{ra} for the 16 DOE points.

Point	Range Detect	Endo/Exo	Range Engage	P_K
1	-	-	-	-
2	+	-	-	-
3	-	+	-	-
4	-	-	+	-
5	-	-	-	+
6	+	+	-	-
7	+	-	+	-
8	+	-	-	+
9	-	+	+	-
10	-	+	-	+
11	-	-	+	+
12	+	+	+	+
13	-	+	+	+
14	+	-	+	+
15	+	+	-	+
16	+	+	+	-

Table 14: DOE Corner Values

A multi variant regression analysis was performed on the averaged data output. The regression analysis established a prediction formula.

$$P_{ra} = 6.55^{10^{-6}}(X1) + 0.465(X2) + 4.63^{10^{-4}}(X3) + 0.144(X4) + 0.023$$

where:

X1= Range to Detect

X2= Endo/Exo-atmospheric Capability

X3= Range to Engage

X4= P_K

The regression equation was used to predict the P_{ra} for the same 16 points used for the DOE. The results of this prediction can be seen in the normalized star plots of Figure 22, which exhibit a high degree of consistency between the simulated and predicted regression models. This is further reinforced by the regression analysis statistics R-Squared value of 0.89, indicating that 0.89 of the dependent variable, Pra, can be explained by the independent variables. The DOE regression results are presented in Table 15.

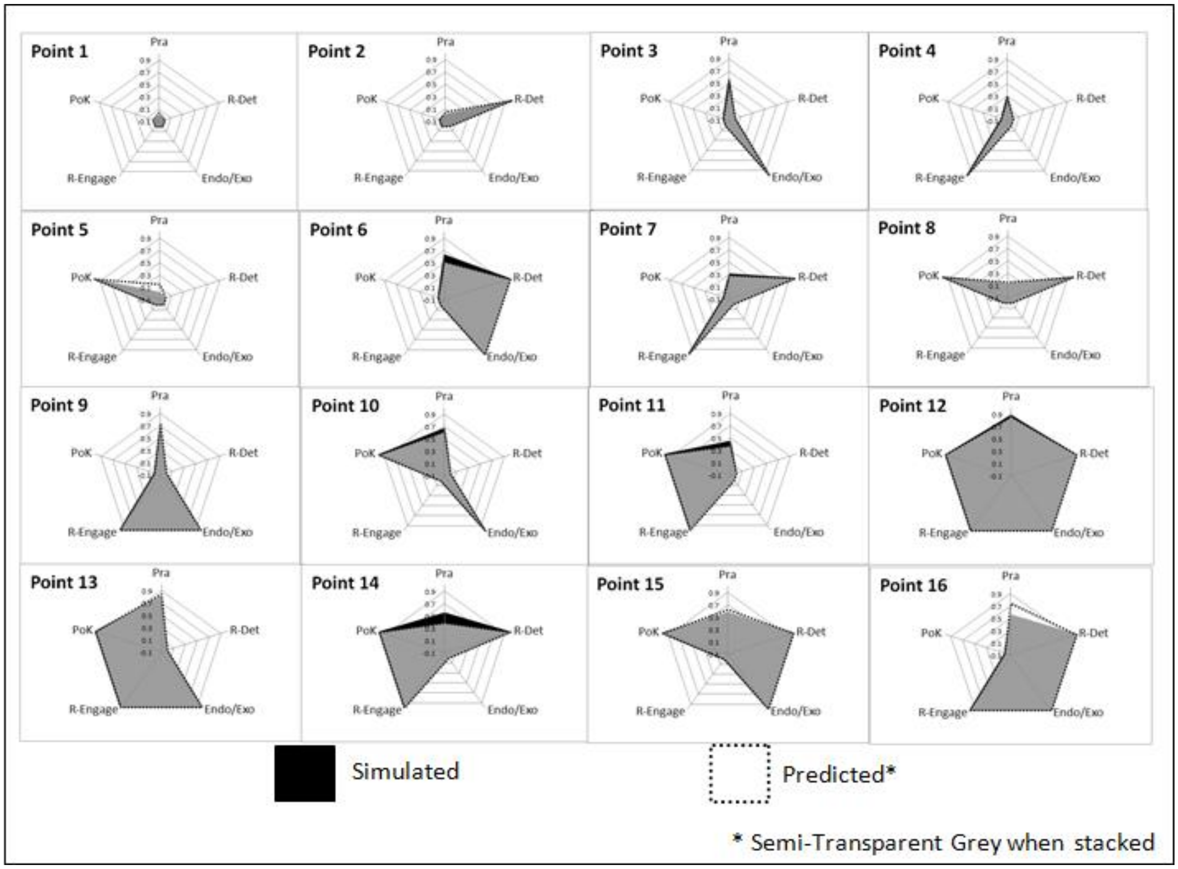


Figure 22: DOE Simulation vs. Regression Prediction Star Plots

	Intercept	R-Det	Endo/Exo	R-Engage	PoK	Intercept
Coefficients	0.0229	0.0000	0.4647	0.0005	0.1438	0.0229
Standard Error	0.0685	0.0001	0.0563	0.0001	0.0823	0.0685
t-Statistic	0.3336	0.0896	8.2614	4.0763	1.7472	0.3336
p-Value	0.7450	0.9302	0.0000	0.0018	0.1084	0.7450
Lower 5%	-0.1279	-0.0002	0.3409	0.0002	-0.0374	-0.1279
Upper 95%	0.1736	0.0002	0.5885	0.0007	0.3250	0.1736

Table 15: DOE Regression Results

The p-Value for only Endo/Exo atmospheric capability and the Maximum Range to Engage indicate statistical significance at 90% confidence or 0.10 alpha levels. This is further demonstrated in the tornado analysis of Figure 23.

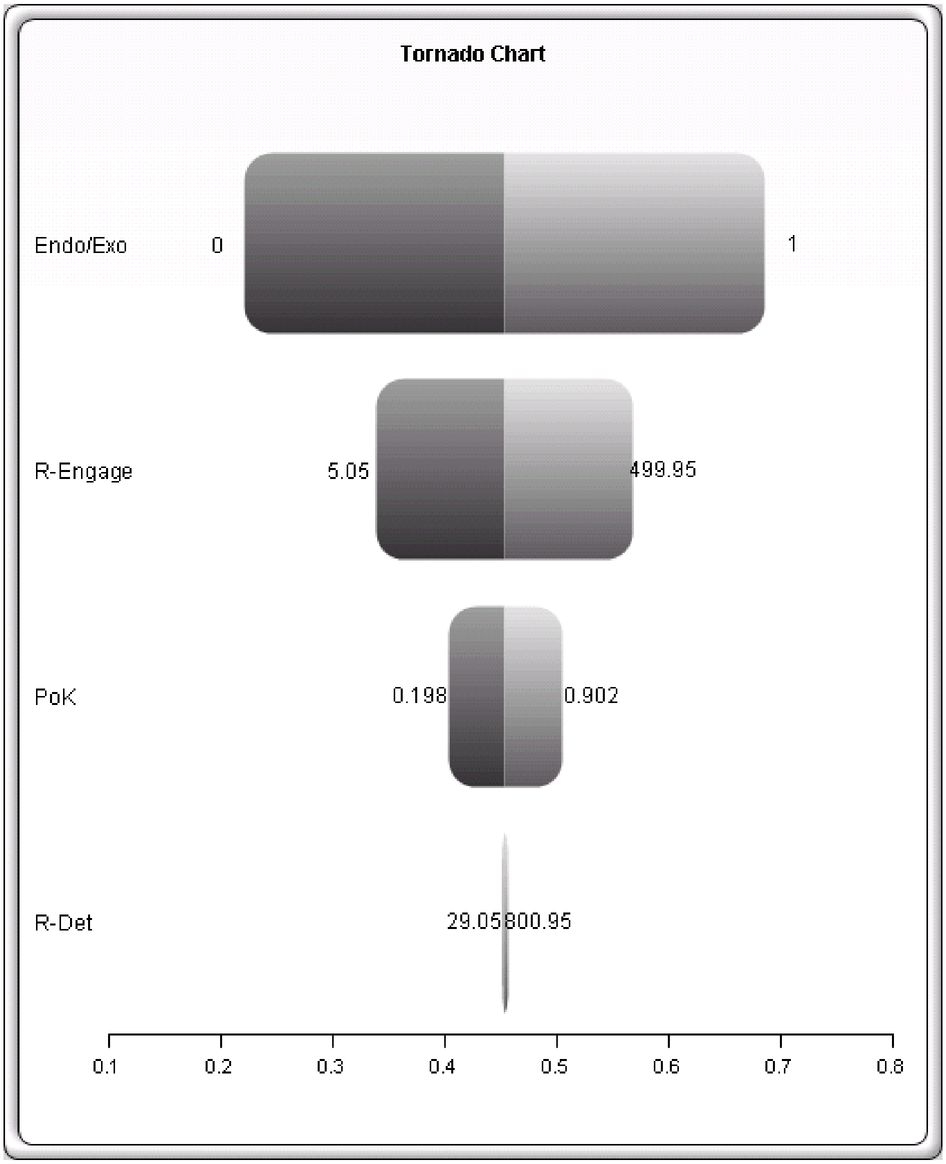


Figure 23: Tornado Analysis Output

The Tornado Analysis reinforces that the DOE regression is most sensitive to perturbations of the Endo/Exo atmospheric capability followed by the Range to Engage variable. Furthermore, the regression statistics and star plots substantiate that the regression prediction has a high degree of consistency with the modeled results. See

Appendix G. BMD Engagement Sequence for a detailed timeline of the BMD engagement process sequencing of events.

XI. ANALYSIS OF ALTERNATIVES

The analysis of [system] alternatives (AoA) was performed on two levels. First, research was conducted to identify candidate system components capable of meeting the requirements of the notional functional architecture. Second, models of these components were developed, grouped in representations of candidate physical architecture variants, and integrated into a larger BMD simulation, which enabled assessment of candidate BMD system performance against simulated missile attack conditions prescribed in the design reference mission. The subsequent "system of systems" analysis of variants, served as the basis for selection of the physical system architecture for the proposed BMD mission package.

The four main components of the functional architecture served as the primary focus of the component analysis of alternatives; detection, control, engagement (launch), and engagement (interception). For each case, a series of measures of effectiveness were translated into key performance parameters based on the overall system requirements. For each, thresholds were established to define how the analysis would be conducted (Figure 24).

	Cost C	Range Ra	Sensitivity Sn	Size Si	Reliability Re	Exportability E	Maintainability M	Availability Av	Survivability Su	Architecture Ar	BMD-Capable B	Sea-Based S	Probability of Kill Pk	Vertical Launcher L
Detection	✓	✓	✓	✓	✓	✓	✓	✓	✓	✗	✗	✗	✗	✗
Control	✓	✗	✗	✗	✗	✗	✗	✓	✗	✓	✓	✓	✗	✗
Engage (launch)	✓	✗	✗	✓	✗	✗	✗	✓	✗	✗	✗	✗	✗	✓
Engage (intercept)	✓	✓	✗	✓	✗	✗	✗	✗	✗	✗	✓	✓	✓	✗

Figure 24: Performance Criteria Assignment Matrix

Swing weights were developed to provide additional analysis criterion for each subsystem (Figure 25). The swing weight evaluation was conducted using the standard variance versus importance matrix where all criteria were assigned a value from 0–10. These values were then normalized to determine each criterion's overall weighted importance for use in the alternatives analysis.

Detection Swing Weight:

		Importance		
		High	Med	Low
Variation	High	Ra	Sn	E
	Med	Si	Re	Av
	Low	C	Su	M

		Importance		
		High	Med	Low
Variation	High	10	9	5
	Med	9	8	4
	Low	8	7	2

		Importance		
		High	Med	Low
Variation	High	0.2	0.1	0.1
	Med	0.1	0.1	0.1
	Low	0.1	0.1	0

Control Swing Weight:

		Importance		
		High	Med	Low
Variation	High	C		Av
	Med	B		
	Low	S	Ar	

		Importance		
		High	Med	Low
Variation	High	10		6
	Med	8		
	Low	6	5	

		Importance		
		High	Med	Low
Variation	High	0.3	0	0.2
	Med	0.2	0	0
	Low	0.2	0.1	0

Engage (launch) Swing Weight:

		Importance		
		High	Med	Low
Variation	High	Si	L	
	Med		Av	
	Low	C		

		Importance		
		High	Med	Low
Variation	High	10	7	
	Med		5	
	Low	8		

		Importance		
		High	Med	Low
Variation	High	0.3	0.2	0
	Med	0	0.2	0
	Low	0.3	0	0

Engage (intercept) Swing Weight:

		Importance		
		High	Med	Low
Variation	High	C	Pk	
	Med	Ra	Si	
	Low	B		

		Importance		
		High	Med	Low
Variation	High	10	8	
	Med	9	7	
	Low	8		

		Importance		
		High	Med	Low
Variation	High	0.2	0.2	0
	Med	0.2	0.2	0
	Low	0.2	0	0

Figure 25: Swing Weight Analysis

In order to determine the component pool, a morphological box (Appendix F. Morphological Box) was created to group all plausible system permutations. The system pool consisted of existing domestic systems, foreign systems, development projects, and the plausibility of creating a new system for this specific need.

A. COMPONENT ANALYSIS OF ALTERNATIVES

1. Detect

The detection analysis of alternatives focused on those systems that were considered to meet some or most of the mission requirements per the morphological box. Detection elements were analyzed primarily based on range, sensitivity, and physical size (per the swing weight analysis). In this case, cost was not considered a primary concern. The derived values are normalized by regression analysis to convert all values to a linear scale.

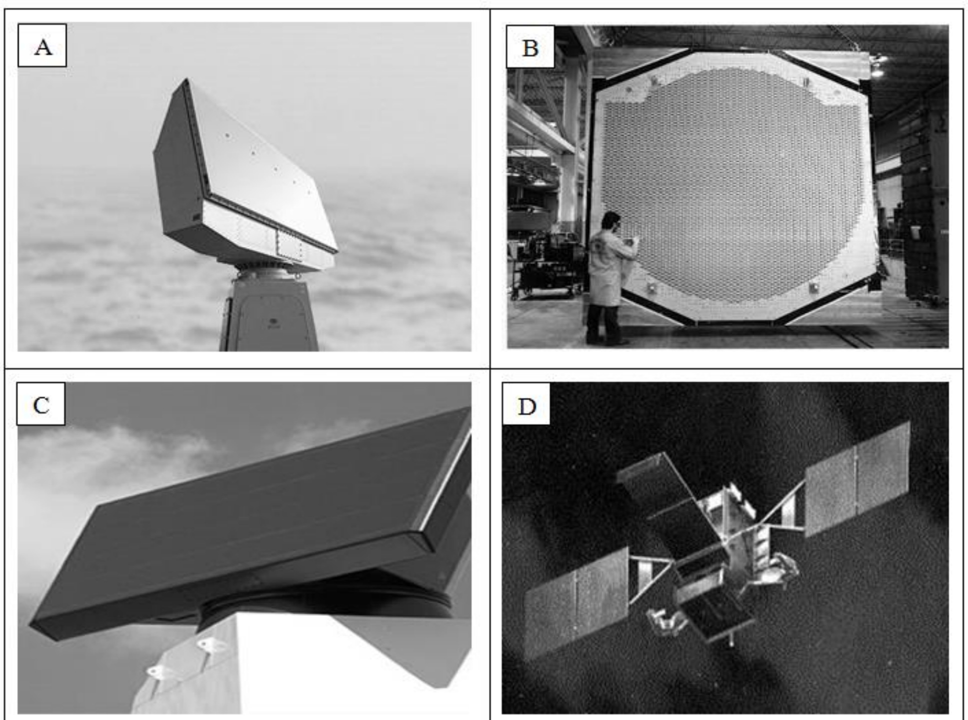
Overall, the THAAD, AMDR, and SPY-1F systems proved most suitable to the system architecture; however, nearly all alternatives were capable of meeting mission requirements (Figure 26). Selected images of the analyzed components can be seen in Figure 27

.

Detection Weighted Values

Evaluation Measure	Objective	Weight	TRS-3D	Sea Giraffe	SPY-1 F(V)	AMDR	AN/TPY-2	AN/MPQ-53	AN/TPS-80	SR/MFCR	SIBRS	SMART-L	Iron Dome
Cost	Min	0.129	0.10	0.10	0.12	0.13	0.06	0.13	0.13	0.00	0.13	0.13	0.06
Range	Max	0.1613	0.06	0.06	0.11	0.11	0.13	0.06	0.08	0.16	0.10	0.10	0.08
Sensitivity	Max	0.1452	0.01	0.01	0.04	0.13	0.13	0.04	0.04	0.13	0.04	0.04	0.04
Size	Min	0.1452	0.14	0.14	0.11	0.11	0.09	0.12	0.12	0.15	0.09	0.09	0.13
Exportability	Yes	0.0806	0.08	0.08	0.08	0.00	0.08	0.08	0.08	0.00	0.08	0.08	0.00
Availability	Max	0.0645	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.01	0.01	0.01
Survivability	Yes	0.1129	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.00	0.11
Architecture	Yes	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			0.52	0.53	0.58	0.60	0.61	0.55	0.57	0.55	0.56	0.44	0.44

Figure 26: Detection Alternatives Analysis



A: TRS-3D (From EADS North America, 2013) B: SPY1-F (From Military Review, 2012)
C: SMART-L (From Thales, n.d.) D: SIBRS (From USAF, n.d.)

Figure 27: Select Examples of Detection Systems

2. Control

The control elements were very heavily scrutinized on cost and existing BMD capability (Figure 28). Given the latter, it comes as no surprise that the BMD-capable platforms significantly outperformed. Aegis was the top contender and was, therefore, ultimately one of the control elements selected for use later in the downselect process.

Control Weighted Values

Evaluation Measure	Objective	Weight	AEGIS	ICMS	COMBATSS-21	THAAD	PATRIOT	PAAMS	IRON DOME	MEADS BM C4I
Cost	min	0.2857	0.0105	0.078	0.0151	0.027	0.033	0.017	0.049	0.057
Sea Based	Yes	0.1714	0.1714	0.171	0.1714	0	0	0.171	0	0
BMD Capable	Yes	0.2286	0.2286	0	0	0.229	0.229	0.229	0.229	0.229
Availability	max	0.1714	0.0244	0.022	0.0229	0.02	0.024	0.02	0.023	0.015
Architecture	open	0.1429	0.1429	0.143	0.1429	0	0.143	0	0	0.143
			0.58	0.41	0.35	0.28	0.43	0.44	0.30	0.44

Figure 28: Control Alternatives Analysis

3. Engage (Launch)

Physical size was the primary concern of the launcher component of the engagement element. Being a much smaller displacement sea frame compared to its larger destroyer and frigate cousins, space is a significant constraint on the LCS sea frame. The launcher AoA shows that THAAD scored highest across all systems with Mk41 earning top place among vertical launch capable variants (Figure 29).

Engagement (launcher) Weighted Values								
Evaluation Measure	Objective	Weight	Mk41VLS	Sylver A50 VLS	Patriot	THAAD	MEADS	IRON DOME
Cost	Min	0.2667	0.008	0.006	0.002	0.121	0.121	0.009
Size	Min	0.3333	0.119	0.119	0.161	0.172	0.138	0.091
Vertical or Box Launcher	VLS	0.2333	0.233	0.233	0.21	0.21	0.21	0.21
Availability	Max	0.1667	0.031	0.03	0.031	0.029	0.019	0.025
			0.391	0.388	0.405	0.532	0.488	0.335

Figure 29: Launch Engagement Alternatives Analysis

4. Engage (Intercept)

The interceptor analysis of alternatives represents the most critical element of the BMD architecture. Availability was the primary concern; however, nearly all systems analyzed exhibited an operational availability exceeding the system requirement (and those that did not were eliminated from the selection pool). As a result, this statistic was omitted from the analysis and cost, range, and probability of kill became the highest weighted factors (respectively). Figure 31 highlights the results of the analysis showing that the THAAD and ESSM systems prove the best fits for the system needs. Details regarding the THAAD interceptor can be seen in Figure 30.

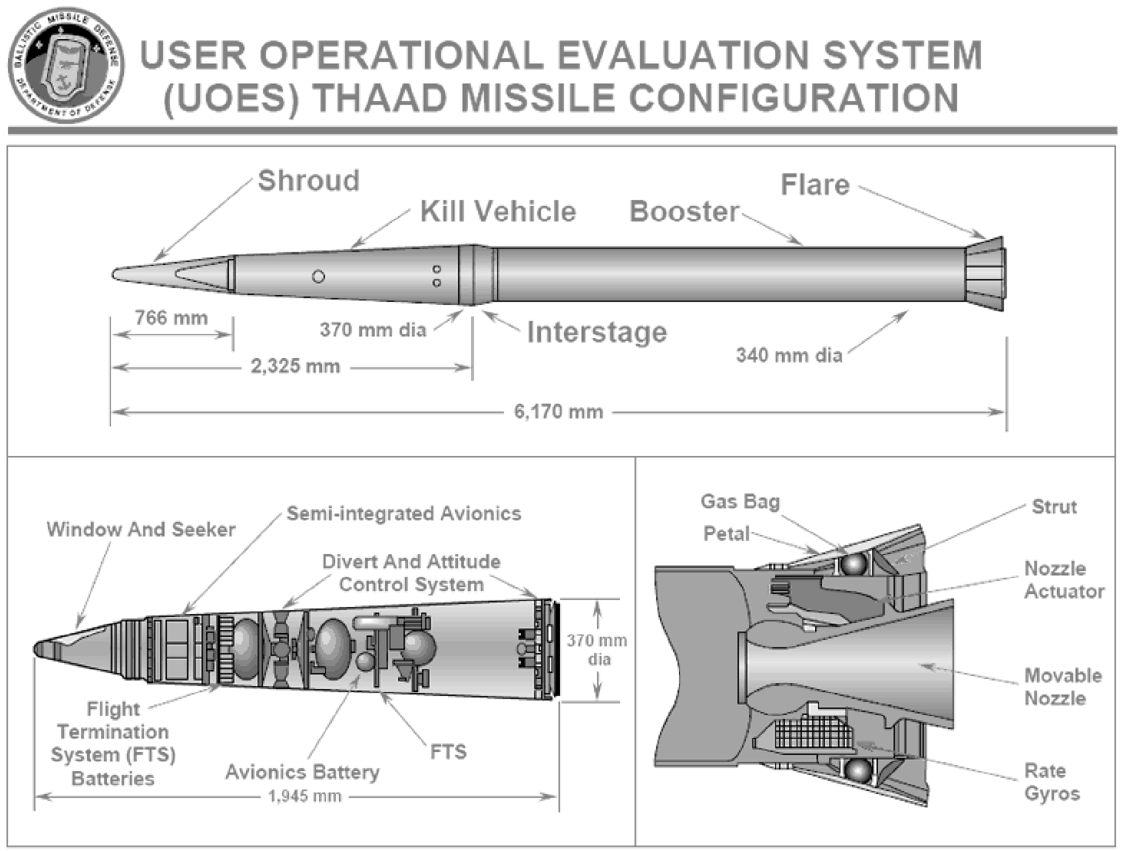


Figure 30: Details on the THAAD Interceptor (From Defense Industry Daily, 2013)

Engagement (Interceptor) Weighted Values

Evaluation Measure	Objective	Weight	GRIFFIN	RAM	PAC3	ESSM	HAWK	THAAD	ASTER 15	ASTER 30
Cost	Min	0.2381	0.085	0.107	0.218	0.226	0.101	0.132	0.12	0.13
Range	Max	0.2143	0.003	0.004	0.007	0.02	0.023	0.091	0.01	0.05
BMD-Capable	Yes	0.1905	0.095	0.095	0.19	0.19	0.095	0.19	0.19	0.19
Size	Min	0.1667	0.021	0.06	0.071	0.052	0.073	0.077	0.05	0.05
Probability of Kill	Max	0.1905	0.024	0.026	0.025	0.026	0.023	0.023	0.02	0.02
			0.227	0.293	0.511	0.514	0.314	0.514	0.39	0.44

Figure 31: Intercept Engagement Alternatives Analysis

B. SYSTEM OF SYSTEMS ANALYSIS OF ALTERNATIVES

1. Variant A: Maximizing Integration

In order to minimize acquisition cost and preserve the original LCS mission package concept, a variant utilizing only those components that easily integrate within the open architecture of the LCS sea frame was considered. The LCS, in its open architecture design, has multiple designated areas for swappable weapons modules. Based on the class of LCS, this includes several rear stations for smaller foot-printed weapons systems and a single larger forward footprint, current CONOPS for LCS has this station occupied by the forward gun weapons system.

Variant A takes advantage of existing detection systems utilizing the TRS-3D radar (Freedom Class) or the Sea GIRAFFE radar (Independence Class). These radars, while broadcasting in low-resolution C-band, have proven capability for detecting near-range ballistic missile threats. A separate, high frequency targeting radar will be necessary for engagement.

The fire control system will utilize the existing COMBATSS-21 system. This system already shares 80% of its code with the Aegis weapons system. Significant software modification would be necessary to provide BMD capability to the Variant A design.

The launcher, based on the AOA, would be a slightly modified design based on the THAAD launcher. Given the low footprint, this could integrate into the forward space occupied by the gun weapons system or one of the mid-ship spaces, currently unoccupied.

Variant A Summary:

Detection: TRS-3D or Sea GIRAFFE (modified)
Control: COMBATSS-21 (modified)
Launcher: THAAD (modified)
Engage: THAAD

2. Variant B: Maximizing Component Performance

Variant B stresses the use of integrating existing weapons systems. However, rather than minimizing requisite modification to the sea frame, the emphasis was placed on reducing the modification of the BMD system elements.

Variant B uses a smaller, BMD-specific radar system mounted in an auxiliary location in a weapons station module. A smaller radar such as SPY-1F has the capability to provide three dimensional, 360 degree, total field of view coverage.

The fire control system will require moderate modification, but will be heavily based on the Aegis weapons system.

A vertical launching system that can fit into the larger, forward weapons station will provide increased defense against ballistic missile threats. Likewise, a vertically launched missile, such as the ESSM will provide proven engagement capability from a sea-based platform.

Variant B Summary:

Engagement: SPY-1F

Control: Aegis BMD 4.0.x

Launcher: Mk41 VLS

Engagement: ESSM

3. Variant C: Maximizing BMD Capability

Variant C will completely forego the LCS open architecture and provide a BMD-specific solution based on the existing sea frame. As a result, two emergent paths are possible; new systems can be developed to accommodate the existing LCS footprint or the LCS can be physically altered to accommodate existing systems. Either way, both development cost and operational costs would increase significantly over Variant A or

Variant B. However, BMD capability would be increased significantly to match that of the Aegis BMD system. A contractor illustration of a proposed BMD ship based off of the LCS sea frame can be seen in Figure 32.

Variant C Summary:

Engagement: New System Design

Control: New System Design

Launcher: New System Design

Engagement: New System Design

Figure 32: Illustration of Proposed BMD LCS Variant (From Ewing, 2009)

C. DOWNSELECT METHODOLOGY

The downselect strategy for the variant options is based on the initial requirements and the overall cost versus performance, while existing within the guidelines set forth for system integration, DRM and the stakeholder needs. Trade studies were performed to downselect between the variants and choose the optimum variant for the design reference mission. The downselect evaluation criterion was to meet the key mission performance parameters and display an equivalent or better performing system than the fielded Aegis system.

The three variants, based on the AOA and the simulation results, focused on lowest cost/maximum integration, maximum effectiveness, or maximum BMDS capability. The three variants ascend from the least to most costly solution. Variant A preserves the mission package concept by choosing BMD-capable systems that will physically fit to the LCS sea frame but require some modification for integration. Variant B focuses on the integration of existing BMD-capable systems without modification. Variant C focuses on the implementation of a custom design to meet the established requirements.

The trade-offs chosen in order to downselect between the three where cost, complexity, capability and the ability to meet the rapid deployment schedule. In the next section cost comparisons between the different variants are made to view the most cost effective variant that would give the best BMD capability within the DRM.

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XII. PROPOSED SOLUTION

A. COST MODELING

In the current defense environment, cost plays a crucial role in any acquisition decision. On par with performance, total ownership cost (TOC) is a crucial figure that is closely scrutinized by key decision makers. Fortunately, there are many well-developed tools to help forecast TOC. These tools leverage the latest statistical algorithms and also take advantage of empirical program cost and schedule performance data of past programs.

TOC is a cost figure that aggregates the entire estimated cost of designing, procuring, operating, and eventually, disposing the weapons system. However, TOC also reflects the costs associated with personnel, ordnance, and other indirect costs. A subset of TOC that does not account for these costs is called system Life-Cycle Cost (LCC). LCC is the most commonly used figure when discussing expected programmatic budgets. Figure 33 shows the official DoD-sanctioned LCC breakdown as presented by the Defense Acquisition University (DAU, 2012).

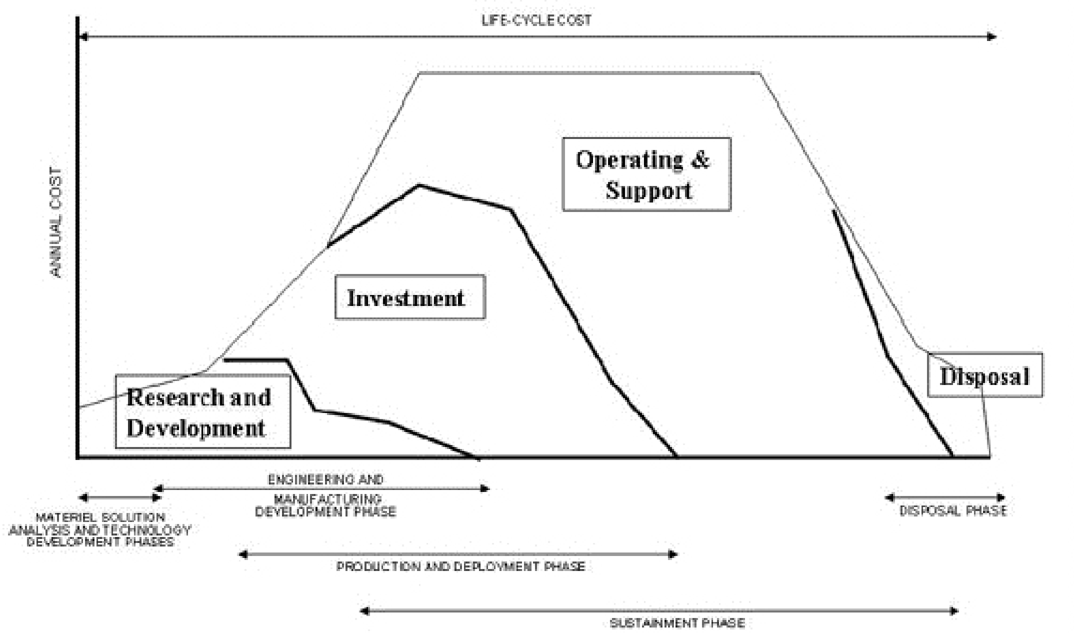

Figure 33: Defense Program Life-Cycle Cost (From DAU, 2012)

Life-Cycle Cost can be further broken down based on the phase of system development of the acquisition program (Figure 34). This is important because not all three proposed variants are in the same phase of system development. Variant A is in a late phase of system evolution as many of its comprising components technologically mature. Variant C is the least technologically mature; therefore, it is in the earliest stages of evolutionary development. These factors are considered in the final, rolled-up LCC estimates.

For all three variants, the COCOMO II software analysis tool and Advance Mission Cost Model (AMCM) served as primary reference datasets for the hardware and software development/modification calculations. Note that all values are in FY12 dollars and are based on a monthly rate of $24K per person-month ($150 per hour, burdened).

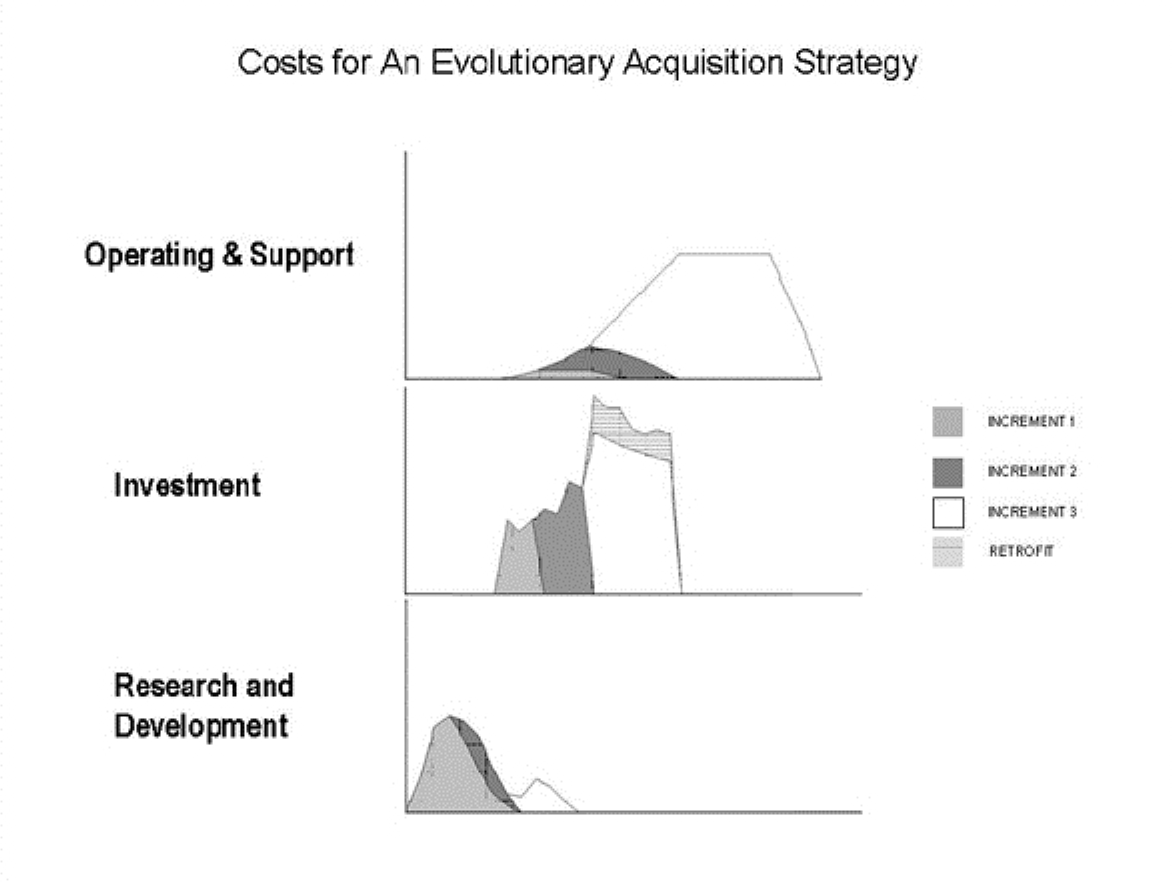

Figure 34: Breakdown of Life-Cycle Cost Elements (From DAU, 2012)

1. Variant A Life-Cycle Cost:

Summary:

Detect: $8.61M for TRS-3D radar

Control: $140M for fire control system

Engage (L): $17.3M for THAAD modified launcher

Engage (I): $38M for 100 THAAD missiles

Sea Frame: $245M for base LCS sea frame

Variant A uses the radar system integral to the current LCS sea frame, yet BMD capability upgrades are estimated to cost an additional $8.61M per hull. The fire control system is a modified version of the Aegis-based COMBATSS-21. However, the software elements of COMBATSS-21 are comprised of 2.5M source lines of code (SLOC) whereas Aegis BMD has 3.5M SLOC. In order to upgrade to BMD capability, an estimated 1M additional SLOC will be written and approximately 0.5M SLOC will reqire modification. Predictive analysis, using the COCOMO II software, indicates that this upgrade is anticipated to cost $140M.

The engagement elements of the BMDS are both derived from the currently fielded THAAD weapons system. Moderate modifications are required to equip the componets for shipboard use in addition to the cost of the core weapons system. Based on AMCM cost modeling, this equates to $17.3M for the launcher mechanism and $38M for a salvo of 100 interceptors.

Finally, as minimal modification to the sea frame is allowed, the cost associated with developing and bringing forth the Variant A solution is estimated at $245M. This figure is derived from the 2010 proposal submitted by Lockheed-Martin and Marrinette Marine, adjusted for FY12 cost of money.

2. Variant B Life-Cycle Cost:

Summary:

Detect: $12.2M for SPY-1F radar

Control: $66.1M for fire control system

Engage (L): $9.61M for Mk41 VLS

Engage (I): $77.6M for 100 ESSM

Sea Frame: $292M for slightly modified base LCS sea frame

Variant B upgrades the radar system to the Aegis-based SPY-1F array. As this is already developed and fielded, the cost is relatively low at $12.2M (accounting for increased intgration cost). The core Aegis 4.0.X derived fire control system was chosen for Variant B. However, in order to integrate with the LCS architecture, an estimated 0.5M SLOC will need to be written and an additional 1M modified for an estimated cost of $66.1M.

The launcher selected for use is the Mk41 vertical launching system (VLS). Slight modification will be necessary to integrate with the weapons system architecture. This brings the estimated cost to $9.61 per launcher. However, significant modification to the LCS sea frame will be necessary to accommodate the Mk41's footprint. These costs are captured in the increased sea frame cost per the AMCM modeling. Finally, cost modeling for the selection of the evolved sea sparrow missile interceptor equates to $77.6M for a salvo of 100 interceptors.

3. Variant C Life-Cycle Cost:

Summary:

Detect: $19.1M for new radar

Control: $301M for fire control system

Engage (L): $23.5M for new launcher

Engage (I): $586M for new missile

Sea Frame: $346M for new design sea frame based on LCS design

Variant C is composed entirely of new or heavily modified components, in addition to the construction of a novel sea frame based on the LCS architecture. This concept is closely correlated with the U.S. Navy's foreign military sales (FMS) development effort for the Saudi Naval Expansion Program (SNEP II).

Using SNEP II estimates and AMCM derivations, the cost for a new detection radar is $19.1M. The heavily modified fire control software will require an estimated 2M new SLOC, with 0.5M additional SLOC modified for a projected cost of $301M. The engagement elements will run approximately $23.5M and $586M respectively for the design and development of new systems (assuming very high complexity and a 2025 initial operating capability).

Finally, the sea frame modifications will increase by approximately 40% to an estimated figure of $346M per sea frame (assuming a 20 ship procurement profile). Table 16 captures the rolled up component costs for each system element for all three variants.

	Detect	**Control**	**Launch**	**Intercept**	**Sea Frame**
Variant A	$8.61	$140	$17.3	$38	$245
Variant B	$12.2	$66.1	$9.61	$77.6	$292
Variant C	$19.1	$301	$23.5	$586	$346

Margin of Error: ±3%

Table 16: Component LCC vs. System Variant (in $Millions USD)

	RDT&E	**Procurement**	**Operations**	**Disposal**	**Total**
Detect	22%	49%	33%	2%	100%
Control	75%	15%	10%	0%	100%
Launch	22%	49%	33%	2%	100%
Intercept	27%	33%	39%	0%	100%
Sea Frame	1%	31%	63%	5%	100%

Table 17: LCC Percentage based on System Definition

	RDT&E	Procurement	Operations	Disposal	Total
Variant A	$2.98	$8.96	$14.9	$2.98	$29.8
Variant B	$3.06	$9.18	$15.3	$3.06	$30.6
Variant C	$4.63	$13.9	$23.2	$4.63	$46.3

Margin of Error: ±3%

Table 18: Aggregate LCC per System Variant (in $Billions USD)

Table 17 discusses the total LCC percentages based on system component according to the DoD-revised 21st century procurement estimates (DODINST 5000.1, 1999). These figures, along with the component Life-Cycle Cost tabulations allow for an aggregate summation of LCC for each variant (Table 18). From this data, Variant A and Variant B are readily recognized to have equivalent LCCs (compensating for margin of error). Further downselect between these three variants will be conducted in the following verification and validation sections.

B. VERIFICATION AND VALIDATION

The three compiled variants were simulated against the DRM to determine a predicted P_{ra}. From the Analysis of Alternatives, System of Systems downselect, Variant A was composed of either the EADS TRS-3D or Sea GIRAFFE (modified) for the sensor suite. As the two the radar packages had a similar detection range (EADS TRS-3D 200 km and modified Sea GIRAFFE 180 km) they were not modeled as discrete variants.

To enable comparative assessments of the variants operating in likely deployment modes offering best-possible mission effectiveness, the relative P_{ra} was based on the resources provided by two LCS BMD capable platforms. Target illumination for variant A1, A2, and B was modeled as being provided by CEAMOUNT Solid State Continuous Wave Illuminator. With four discrete emitting faces mounted at 90^o intervals as shown in Figure 35. Two of the illuminator faces would be in the beam shadow of the incoming salvo of ballistic missiles.

Based on this configuration, it is assumed that at least two ballistic missile targets can be illuminated per panel, making for a total of four per ship. The combat system for all variants modeled is assumed to allow for a system of systems approach to target allocation based on probability of success and availability. Target illumination resource sharing to allow Launch-on-Remote (LoR) is included in Variant C modeling.

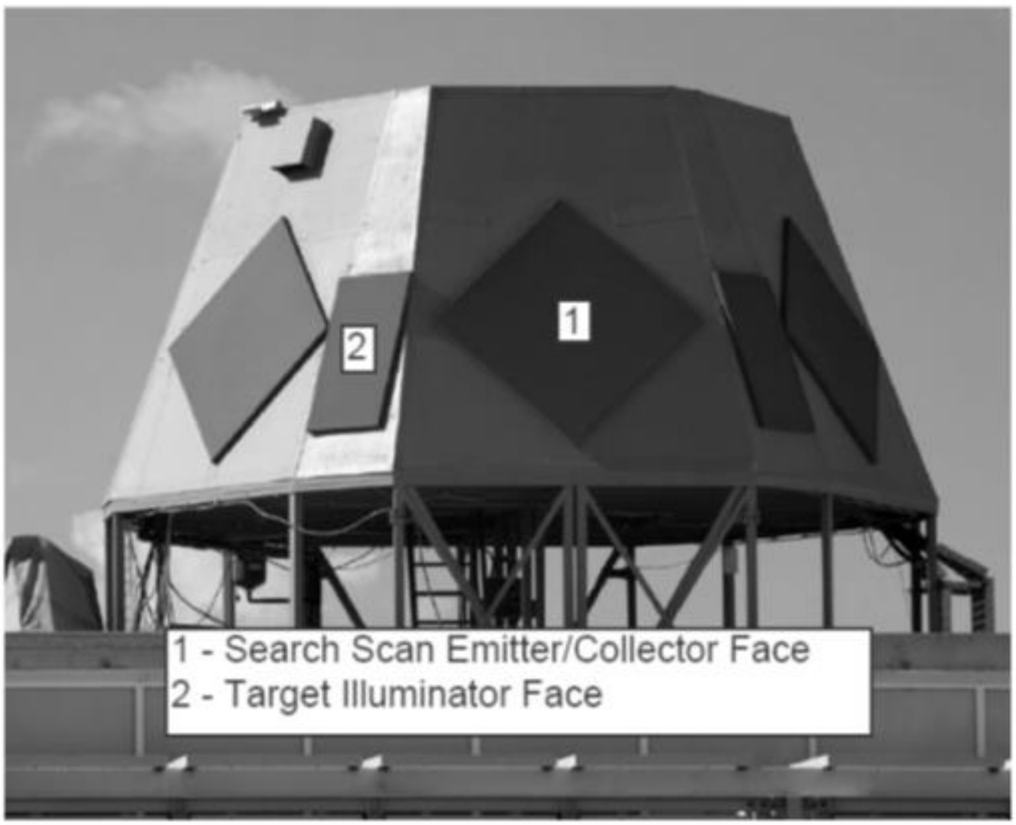

Figure 35: Radar Cupula Configuration (From CEA, 2011)

Thirty (30) simulation runs were conducted for each variant and an average P_{ra} was for each was calculated. These results are compared in Figure 36.

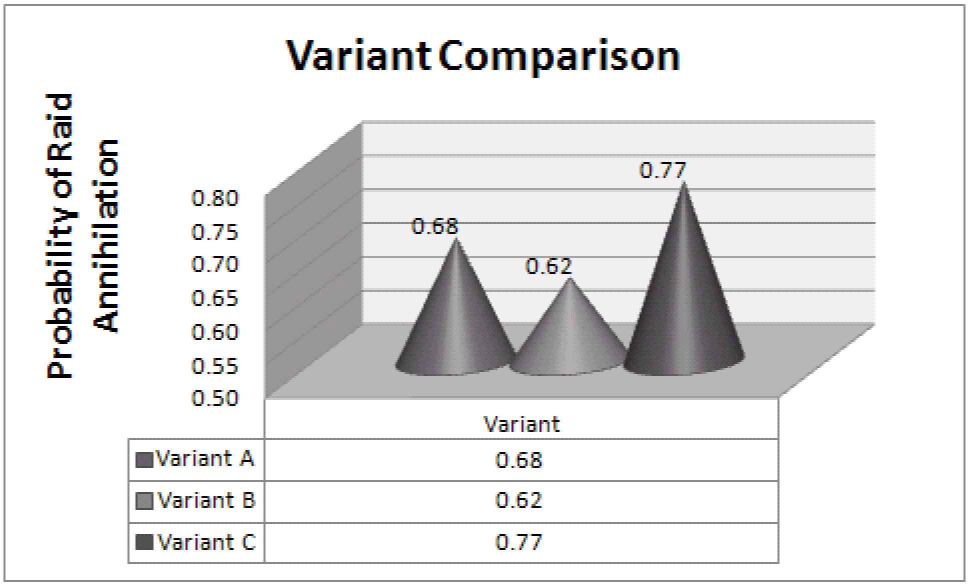

Figure 36: Variant Simulation Results Comparison

No limitation was provided to the number of interceptors available to the LCS BMD platforms for variant comparisons. The simulation results for each run provided a total number of interceptor launches these totals were averaged and can be seen in Figure 37. The interceptor consumption averages will be used to determine feasibility of LCS launcher quantity sizing.

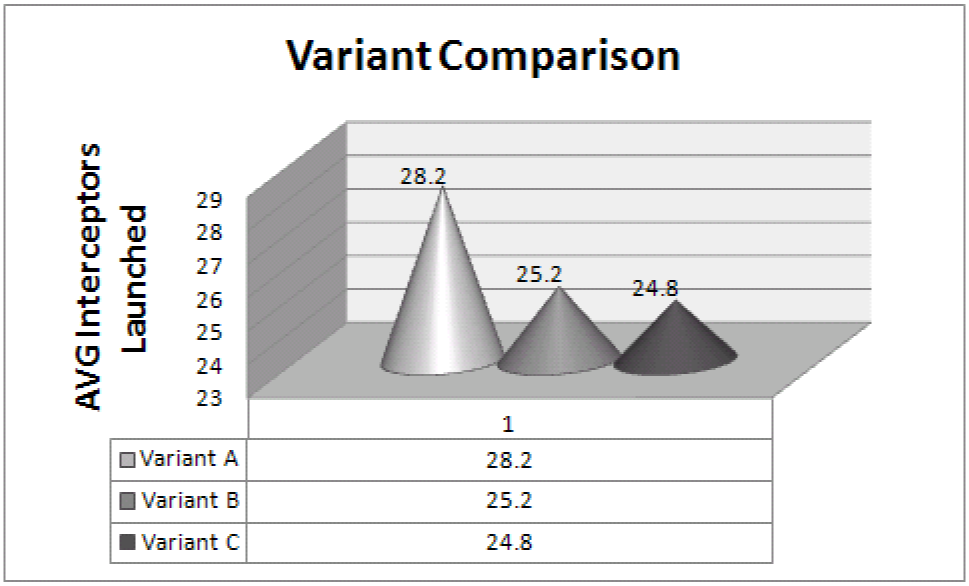

Figure 37: Average Interceptor Launches per variant

C. INTEGRATION

A high level component integration assessment was performed to further evaluate feasibility. The power and space available for the monohull and trimaran versions are given in the High Level Requirements section of this report, but to summarize, the LCS monohull variant has two weapons module stations, and the trimaran has three, each with about 50 cubic meters of useable volume. Each of the internal support module stations has about 36 cubic meters of volume. The power available varies station to station, but no more than 50 kW is available at any single station.

1. Solution Variant A Integration

The first solution variant meets the project requirement for a true “mission package.” No major modifications to the sea frame are required. The system uses the TRS-3D or Sea GIRAFFE radar and the COMBATSS-21 combat management system already installed. If the COMBATSS-21 system can be programmed and configured to interface with the BMDS launcher system, very little additional power would be required for combat management and fire control.

If the launcher cannot be integrated with the existing combat system, then a mission module suite similar to the U.S. Army Battle Management/Command, Control, Communications, and Intelligence (BMC3I) package is recommended for integration. The BMC3I already resembles a mission package in that it is packaged as several portable conex-like vans. The suite includes a tactical operations station and a launch control station that together require 15 kW of power, and it also includes an operator control unit that requires another 15 kW. Each of the three BMC3I package components fit onto the back of a HMMWV. The same three components could be modified for shipboard use and easily fit into three of the LCS internal mission module stations (Department of the Army, 2000).

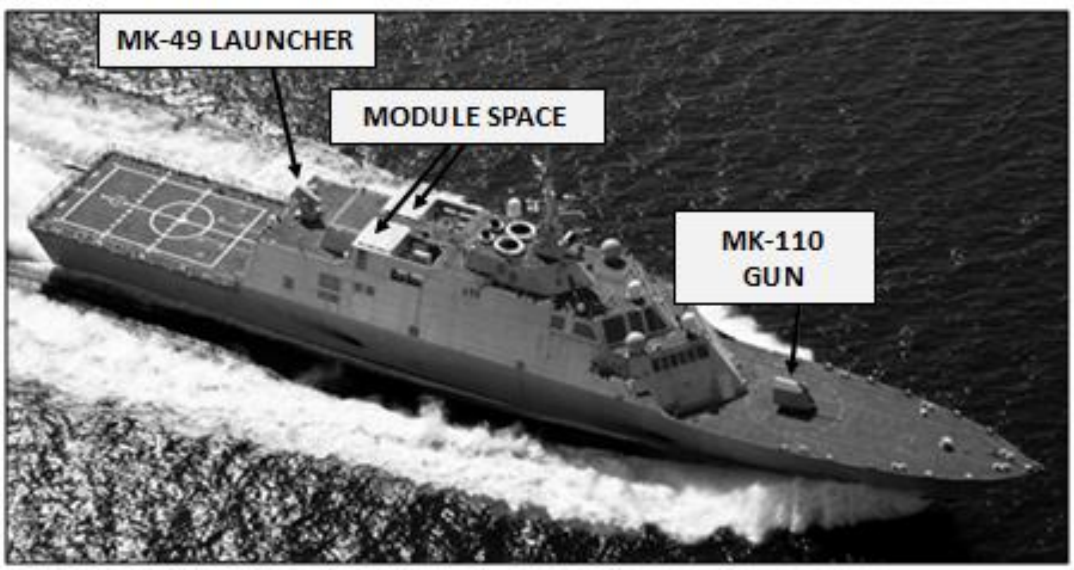

Figure 38: LCS-1 System Integration (After SeaForces, 2012)

The launcher system of Variant A will likely require significant modifications in order to be packaged in the LCS weapons module. The THAAD launcher is typically a truck-mounted system. Containers 7.0 meters long x 0.5 meters wide x 0.5 meters high are typically assembled in groups of eight. The containers are used to store, transport, and launch THAAD missiles. An assembly of eight containers requires 10 kW of power.

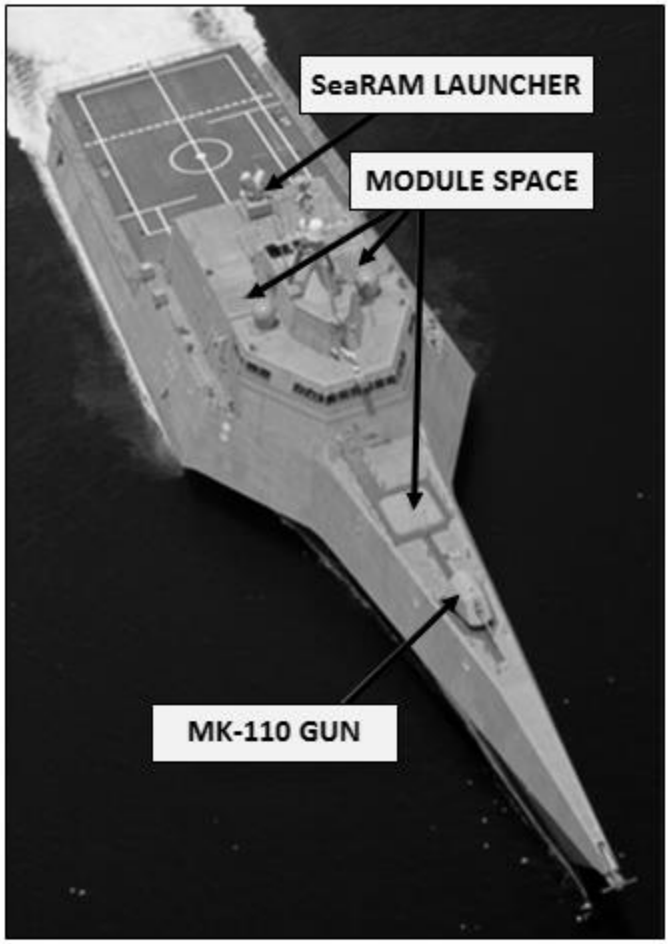

Figure 39: LCS-2 System Integration (After SeaForces, 2012)

The 50 cubic meter space envelope available at each weapon station is not well-suited for integrating a long, missile cell type weapon that sits flush with the ship's topside surfaces. Additional analyses are needed to determine exactly how the canisters would be installed, but for this concept design, it was estimated that eight cells could be installed at each weapons module stations, resulting in at least 16 total cells. 10 kW per eight cell weapons module was applied to the concept resulting in a total launcher power requirement of 20 kW.

Two support modules, each requiring 10 kw, were added to the package for missile and launcher equipment and maintenance bringing the total additional power required to support the BMD mission package to 70 kw, including the THAAD control and operations stations.

2. Variant B Integration

The second variant requires installation of a higher powered radar which is better suited for ballistic missile detection and tracking. This would be a significant effort; the ship would need to be taken out of service for an extended period to perform this technology upgrade. While this approach is not aligned with the “mission package” concept, the effort would yield a ship that would be much more effective in performing the BMD mission.

The SPY-1F radar would require a least an additional 25 kw of power over the currently installed TRS or Sea GIRAFFE radars (Jane's, 2012). Although this power would not be supplied from the mission modules, the added power demand will likely require more installed power on the LCS or the addition of power generator modules. The SPY-1F would also require a large amount of additional volume and structure to support the array faces. Futher analyses are required to determine if the LCS has adequate design margin and stabiltiy to support such a modification.

For combat management, the Aegis BMD 4.0 CMS would also likely require additional power over the currently installed COMBATSS system. However, it would not be supplied from the module stations.

For engagement, four Mk41 VLS cells would be installed at each weapon module station in a manner similarly envisioned for the THAAD launcher system. Again, modifications to the cells and the weapons stations would be required to fit the launcher system. The MK 41 cells add capabiltiy over the THAAD by allowing four ESSM missiles in each cell. The total power needed for the launcher system is not known, but 50 kW is anticipated to be sufficient.

XIII. RECOMMENDATIONS AND CONCLUSION

A. SUMMARY

The objective of this concept design study was to assess the feasibility of a BMD mission package for the LCS. A systems engineering approach was used to perform the conceptual design of a BMD capable LCS. Through requirements analysis, cost and performance thresholds were determined and the LCS sea frame integration metrics were identified.

Only publicly sourced information was used in the analysis. This necessitated use of a comparative approach for measuring system performance against an assumed success measure—that the Aegis platform meets the U.S. Navy requirement for BMD and, therefore, the proposed LCS BMD solution would need perform at least as effectively in the specified DRM. A high-level assessment of possible threats guided the development of a DRM where the threat country launches a combination of scud and ballistic missiles from three different locations, all within 800 km of the asset. The Aegis BMD system was simulated in the DRM and the probability of raid annihilation was used to quantify the system's performance.

To determine LCS solution characteristics, a design of experiments was conducted using a range of available radars, combat management systems, and engagement systems. The result produced several "packages" that met the requirement to perform as effectively as the Aegis system in the DRM. An analysis of alternatives, that included system costs, was performed that further reduced the possibilities to one "mission package" of BMD system components that meet the performance threshold and LCS sea frame limitations. Additionally, two other solution variants were produced that would be more effective in the DRM but would not integrate as a mission packages. Both would require significant changes to the sea frame.

The analysis ultimately showed that two Littoral Combat Ships positioned near an asset, each equipped with 16 THAAD launchers and missiles, using the currently installed TRS-3D or Sea GIRAFFE radars, could intercept an incoming salvo of short range ballistic missiles and scud missiles more effectively than one Aegis equipped destroyer. Furthermore, the cost of two BMD-equipped LCSs is half as much as an Aegis equipped destroyer. Technical and programmatic risks were identified and several large assumptions were made over the course of system concept development, but the analysis showed that the LCS can play a role in BMD.

Proposed variant performance has been estimated using the developed BMD simulation. P_{ra} was used as the primary MOP and System Cost was used as the primary MoS for comparing the variants. These primary MOEs are plotted on Figure 40. Estimated system Life-Cycle Cost is on the horizontal axis, in billions of USD, and P_{ra} is plotted on the vertical axis.

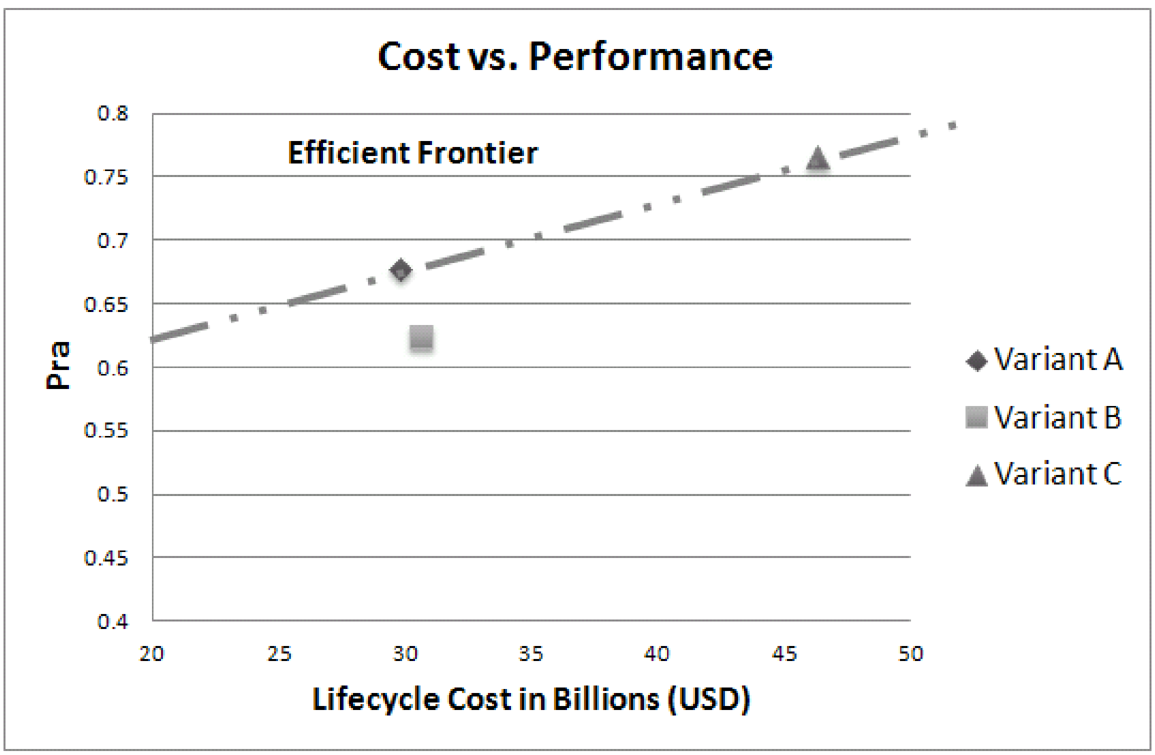

Figure 40: LCS BMD Variant Efficiency Frontier

Variant A and Variant C establish the efficient frontier for the decision space. Variant B is dominated by Variant A as Variant A has superior P_{ra} and costs less than Variant B.

At project inception the LCS BMD capability was intended to be a Mission Package, integrating with the open architecture of the LCS program. This open architecture integration requirement was made a MoS. Using the open architecture integration MoS as the secondary criteria for analysis, Variant A is the clear selection. Not only does it provide the lowest cost solution, it is hypothesized to have significantly higher P_{ra} (via modeling) than the KPP of 0.55 derived from the Aegis solution.

To test this hypothesis a one sided hypothesis test was executed;

$$H_o : P_{ra}(VariantA) < P_{ra}(Aegis)$$
$$H_A : P_{ra}(VariantA) \geq P_{ra}(Aegis)$$

Or

$$H_o : P_{ra}(VariantA) < 0.55$$
$$H_A : P_{ra}(VariantA) \geq 0.55$$

$$P_{ra}(SimulatedVariantA) = 0.68$$
$$N = 30$$
$$S = .024$$
$$t = \frac{\sqrt{n}(\overline{X} - \mu)}{s} = \frac{\sqrt{30}(0.68 - 0.55)}{.024} = 27.17$$

P value is:

$$p - value = P(X \geq 27.17)$$
$$df = n - 1$$
$$df = 30 - 1 = 29$$
$$p - value = 5.73 \times 10^{-22}$$

The calculated p-value was verified using the Microsoft Excel t-test function to be $5.74\text{x}10^{-22}$ for the subject datasets. This small p-value indicates that the null hypothesis is false and that there is statistical evidence to accept the alternate hypothesis that the P_{ra} for the Variant A is superior to that of the Aegis solution.

B. RECOMMENDATIONS

Moving forward, further efforts to develop a BMD mission package should look at weapons system integration in more detail and consider a system of systems approach where the system interfaces with existing and future BMD assets, such as ground based systems and space based sensors. In addition, non-publically available classified component characteristics and performance data should be incorporated into the simulation to more accurately reflect actual system performance capabilities.

The open architecture design of the LCS will eventually present the U.S. Navy with the ability to meet nearly every threat and perform any mission by integrating suites of tailored off-the-shelf components. Today, in this nascent stage of evolutionary development, LCS programs face expected and unexpected technical and political challenges that, once overcome, will ultimately make the programs stronger and more effective. As the LCS proves itself in its ability to perform the ASW, ASuW, and MCM missions, Navy program offices will be looking for the next packages to align to address future capability gaps.

In an assessment of future capability-need, countless sources cite gaps in BMD. Arms control groups in the U.S. and abroad recognize that ballistic missiles are no longer solely controlled by a few countries, and that no one really has a clear picture of who has what. Regional incidents, such as the October 2000 attack on the USS Cole (DDG-67), serve as an ever-present reminder that the smallest force has the means to conduct Anti-Access/Area Denial (A2/AD) operations that can effectively halt U.S. naval efforts by cutting off access to resources or key assets.

C. CONCLUSION

As noted, this project revealed the viability of an LCS mission package for fulfilling emerging regional BMD mission needs. The LCS, however, is not envisioned to perform midcourse detection and engagement of medium and long range ballistic missiles from a sea based platform, as the installed power and volume exceeds the capabilities of the LCS. This mission role is expected to remain exclusively with Aegis-equipped platforms for the foreseeable future. Nevertheless, the overall demand is expected to increase as the inventory of BMD-capable ships is limited and will likely stretched thinner over the next decade.

As the LCS inventory grows, cost-effective short and medium range BMD coverage over a wider expanse of littoral assets does appear feasible through the introduction of BMD mission packages.

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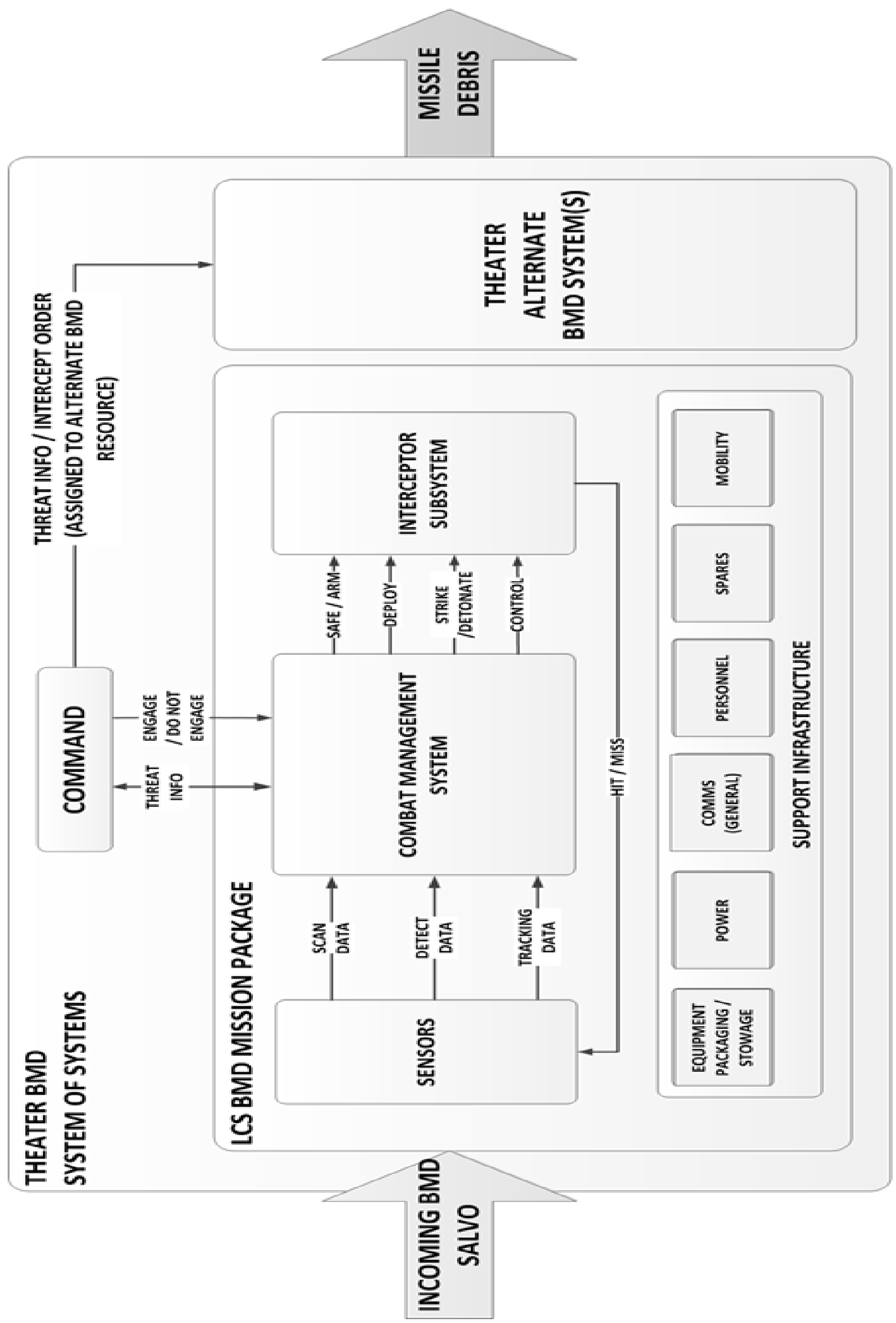
APPENDIX A. CONTEXT MODEL FOR LCS BMD SYSTEM



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APPENDIX B. UNITS OF MEASUREMENT

Measurement	Unit
Meters	m
Kilometers	km
Inches	in
Feet	ft
Pounds	lbs
Kilograms	kg
Knot (nautical miles per hour)	kt
Kilowatts	kW
Megawatts	MW
Hertz (frequency)	Hz
Probability of X	P_{XX}
Currency (FY12 $)	USD

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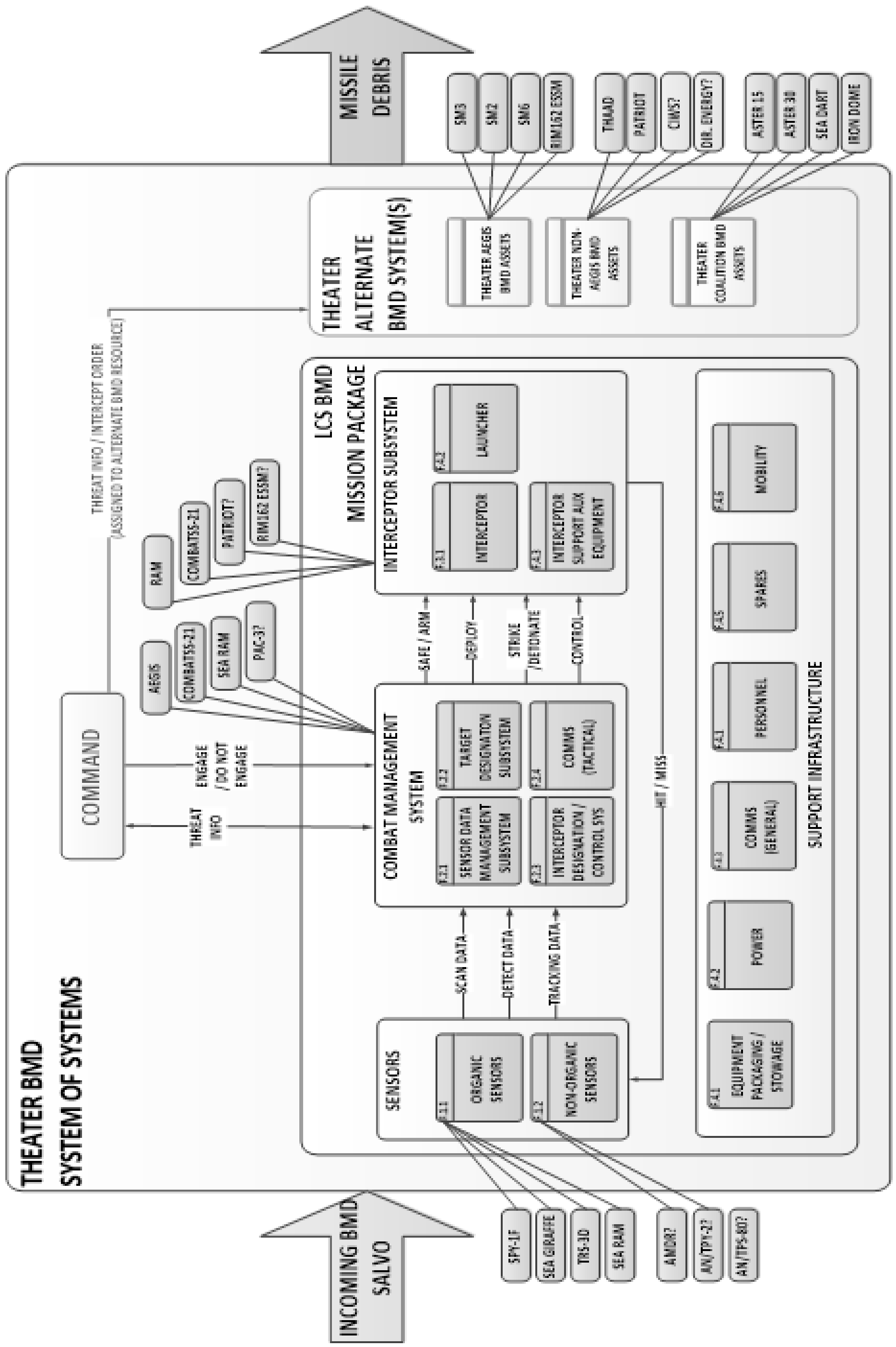
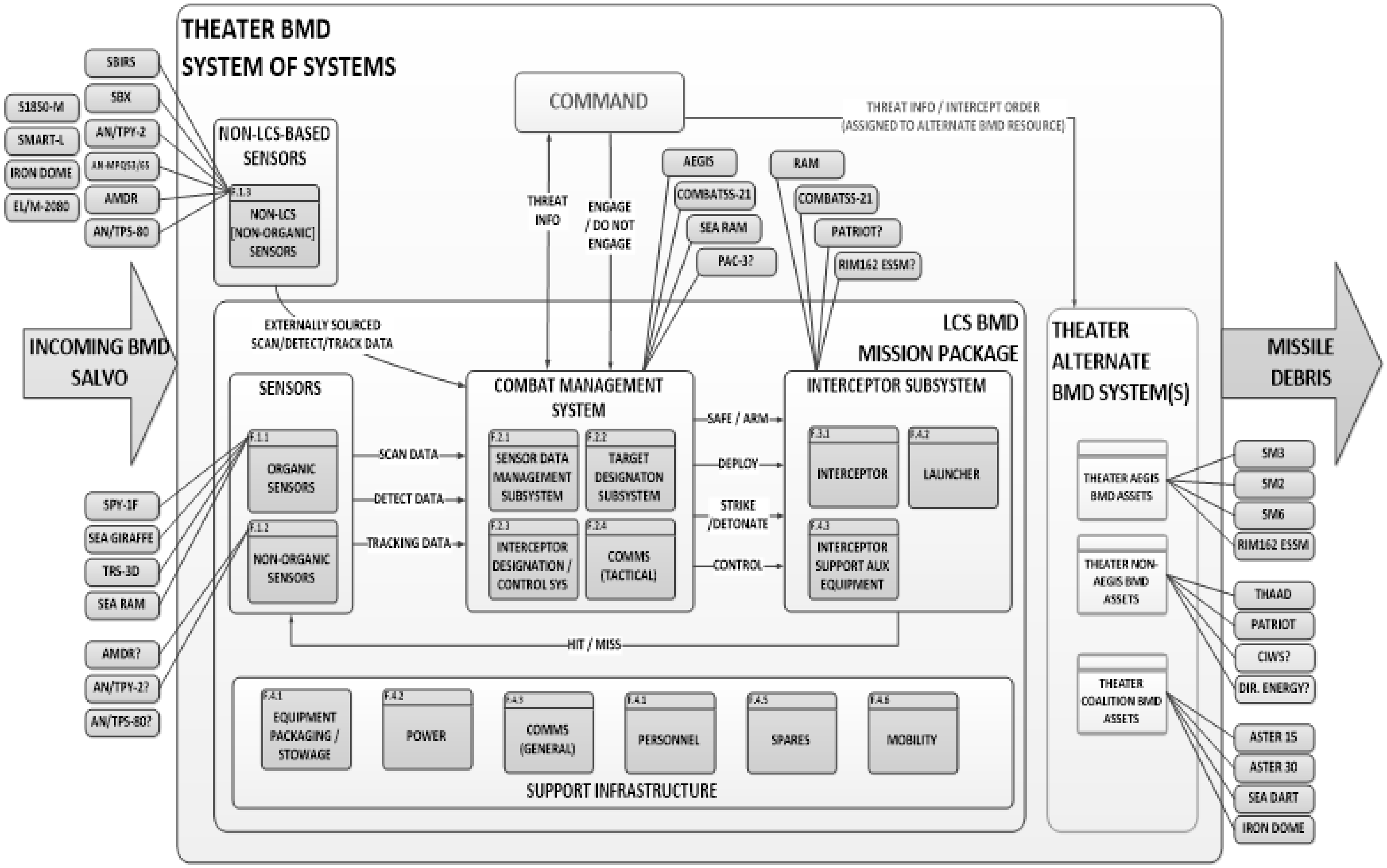
APPENDIX C. PHYSICAL ARCHITECTURE




THEATER BMD
SYSTEM OF SYSTEMS
COMMAND
THREAT INFO / INTERCEPT ORDER
(ASSIGNED TO ALTERNATE BMD RESOURCE)
SBIRS
SBX
AN/TPY-2
AMDR
AN/TPS-80
S1850-M
SMART-L
IRON DOME
EL/M-2080
NON-LCS-BASED SENSORS
F.1.3
NON-LCS [NON-ORGANIC] SENSORS
THREAT INFO
ENGAGE / DO NOT ENGAGE
AEGIS
COMBATSS-21
SEA RAM
PAC-3?
RAM
COMBATSS-21
PATRIOT?
RIM162 ESSM?
EXTERNALLY SOURCED SCAN/DETECT/TRACK DATA
LCS BMD
MISSION PACKAGE
INCOMING BMD SALVO
THEATER ALTERNATE BMD SYSTEM(S)
MISSILE DEBRIS
SENSORS
F.1.1
ORGANIC SENSORS
F.1.2
NON-ORGANIC SENSORS
SCAN DATA
DETECT DATA
TRACKING DATA
COMBAT MANAGEMENT SYSTEM
F.2.1
SENSOR DATA MANAGEMENT SUBSYSTEM
F.2.2
TARGET DESIGNATON SUBSYSTEM
F.2.3
INTERCEPTOR DESIGNATION / CONTROL SYS
F.2.4
COMMS (TACTICAL)
SAFE / ARM
DEPLOY
STRIKE /DETONATE
CONTROL
INTERCEPTOR SUBSYSTEM
F.3.1
INTERCEPTOR
F.4.2
LAUNCHER
F.4.3
INTERCEPTOR SUPPORT AUX EQUIPMENT
HIT / MISS
SPY-1F
SEA GIRAFFE
TRS-3D
SEA RAM
AMDR?
AN/TPY-2?
AN/TPS-80?
THEATER AEGIS BMD ASSETS
THEATER NON-AEGIS BMD ASSETS
THEATER COALITION BMD ASSETS
SM3
SM2
SM6
RIM162 ESSM
THAAD
PATRIOT
CIWS?
DIR. ENERGY?
ASTER 15
ASTER 30
SEA DART
IRON DOME
F.4.1
EQUIPMENT PACKAGING / STOWAGE
F.4.2
POWER
F.4.3
COMMS (GENERAL)
F.4.4
PERSONNEL
F.4.5
SPARES
F.4.6
MOBILITY
SUPPORT INFRASTRUCTURE

APPENDIX D. SYSTEM DESIGN RISKS

RISK IDENTIFICATION			QUALITATIVE RATING			RISK RESPONSE		
RISK DESCRIPTIONS		RISK CATEGORY	PROB.	IMPACT	RISK SCORE	RISK HANDLING APPROACH	RISK MITIGATION	MONITORING PLAN
OPERATIONAL RISKS								
O1	The design may incur operational risks as the required crew size may increase to a level not supported by the LCS in order to meet mission success	OPERATONAL	3	5	**HIGH**	CONTROL	Detailed Resource Analysis; Maximize automation where appropriate. Leverage existing crew resources as best possible	Simulation Results indicate need for greater number of resources to perform mission
O2	The duration of BMD missions may surpass the at sea capability of the LCS	OPERATIONAL	2	5	**MED**	CONTROL	Assess mission duration; trade against resource rotation strategies	N/A
O3	The Level I+ survivability capabilities of the LCS may be a risk to mission success in ability to handle threats	OPERATIONAL	4	4	**HIGH**	CONTROL	Assess/ Review Survivability against expected BMD threats	Evaluate simulation results of expected BM threats
O4	Insufficient Configuration Management and Product Road mapping may impede the ability to perform future technology refreshes on time and per budget, impacting operational readiness of the LCS fleet	OPERATIONAL	3	4	**MED**	CONTROL	Extensive Detail Planning effort needed to develop primary COAs and contingencies	N/A
PROGRAM/PROJECT RISKS								
P1	Due to budget constraints and the criticism facing the LCS the amount of ships may be reduced and or even canceled putting the project in jeopardy-Supportability of the mission may be reduced	PROGRAM	3	4	**MED**	CONTROL	Simulation of DRM with the minimum/maximum number of LCS's to show LCS usability. Also, Analysis of Alternative platforms	Asses Simulation results and monitor LCS program
P2	Cost deviation risks may be incurred by the design due to the use of new technology (radars, modified missile launchers, BMD communications)	PROGRAM	2	4	**MED**	CONTROL	Detailed Analysis on compatibility of new technology and comparable alternatives	AOA results to determine most cost effective/ technically feasible design
P3	The use of BMD missile launchers on the LCS platform may cause structural damage to the LCS	PROGRAM	3	3	**MED**	CONTROL	Detailed Analysis on structural integrity of LCS platform vs. the structural integrity needed for VLS	N/A

	RISK DESCRIPTIONS	RISK CATEGORY	PROB.	IMPACT	RISK SCORE	RISK HANDLING APPROACH	RISK MITIGATION	MONITORING PLAN
PROGRAM/PROJECT RISKS CONT…								
P4	Political risk as our DRM requires LCS platforms in the littoral waters of potential adversaries or friendly nation and may be interpreted as a declaration of war or violation of territorial waters	PROGRAM	3	4	**MED**	CONTROL	Simulation of DRM and evaluation of threshold distance to adversary shore line	N/A
TECHNICAL RISKS								
T1	The use of the LCS platform to perform our missions may not be feasible as the technical maturity of the LCS vessel may impact performance. The LCS platform is essentially still being vetted	TECHNICAL	3	4	**MED**	CONTROL	Detailed simulation efforts to show the feasibility of LCS use	Asses simulation results and monitor LCS program testing
T2	Using higher power radars for tracking on the LCS may negatively affect the power grid of the LCS	TECHNCAL	2	1	**LOW**	CONTROL	Research of LCS power grid and radar power requirements	N/A
T3	Interoperability and integration of the LCS platform with BMD systems may not be fully achieved	TECHNICAL	3	2	**LOW**	CONTROL	Detailed research of historical integration mitigation methods for other BMD navy platforms	N/A
T4	COTS equipment may have to be modified to fit on the LCS platform imposing a technical risk of integration	TECHNICAL	2	4	**MED**	CONTROL	Detailed technical analysis of COTS equipment and prototype testing	N/A
T5	Limited alternative risks for the acquisition of BMD capable radar for scanning, detection and tracking of short to medium range ballistic missiles	TECHNICAL	3	3	**MED**	CONTROL	Simulation of alternative DRM strategies	N/A
T6	The integration of the LCS platform with foreign BMD systems may incur information security risks	TECHNICAL	1	2	**LOW**	CONTROL	Detailed research of historical data on information sharing among foreign BMD systems	N/A

APPENDIX E. SYSTEM REQUIREMENTS

REQ 0 MISSION PACKAGE SYSTEM REQUIREMENTS

REQ.1 FUNCTIONAL REQUIREMENTS

REQ.1.1 INPUT REQUIREMENTS

REQ.1.1.1 The system shall accept command and control from the operator

REQ.1.1.2 The system shall monitor environmental information from its operational environment

REQ.1.1.3 The system shall accept data from satellites and other national assets

REQ.1.2 OUTPUT REQUIREMENTS

REQ.1.2.1 The system shall provide its status to the operator

REQ.1.2.2 The system shall provide battle damage assessment (BDA) to the operator

REQ.1.2.3 The system shall provide post mission data at the end of mission

REQ.1.2.4 The system shall has the capability of sending, receiving, and processing situational reports related to ballistic missile flight path

REQ.1.3 EXTERNAL INTERFACT REQUIREMENTS

REQ.1.3.1 The system components shall remain operable after being exposed to temperatures ranging from -40 to 55 Celsius degree.

REQ.1.3.2 The system shall works under humidity OF 95%

REQ.1.3.3 The system shall remain functional during 45 kt wind conditions

REQ.1.3.4 The system shall works in sea state

REQ.1.3.5 The system shall be able to handle the air blast

REQ.1.3.6 The shall be able to works in the EMP environment

REQ.1.3.7 The system shall be able to handle the vibration

REQ.1.3.8 The system shall be able to handle the mechanical shock

REQ.1.4 FUNCTION REQUIREMENTS

REQ.1.4.1 The BMD system shall scan for the threats to the protected area 24 hours a day, 7 days a week with 99.99% accuracy

REQ.1.4.2 The BMD system shall provide the ability to track all incoming missile threats approaching the protected area.

REQ.1.4.2.1 The system shall sense all objects entering protected area

REQ.1.4.2.2 The system shall determine flight characteristics of all objects in range

REQ.1.4.2.3 The system shall feed tracking data to detection system.

REQ.1.4.2.4 The system shall classify object if signature/threat status.

REQ.1.4.2.5 The system shall provide notification to decision authority.

REQ.1.4.3 The BMD system shall provide the ability to detect threats approaching the protected area with 99.99% accuracy.

REQ.1.4.3.1 The system shall continuous monitoring of incoming threat(s).

REQ.1.4.3.2 The system shall be able to communicate of threat characteristics.

REQ.1.4.3.3 The system shall have the capability of prioritization of threats.

REQ.1.4.3.4 The system shall be able to communicate of threat status.

REQ.1.4.4 The BMD system provides the ability to conduct command and control over activities to manage threat neutralization activities.

REQ.1.4.4.1 The system shall be able to determine the course of action.

REQ.1.4.4.2 The system shall be able to command the system to intercept.

REQ.1.4.4.3 The system shall be able to command the system to safe interceptor.

REQ.1.4.5 The BMD system shall provide the ability to engage threats with 99.99% accuracy.

REQ.1.4.5.1 The system shall be able to perform selection of interceptor.

REQ.1.4.5.2 The system shall be able to perform fire control solution upload.

REQ.1.4.5.3 The system shall be able to perform arming of interceptor.

REQ.1.4.5.4 The system shall be able to perform deployment of interceptor.

REQ.1.4.5.5 The system shall be able to perform interception of threat(s).

REQ.2 NON-FUNCITONAL (SYSTEM-WIDE) REQUIREMENTS

REQ.2.1 SUITABILITY REQUIREMENTS

REQ.2.1.1 The system shall has the operational availability of 0.95

REQ.2.1.2 The system shall has the Mean Time Between Maintenance (MTBM) of 22 hours

REQ.2.1.3 The system shall has the Mean Time Operational Mission Failure (MTBOM) of 48 hours

REQ.2.1.4 The system shall have a scheduled maintenance of no more than 2 hours.

REQ.2.1.5 The usability for training shall be measure in days to properly trained personnel.

REQ.2.1.6 The system shall have the efficiency of 0.95.

REQ.2.1.7 The system shall have the error rate less than 0.05

REQ.2.1.8 The system shall provide user friendly interfaces

REQ.2.1.9 The system shall provide the redundancy

REQ.2.1.10 The system shall be able to survive the small arms

REQ.2.1.11 The system shall have the BMD contact survivability

REQ.2.1.12 The system shall be able to survive of air blast

REQ.2.1.13 The system be comparable with assets defended

REQ.2.1.14 The system shall works with fielding

REQ.2.1.15 The system shall have the scalability

REQ.2.1.16 The system shall have the flexibility

REQ.2.2 PHYSICAL REQUIREMENTS

REQ.2.2.1 The system control station shall be able to operate on a power supply of either alternating current (AC) or direct current (DC)

REQ.2.2.2 The system shall not require more than LCS current physical power

REQ.2.2.3 The weapon system shall be able to fit the current LCS mission package slot

REQ.2.3 TECHNOLOGY REQUIREMENTS

REQ.2.3.1 The system shall have the capability of upgrading to near future technology.

REQ.2.3.2 The system shall incorporate existing technology that can be obtained within 3 months.

REQ.2.4 STANDARDS AND PROTOCOLS

REQ.2.4.1 The system shall be built on common components architecture

REQ.2.4.2 The system shall be to communicate with C2

REQ.2.4.3 The system shall works with detection systems

REQ.2.4.4 The system shall works with tracking systems

REQ.2.4.5 The system shall works with weapon systems

REQ.2.4.6 The system shall works with support systems

REQ.2.4.7 The system shall be capable with foreign BMD systems

REQ.2.4.8 The system shall be operated by 10 or fewer within 24 hours.

REQ.2.4.9 The system shall has the software integration ability

REQ.2.4.10 The system shall has the physical integration capability

REQ.2.4.11 The system shall has the capability of electrical integration

REQ.2.4.12 The system shall integrate with current as well as future global U.S. Ballistic Missile Defense System (BMDS)

REQ.2.5 COST REQUIREMENTS

REQ.2.5.1 The completed mission package shall cost less than one half of an AEGIS system (about $600M (FY12 $))

REQ.2.6 SCHEDULE REQUIREMETNS

REQ.2.6.1 The LCS integrated system shall target a capability need in the 2020 timeframe.

REQ.2.6.2 The system shall be deployment ready before 2025.

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APPENDIX F. MORPHOLOGICAL BOX

DETECT	CONTROL	ENGAGE	
		LAUNCH	INTERCEPT
EADS TRS-3D	AEGIS	Mk41VLS	PATRIOT/PAC 3
SEA GIRAFFE	PAAMS -Principal Anti Air Missile System (PAAMS)	Sylver A50 VLS	THAAD
SPY-1F(V)	INTEGRATED COMBAT MANAGEMENT SYSTEM	Patriot	GRIFFIN Block IIB *missile*
AN/MPQ-53 (PATRIOT)	COMBATSS-21 (LOCKHEED-MARTIN)	THAAD	Rolling Airframe Missile
AN/TPS-80 (G/ATOR)	THAAD	MEADS	ESSM
AMDR (IN DEVT)	PAC-3 (PATRIOT)	IRON DOME	HAWK
AN/TPY-2 (THAAD)	Battle MGT& Weapon Control (BMC) - IRON DOME	TOR VLS	ASTER 15
MEADS SR/MFCR	MEADS BMC4I		ASTER 30
SPACE-BASED INFRARED SYS (SBIRS)			SM-2
S1850M Long Range Radar			SM-3
IRON DOME (ISRAEL)			SM-6
SBX			EXOATMOSPHERIC KILL VEHICLE
SPY-1B/D			SEA DART
SPY-1D(V)			AIRBORNE LASER
SPY-1F			CWSS
SPY-1K			GROUND-BASED LASER
AN/FPS-108 COBRA DANE			
Fylingdales Early Warning Radar (RAF)			
HIGH ALTITUDE AIRSHIP			
Elevated Netted Sensor System (JLENS)			
Near Field Infrared Experiment (NFIRE)			
STSS			
THULE UPGRADED EARLY WARNING RADAR			
SMART-L			
EL/M-2080 GREEN PINE (ISRAEL)			

Doesn't meet key requirements | Meets some requirements | Meets most requirements

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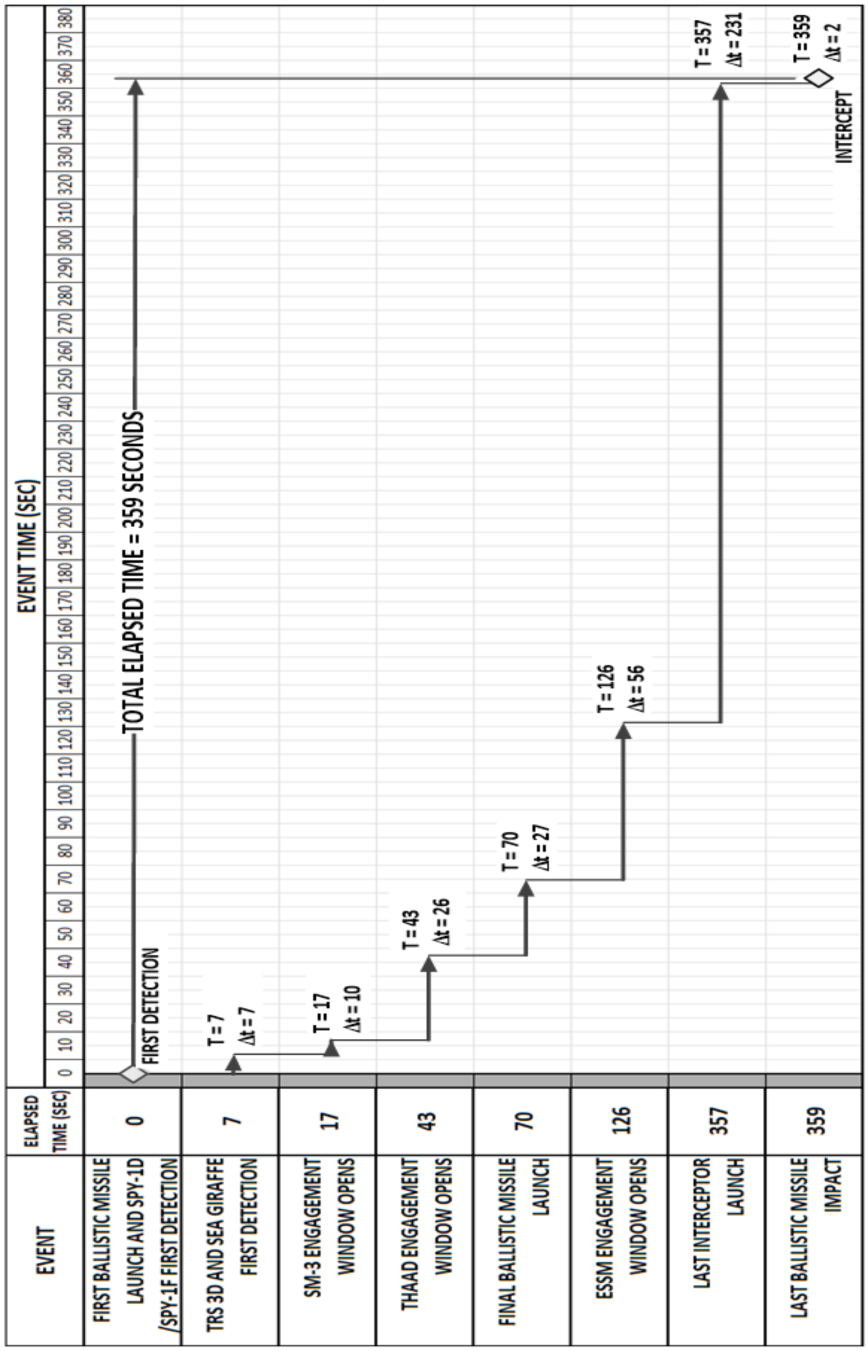
APPENDIX G. BMD ENGAGEMENT SEQUENCE



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