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System Architecture for Anti-Ship Ballistic Missile Defense (ASBMD)

by

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Approved for public release; distribution is unlimited.

Prepared for the Chairman of the Systems Engineering Department in partial fulfillment of the requirements for the degree of Master of Science in Systems Engineering.

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Recent studies suggest that China is developing a new class of ballistic missiles that can be used against moving targets, such as ships. One such technology is anticipated to cover a range of 2,000 kilometers and operate at a speed of Mach 10. The threat is also capable of maneuvering both during the midcourse and terminal flight phases for the purposes of guidance, target acquisition, and countermeasures. This threat could greatly impact the current concept of operations of U.S. Navy ships and alter national defense policies. While current ballistic missile defense solutions are capable of intercepting threats in midcourse and terminal flight phases, no comprehensive system has been developed to counter a ballistic missile threat that can (1) maneuver upon reentry in the endoatmosphere and (2) be used to attack a moving defended area, such as a U.S. Navy carrier strike group (CSG). To fulfill this need, the Anti-Ship Ballistic Missile Defense (ASBMD) team conducted research and developed a notional architecture for a system of systems solution that could be integrated into the existing Ballistic Missile Defense System (BMDS) to effectively counter this threat. This thesis documents the process that was used to select and integrate the proposed ASBMD architecture.

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ABSTRACT

Recent studies suggest that China is developing a new class of ballistic missiles that can be used against moving targets, such as ships. One such technology is anticipated to cover a range of 2,000 kilometers and operate at a speed of Mach 10. The threat is also capable of maneuvering both during the midcourse and terminal flight phases for the purposes of guidance, target acquisition, and countermeasures. This threat could greatly impact the current concept of operations of U.S. Navy ships and alter national defense policies. While current ballistic missile defense solutions are capable of intercepting threats in midcourse and terminal flight phases, no comprehensive system has been developed to counter a ballistic missile threat that can (1) maneuver upon reentry in the endoatmosphere and (2) be used to attack a moving defended area, such as a U.S. Navy carrier strike group (CSG). To fulfill this need, the Anti-Ship Ballistic Missile Defense (ASBMD) team conducted research and developed a notional architecture for a system of systems solution that could be integrated into the existing Ballistic Missile Defense System (BMDS) to effectively counter this threat. This thesis documents the process that was used to select and integrate the proposed ASBMD architecture.

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While there are currently ballistic missile defense solutions capable of intercepting threats in the midcourse and terminal phases of flight, no comprehensive system has been developed to counter a ballistic missile threat that can (1) maneuver upon reentry in the endoatmosphere and (2) be used to attack a moving defended area, such as a U.S. Navy carrier strike group (CSG).

To fulfill this need, the Anti-Ship Ballistic Missile Defense (ASBMD) team conducted research and developed a notional architecture for a system of systems solution that could be integrated into the existing Ballistic Missile Defense System (BMDS) to effectively counter this threat.

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ABBREVIATIONS AND ACRONYMS

AAW	Anti Air Warfare
ABL	Airborne Laser
ACTS	Aegis Combat Training System
Alt	Altitude
AoA	Analysis of Alternatives
ASBM	Anti-Ship Ballistic Missile
ASBMD	Anti-Ship Ballistic Missile Defense
AT&L	Acquisition, Technology, and Logistics
BDA	Battle Damage Assessment
BMD	Ballistic Missile Defense
BMDS	Ballistic Missile Defense System
bpsk	Biphase Shift Keying
C&D	Command & Decision
C2BMC	Command and Control, Battle Management and Communications
C2C	Command and Control Constellation
C2I	Command, Control, and Intelligence
C2P	Command and Control Processor
CDL-N	Common Data Link–Navy
CDR	Critical Design Review
CEC	Cooperative Engagement Capability
CEC-D	Cooperative Engagement Capability–Distributed
CJCSI	Chairman of the Joint Chiefs of Staff Instruction
COIL	Chemical Oxygen Iodine Laser
CONOPS	Concept of Operations
CSG	Carrier Strike Group
CSS	Chinese Surface-to-Surface
dB	Decibel(s)
dBm	Decibel(s) referenced to Milliwatt(s)
DBR	Dual-Band Radar
DDG	Guided Missile Destroyer

ABBREVIATIONS AND ACRONYMS (CONTINUED)

DDS	Data Distribution System
DF	Dong Feng (“East Wind”)
Dn	Down
DoD	Department of Defense
DoDAF	Department of Defense Architecture Framework
DoDI	Department of Defense Instruction
DRM	Design Reference Mission(s)
DRMP	Design Reference Mission Profiles
DRMS	Design Reference Mission Scenarios
EO	Electro-Optic
EoR	Engage on Remote
ERM	Element Readiness Manager
FC	Fire Control
FFG	Guided Missile Frigate
FOC	Full Operational Capability
FRP	Full Rate Production
FSA	Functional System Analysis
GBI	Ground-Based Interceptor
GBR-P	Ground-Based Radar–Prototype
GCCSM	Global Command and Control System Maritime
GPS	Global Positioning System
ICD	Initial Capabilities Document
IOT&E	Initial Operational Test and Evaluation
ID	Identification
IFICS	In-Flight Interceptor Communications System
IFTU	In-Flight Target Update
INCO	Installation and Checkout
IOC	Initial Operational Capability
IR	Infrared
JCIDS	Joint Capabilities Integration and Development System

ABBREVIATIONS AND ACRONYMS (CONTINUED)

KA	Kill Assessment
KEI	Kinetic Energy Interceptor
KFA	Key Functional Attribute(s)
kg	Kilogram(s)
km	Kilometer(s)
KPP	Key Performance Parameter
KSA	Key System Attribute(s)
LC	Launcher Control
LCS	Littoral Combat Ship
LoR	Launch on Remote
LRIP	Low Rate Initial Production
m	Meter(s)
MDA	Missile Defense Agency
MOE	Measure of Effectiveness
MOP	Measure of Performance
MP	Mission Processor
MRBM	Medium Range Ballistic Missile
MTBF	Mean Time Between Failures
MW	Milliwatt(s)
N/A	Not Applicable
NGC2P	Next Generation Command and Control Processor
nm	Nautical Mile(s)
NR	Not Ranked
OPIR	Overhead Persistent Infrared
ORTS	Operational Readiness Test System
PAC	Patriot Advanced Capability
Pd	Probability of Detection
PDR	Preliminary Design Review
PK	Probability of Kill
PMP	Project Management Plan

ABBREVIATIONS AND ACRONYMS (CONTINUED)

PRF	Pulse Repetition Frequency
QFD	Quality Function Deployment
RCS	Radar Cross Section
RF	Radio Frequency
SATCOM	Satellite Communication
SBIRS	Space-Based Infrared System
SBT	Sea-Based Terminal
SBX	Sea-Based X-Band Radar
sec	second(s)
SEP	Systems Engineering Process
SM	Standard Missile
SM-T	Standard Missile–Terminal
STSS	Space Tracking and Surveillance System
T&E	Test and Evaluation
TADIL	Tactical Digital Information Link
TADIL-J	Tactical Digital Information Link–Joint
TDACS	Throttleable Divert and Attitude Control System
TDL	Tactical Data Link
TEWA	Threat Evaluation and Weapons Assignment
THAAD	Terminal High Altitude Area Defense
TLAM	Tomahawk Land Attack Missile
UK	United Kingdom
U.S.	United States
UAV	Unmanned Aerial Vehicle
UEWR	Upgraded Early Warning Radar
USNI	United States Naval Institute
VLS	Vertical Lunch System
WCE	Weapon Control Element
WCS	Weapons Control System

I. INTRODUCTION

A. PROBLEM DESCRIPTION

A recent study (Erickson and Yang, 2009) suggests that China is developing ballistic missiles that can be used against moving targets, such as ships. One such technology is said to be able to cover a range of 2,000 kilometers (km) and operate at a speed of Mach 10. The threat is also known to possess the capability to maneuver both during the midcourse and terminal phases of flight for the purposes of guidance, target acquisition, and countermeasures. This type of threat could greatly impact the current concept of operations (CONOPS) of United States (U.S.) Navy ships and alter national defense policies. While there are currently ballistic missile defense solutions capable of intercepting threats in the midcourse and terminal phases of flight, no comprehensive system has been developed to counter a ballistic missile threat that can (1) maneuver upon reentry in the endoatmosphere and (2) be used to attack a moving defended area, such as a U.S. Navy carrier strike group (CSG). To fulfill this need, the Anti-Ship Ballistic Missile Defense (ASBMD) team will propose a notional architecture for a system of systems that could be used to effectively counter this threat.

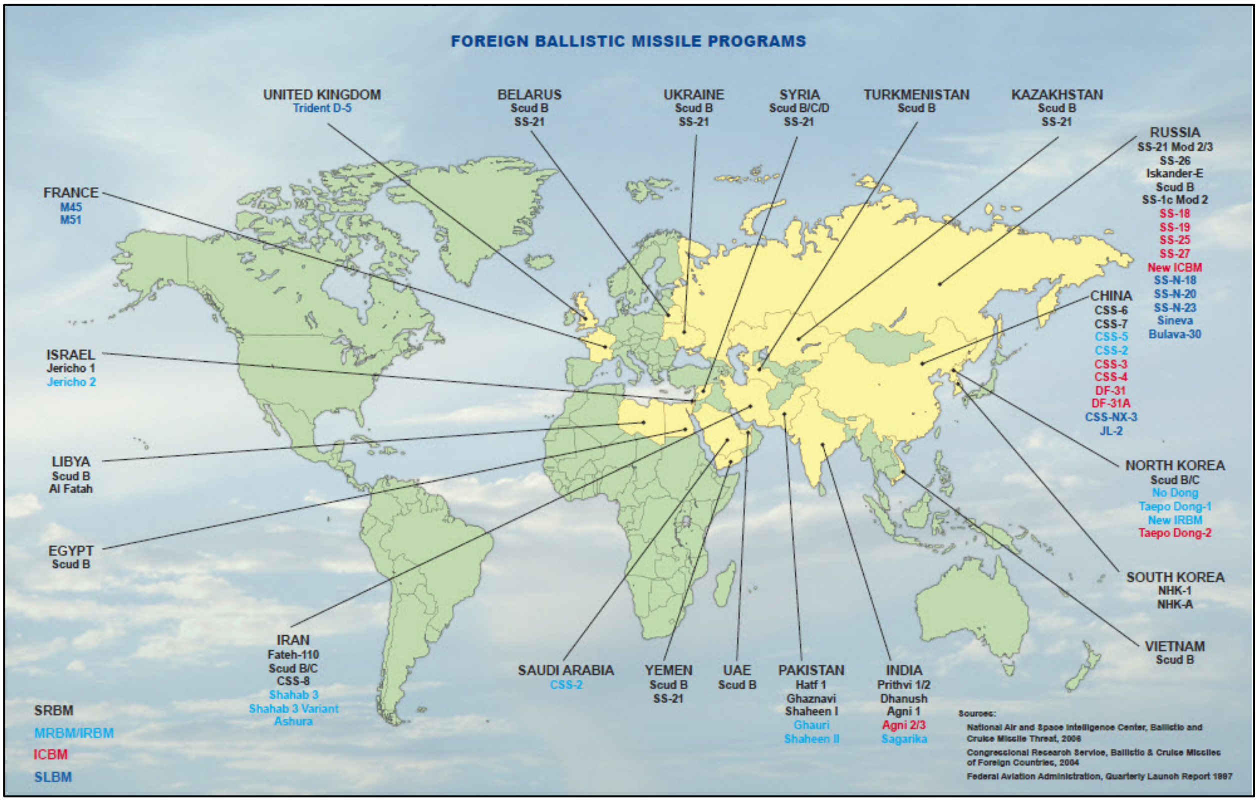
One example of such a threat is from China, which is pursuing an anti-ship ballistic missile (ASBM) based on a variant of its 1,500 km-plus range DF-21/CSS-5 solid propellant medium-range ballistic missile (MRBM). According to the U.S. Department of Defense (DoD), if supported by a sophisticated command and control system with accurate, real-time target data from China's growing family of terrestrial and space-based sensors, ASBMs could pose a significant threat to U.S. Navy CSGs in the Western Pacific. ASBMs would offer a variety of operational effects for Chinese maritime strategy, particularly with regard to missions involving Taiwan. If this coverage is achieved, it could impose significant restrictions on U.S. Naval operations during a Taiwan crisis or even hold U.S. theater land bases, such as those on Okinawa, at risk. Two key technical challenges for ASBM development are target acquisition and terminal phase guidance; these technical challenges are a result of the strict timing and resource constraints that are expected during the terminal phase of ballistic flight.

Figure 1 shows the notational maximum ranges of the DF-21/CSS-5 MRBM from locations in mainland China.

Note: Advertised functional ranges of the Chinese Ballistic Missile arsenal are depicted here. All ranges include limitations due to terrain and required flight trajectories (From Erickson and Yang, 2009).

Figure 1. Notional Maximum Ranges of DF-21/CSS-5

Modern ballistic missiles are based on designs that have been used since World War II. They can be launched from land or sea, from either stationary or mobile platforms. Ballistic missiles have become both the essential long-range artillery of modern warfare and one of the most successful means of exerting international pressure. The threat from ballistic missiles has grown steadily as sophisticated missile technology has become available on a wider scale to countries that are hostile to the U.S. and its allies. Figure 2 depicts the proliferation of these types of ballistic missile threats worldwide as of 2006.

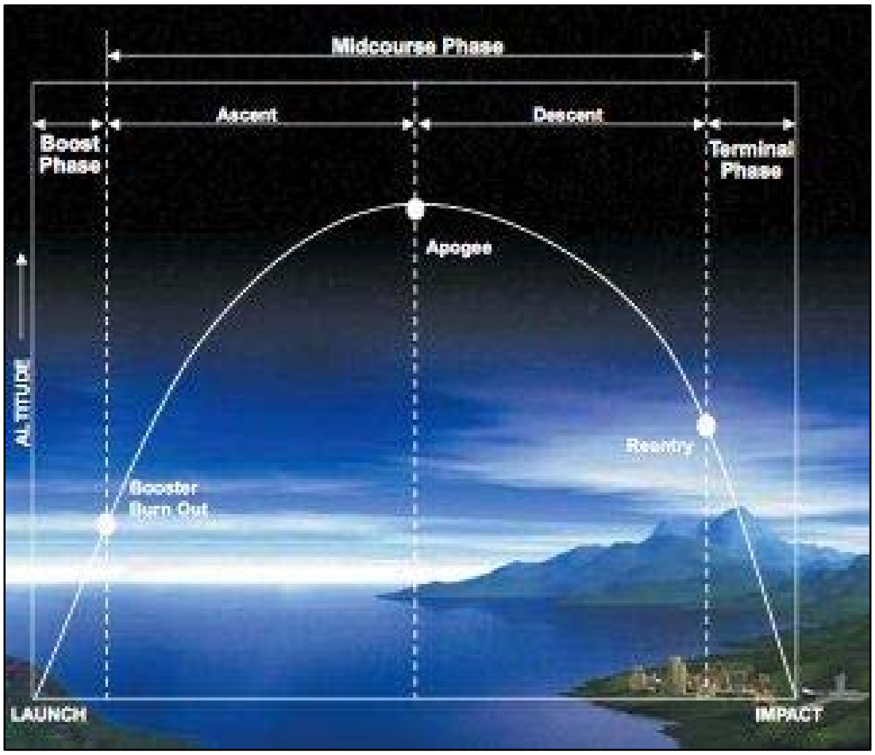


Note: Global ballistic missile proliferation has increased steadily in recent decades. Sophisticated missile technology is now more widely available to both U.S. allies and hostile nations (From Missile Defense Agency (MDA), 2009, April).

Figure 2. Evolving Security Environment, 2006

B. BACKGROUND INFORMATION

The typical ballistic missile uses a rocket engine to give it an initial thrust into the air, after which the only force acting on it is gravity to bring it back down to earth. The rocket engine consists of some form of fuel and oxidizer, whether solid or liquid based. Since ballistic missiles do not depend upon oxygen from the atmosphere, they can spend a portion of their flight beyond the earth’s atmosphere. Longer range ballistic missiles spend the majority of their flight in the vacuum of space. Figure 3 depicts the basic stages of flight for a nominal ballistic missile.



Note: Ballistic missile flight timelines can vary by missile type, but any threat classified as ballistic follows the same general flight profile (From *Missile Defense 101: ICBM Fundamentals*, 2007, May 9).

Figure 3. Stages of Ballistic Missile Flight

C. BOOST PHASE

A ballistic missile's range depends on the ratio between the thrust generated by its engines and the weight that the thrust must overcome. The range of any missile can be lengthened by reducing the load that it must carry. If the missile has multiple stages, the lower stages will drop off after they have expended their fuel, and therefore, lighten the load. At a designated point in space, the last engines shut off or burn out, which ends the boost phase of the missile's trajectory. The time between launch and engine burn out can range from less than one minute to over five minutes. From this point on, the laws of physics will carry what remains of the missile, as well as the payload, to the vicinity of the target.

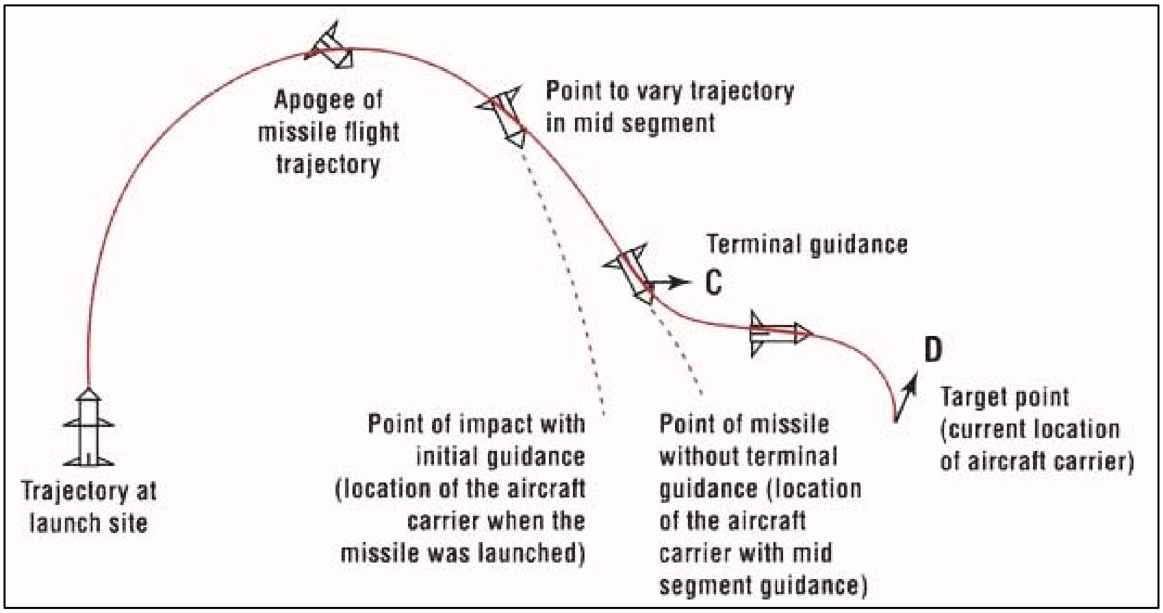
1. Midcourse Phase

The second phase of flight for a ballistic missile is the midcourse phase. As the missile reaches apogee, the section that carries the payload, called the post-boost vehicle, makes final adjustments to the missile's course. During this time, missiles that carry multiple warheads eject each warhead precisely in the direction of its individual target. They can also deploy countermeasures, such as decoys, to give false targets to enemy radars. Some post-boost vehicles are designed to release a number of small submunitions or lethal chemical/biological compounds instead of warheads and decoys. As warheads or reentry vehicles, decoys, and the remains of the missile coast over the top of the ballistic arc, and until they reach the upper edges of the atmosphere above the target, they fall freely. As they do so, these items gradually spread apart along their individual ballistic paths. They reach maximum speed at the end of the midcourse phase, before the atmospheric interference associated with reentry begins.

2. Terminal Phase

The final phase of flight for a ballistic missile is the terminal phase, which begins as the missile reenters the endoatmosphere. At this time, air molecules begin to slow, heat, and burn up any decoys and the remains of the post-boost vehicle. The warhead or reentry vehicle is hardened against heat and pressure and designed to enter the endoatmosphere with minimal damage. The range of the missile determines the angle at which the vehicle or warheads fall onto the target. Warheads from the longest range missiles arrive at shallow angles of little more than 20 degrees, while shorter range deliveries can impact at 45 degrees.

Typically, the warhead of a ballistic missile consists of single or multiple reentry vehicles. These reentry vehicles are free-falling, i.e., they have no independent mechanism that will direct them to their intended target. Their accuracy is dependent on the calculations made before launch, sometimes with minor course corrections being allowed during the midcourse phase of flight. The unique characteristic of the ASBM threat is that it will employ a maneuvering reentry vehicle. These reentry vehicles should be able to calculate course corrections and re-direct themselves to the intended target, such as a ship that has changed position since the time that the threat missile was launched. Figure 4 depicts a notional ballistic missile trajectory with the addition of a maneuvering reentry vehicle.



Note: Recent threat analysis has determined that multiple countries have created and tested a new class of ballistic missile that has the ability to maneuver during the terminal phase of ballistic flight for the purpose of striking moving targets, such as ships. Defense against terminal maneuvers represents a capabilities gap in existing combat systems (From Erickson and Yang, 2009).

Figure 4. Notional ASBM Trajectory with Maneuvering Reentry Vehicle

D. PROJECT DESCRIPTION

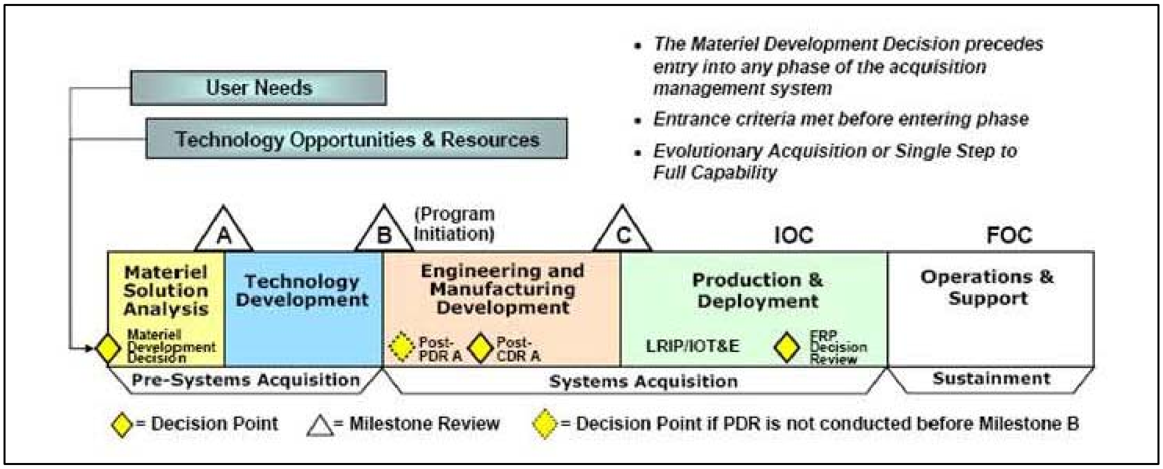
The objective of the proposed ASBMD System is to detect, track, and eliminate ASBM threats. The objective of the ASBMD team was to conduct research and document a proposed architecture for a system of systems solution that could be implemented to combat the evolving ASBM threat. The team has investigated and documented potential solutions to address this threat, while ensuring that currently fielded capabilities are not degraded.

The scope of this Capstone Project includes the research, creation, and documentation of the total system architecture that may be used to combat the identified ASBM threats. The following constraints were identified to bound the system that the team created. These constraints ensured that the team focused the requirements and functionality of the system to address the specific problem statement:

- ASBM threats will be launched from land.
- All current communication mechanisms required for conduct of the ASBMD mission are operational and deployed on all participating systems.
- The ASBMD System will be used for Ballistic Missile Defense (BMD) only.
- The ASBMD System will be integrated into and communicate with the existing BMD System (BMDS).
- The ASBMD System will not degrade the existing BMD network.
- The ASBMD System design will comply with all applicable U.S. military and/or commercial specifications and standards.

E. SYSTEM ENGINEERING APPROACH

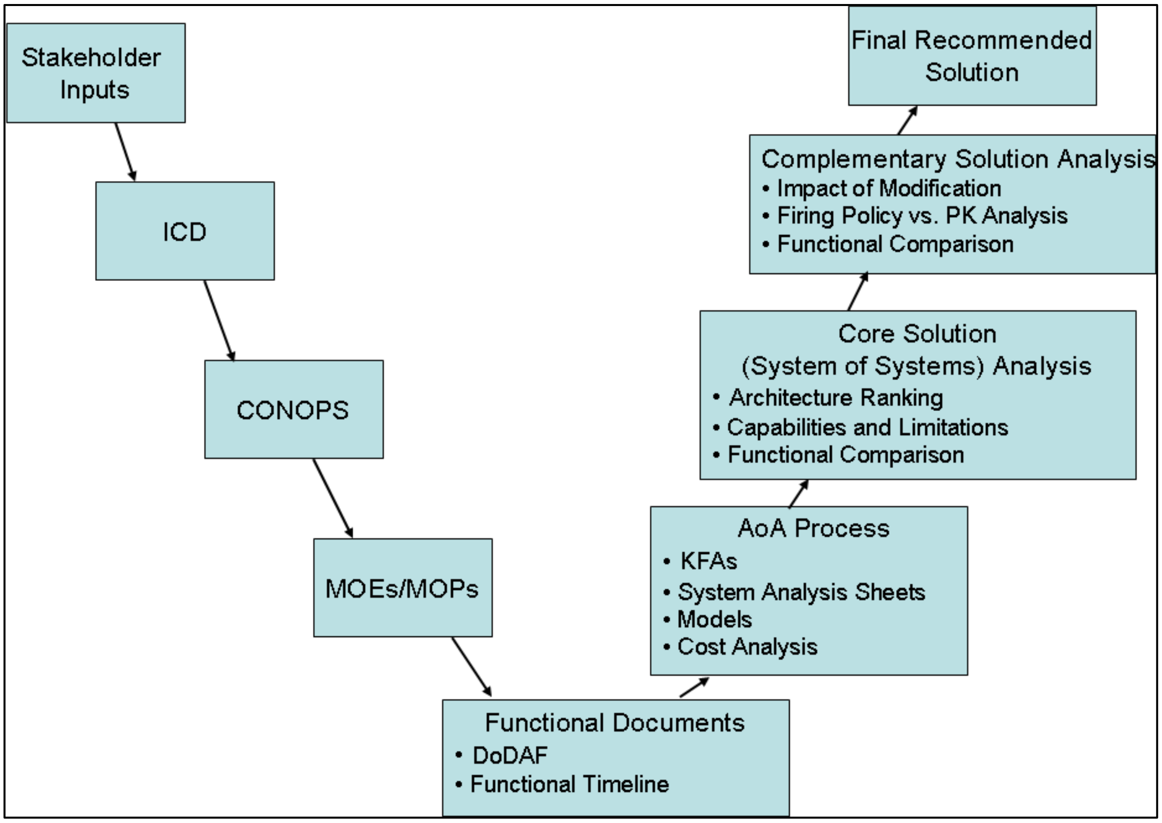
This project will focus on the Materiel Solution Analysis phase of the Defense Acquisition Management System, using Department of Defense Instruction (DoDI) 5000.02 (2008, December 8) as the guide. The ASBMD team has created high-level prototypes of several key documents identified in the Integrated Defense Acquisition, Technology, and Logistics (AT&L) Life Cycle Management Evolutionary Acquisition Program. Figure 5 depicts the high-level view of the Defense Acquisition Management System, with the area addressed by this project shown in yellow.



Note: Application of the Defense Acquisition Management System process is key to ensuring that all aspects of program acquisition and lifecycle management are followed throughout system development and fielding (From DoDI 5000.02, 2008, December 8).

Figure 5. ASBMD Focus within the Defense Acquisition Management Process

The ASBMD team has chosen to follow the "V" model version of the Systems Engineering Process (SEP). A representation of the "V" model for the Materiel Solution Analysis phase is provided in the Integrated Defense Acquisition, Technology, and Logistics Life Cycle Management Chart (Defense Acquisition University, 2009, June 15). The ASBMD team adapted this "V" model for use in ASBMD project development as shown in Figure 6. The "V" model approach provides a detailed framework and development guideline that enabled the team to analyze this capability gap from a top-down perspective. The "V" model is constructed to enable each document or analysis effort to build upon the previous effort, which ensured continuity throughout the project. The "V" model approach also contains continuous feedback loops during all stages of analysis and development, which ensured that analysis and research results were incorporated into the previous documentation. The team tailored the model to work within the limited scope and time allocated for the project; the team chose the specific documentation and artifacts that would provide the most benefit to the project and those that were prerequisites for the next phase of research. The team also chose to limit the scope of some of the documents. These limited-scope documents were designed as excerpts, indicating that the document contained only the sections that the team thought were required to allow the project to progress. The artifacts that were identified as required deliverables are detailed in the following chapters and are listed in section F below.



Note: The "V" model process is used to ensure that each artifact is created from a top-down perspective, ensuring a complete and robust system solution that is fully traceable through the system engineering process (Adapted from Defense Acquisition University, 2009, June 15).

Figure 6. Tailored Materiel Solution Analysis "V" Model

F. DELIVERABLES

The ASBMD team provided the following products for this Capstone project as individual deliverables, which are excerpted in this report:

- **Problem Statement**: Outlines the current system capabilities and threat assessments; this provides details of the current system functional gap.
- **Project Management Plan (PMP)** (Appendix A): Details the approach and schedule for developing the project documentation.

- **CONOPS** (Appendix B): Describes the project CONOPS and initial plan for integration of the solution into existing systems.
- **Functional Area Analysis**: Identifies operational tasks, conditions, and standards needed to accomplish the system objectives.
- **Functional Architecture** (DoD Architecture Framework (DoDAF) products): Depicts the overall system alignment and functions from a high-level system view; these detail interactions within the system and identify the key functions that are performed.
- **Initial Capabilities Document (ICD)** (Appendix C): Identifies the Key Performance Parameters (KPP) and Key System Attributes (KSA) (defined in the Chairman of the Joint Chiefs of Staff Instruction (CJCSI) 3170.01G, Joint Capabilities Integration and Development System (JCIDS) (2009, March 1)), which define the most critical system performance elements. This document is closely tied to the CONOPS to ensure that the KPPs identified meet the overall need of the system as originally defined during the analysis phase.
- **Analysis of Alternatives (AoA) Results**: Details the results of the evaluation of each possible system alternative. This analysis documents the ability of the alternatives to meet KPPs and KSAs, as well as affordability and schedule constraints.
- **Metrics, Models, and Simulation Analysis**: Details the models and associated metrics used to validate the performance of the chosen system to ensure that it meets the established Measures of Effectiveness (MOEs), Measures of Performance (MOPs), and KPPs.

II. SYSTEM ANALYSIS

A. OVERVIEW

This chapter describes the artifacts and analyses that the team created during the functional system analysis of conceptual system architectures. The following sections detail the process that was followed as the team derived high-level requirements from stakeholder inputs and decomposed those system requirements into the functional components of the system.

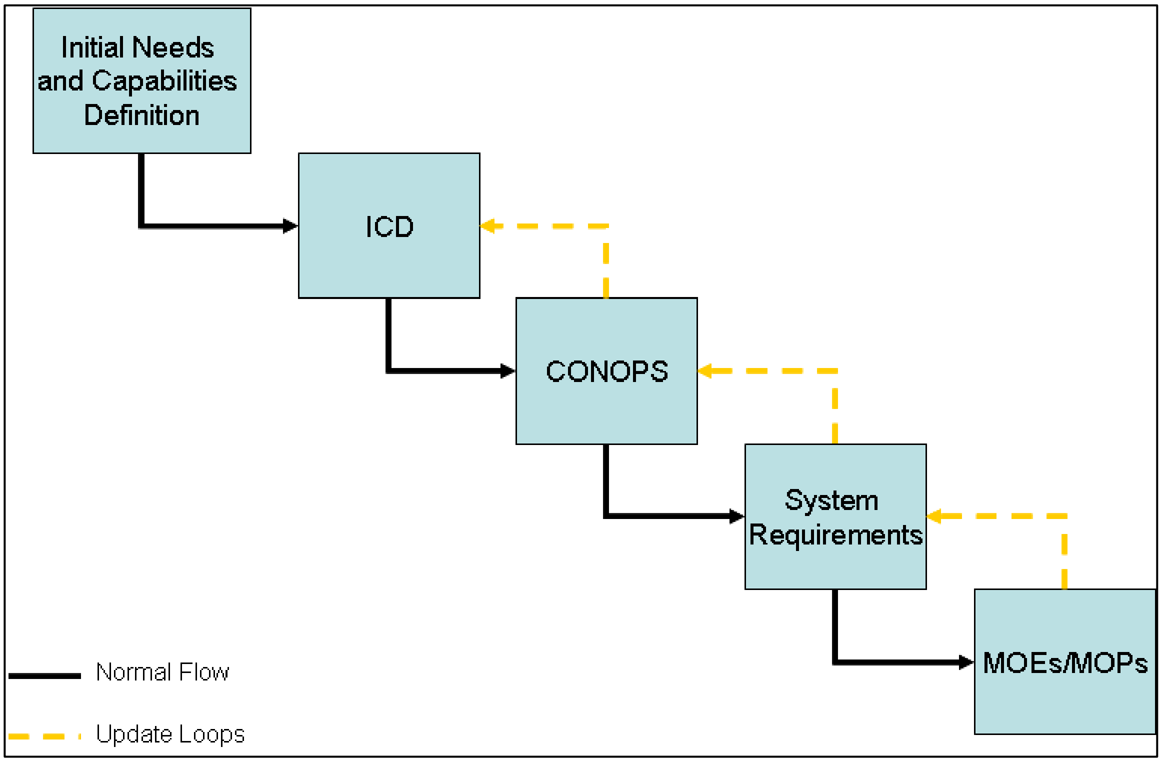
B. STAKEHOLDER ANALYSIS

To ensure that the system engineering process was applied in a manner that would yield a solution to thoroughly address the needs statement and fill the identified capability gap, the team obtained inputs from interested stakeholders. The stakeholders were identified as persons who could provide insight about technology needs from the fleet, program office, and end user perspectives. Inputs from these individuals were obtained via meetings, briefings, and surveys. Their insight was used to frame the analysis products and was also captured in the weighting of needs that was applied during the Functional System Analysis (FSA).

C. FUNCTIONAL SYSTEM ANALYSIS

An FSA is the process that the team used to derive the key functional artifacts required to build the notional ASBMD architecture candidates. This analysis began with a high-level initial needs statement that was similar to the problem statement that the team developed during the initial stages of the project. The next step in the process was to create the operational documentation that would help bound the system; this operational documentation consisted of the CONOPS and Design Reference Missions (DRMs). Using the operational documentation, the team was able to derive high-level system requirements and MOEs/MOPs and perform functional allocation, as well as create functional flow diagrams that detail the interactions of the system. Each step of the FSA process is detailed in the following sections of this chapter.

Figure 7 depicts the requirements generation process flow used to ensure the alignment of the system with the needs statement.



Note: Flow of requirements generation is key to ensuring that the final product meets stakeholder needs and operational/functional requirements.

Figure 7. ASBMD Requirements Generation Process

1. Concept of Operations

a. Purpose

The primary function of the ASBMD CONOPS document was to identify the scope of work for the investigation and documentation of a system architecture that could be used to implement a system to defend against ASBM threats. It detailed the operational needs and mission requirements for such a system. It also discussed potential gaps in the current systems being used to detect, track, and eliminate the latest ballistic missile and ASBM threats.

The ability to detect, track, and eliminate the identified ASBM threat will require, at a minimum, upgrades to existing systems. The primary goal of the team was to perform detailed analyses to determine the most robust system of systems to perform the full detect-to-engage sequence. To achieve this goal, the team would investigate both the use of existing systems and the development of new technologies, as appropriate, to fulfill all required functions.

Due to the maturity of existing capabilities to detect and track ballistic missiles during the boost phase, the ASBMD team focused the detailed analysis and architecture documentation on the post-boost phases of flight: tracking and eliminating the threats during later phases of the ballistic flight-path. Refer to Figure 3 for a graphical representation of a ballistic missile trajectory and its stages.

b. Threat Analysis of the Ballistic Missile Trajectory

Intercepting a missile in its boost phase is an ideal solution for BMD. If the missile is carrying a chemical, biological, or nuclear weapon, the debris would most likely fall on the country that launched the missile. At this altitude, the threat would not have obtained enough velocity to reach its intended target, eliminating the need to completely destroy the threat missile’s warhead. Although attacking a missile while it is struggling against the earth’s gravity is ideal, it poses several significant challenges to a defense system. First, the boost phase is relatively short, limiting the amount of time that sensors will have to detect a launch and relay accurate information about the missile. Second, an interceptor missile would have to be very close or extremely fast to intercept the accelerating missile and properly configured to intercept a target in the boost phase. When possible, for the global coverage and protection against more lethal payloads that it can provide, a capability to intercept a missile near its launch point is always preferable to attempting to intercept that same missile closer to its target.

The midcourse phase allows the largest opportunity to intercept an incoming missile. At this point, the missile has stopped thrusting, and it follows a more predictable path. Depending on the interceptor launch location, multiple interceptors could be launched with a delay between them to determine if the initial attempts were successful. Due to the increased engagement timeline, fewer interceptor sites are needed to defend larger areas. A longer period in space provides an attacking missile the opportunity to deploy countermeasures against a defensive system, if equipped to do so, but the defensive system also has more time to observe and discriminate countermeasures from the warhead.

The terminal phase of ballistic missile flight is normally less than one minute in duration. At this point, defensive systems must be very close to the threat missile's target in order to defend against the attack. Countermeasures are less of a challenge in this phase, as they usually fall at a slower rate than the warhead or are burned up as they reenter the atmosphere. Defensive systems designed for the terminal phase are most effective in protecting nearby troop concentrations, ports, airfields, and staging areas. Currently fielded terminal phase interceptors have not been proven effective against maneuvering reentry vehicles. More information is provided in the next section about current capabilities the U.S. has to counter ballistic threats.

c. Existing Capabilities to Address the Threat

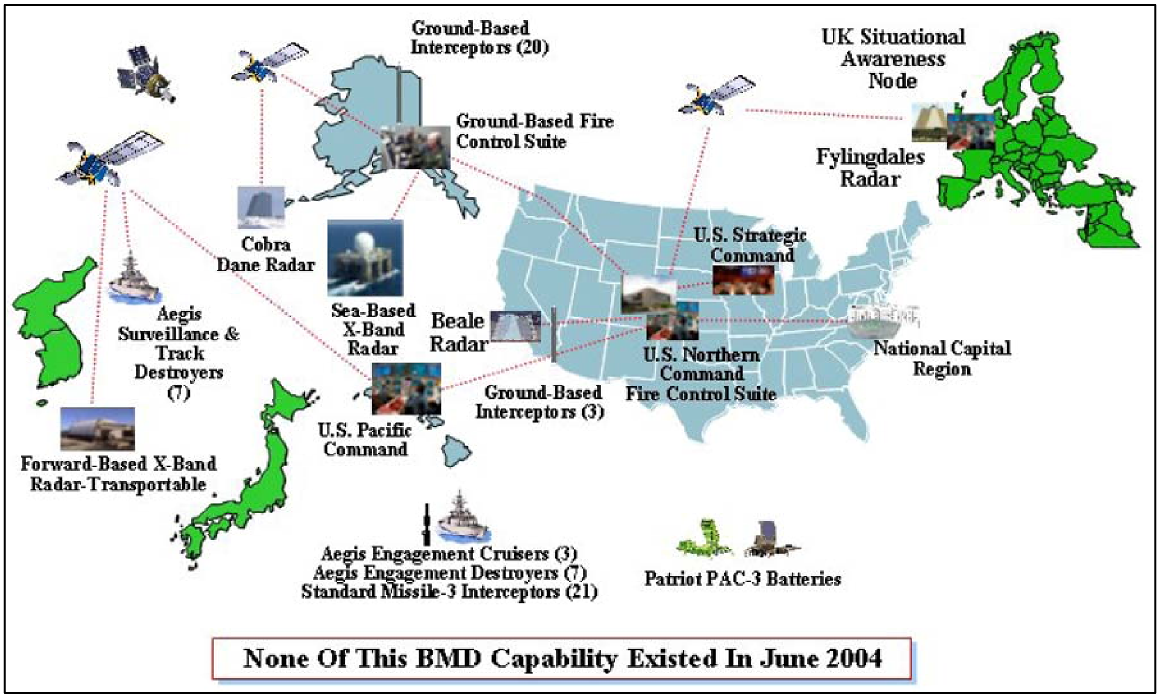
Multiple systems are currently deployed as part of the BMDS that are designed to combat ballistic missile threats. Each individual system is designed to focus on specific phases of the ballistic missile trajectory. When integrated within the BMDS, these systems provide a layered defense capability. Some examples of these systems and their primary functions are provided in Table 1.

Table 1. Existing BMD Systems

Note: The existing BMDS is a layered network comprised of a variety of systems and technologies. These systems provide BMD coverage in a variety of scenarios and ranges for a multitude of ballistic missile threats.

	System Name	Phase	Function
Weapon Systems	Kinetic Energy Interceptor (KEI)	Boost	Intercept
	Airborne Laser (ABL)	Boost	Intercept
	Ground-Based Interceptor (GBI)	Midcourse	Intercept
	Standard Missile (SM)-3 Block IA	Midcourse	Intercept
	Patriot Advanced Capability-3 (PAC-3)	Terminal	Intercept
	SM-2 Block IVA (SM-T)	Terminal	Intercept
	Terminal High Altitude Area Defense (THAAD)	Terminal	Intercept
	Arrow Weapon System	Terminal	Intercept
Sensors	Cobra Dane Radar	Boost/Midcourse	Detection/Tracking
	Cobra Judy Radar	Boost/Midcourse	Detection/Tracking
	Upgraded Early Warning Radar (UEWR)	Boost/Midcourse	Detection/Tracking
	AN/TPY-2 (Forward-Based Mode)	Boost/Midcourse	Detection/Tracking
	Sea-Based X-Band Radar (SBX)	Midcourse	Detection/Tracking
	AN/SPY-1	Midcourse/Terminal	Detection/Tracking
	AN/TPY-2 (THAAD Mode)	Terminal	Detection/Tracking
	Green Pine Radar	Terminal	Detection/Tracking
	PAC-3 Radar	Terminal	Detection/Tracking
	Space Tracking and Surveillance System (STSS)	All	Detection/Tracking
	Space-Based Infrared System (SBIRS)	All	Detection/Tracking

The Aegis BMD System is an example of a successful BMD system. This system uses both remote and local detection/tracking via ground and satellite-based sensor systems, as well as shipboard sensors. Once an external network sensor detects a threat and transitions it to a radar track, the remote systems can "hand over" the threat track to the shipboard AN/SPY-1 radar for organic (ownship) tracking and engagement. The handover of the threat track is accomplished by having the remote tracking system calculate a flight trajectory of the threat track and then cue the organic radar to a point in space where the threat will be at a given time. This method requires direct, high-speed communication between all elements in the system. The Aegis BMD system also relies heavily on the availability of the Standard Missile (SM)-3 or SM-2-Block IV missile to engage and destroy ballistic targets in the midcourse and terminal phases, respectively. These systems currently have no alternate or complementary shipboard weapons that could be used to combat a ballistic threat. Figure 8 is a pictorial representation of the Missile Defense Agency's BMDS, which includes the Aegis BMD system.



Note: Existing U.S. BMD assets as of 2007 are shown. The emerging ballistic missile threat has created an urgent need for a shift in U.S. policy to dedicate resources to the acquisition and fielding of BMD network assets (From Sanders, 2007, June 28).

Figure 8. Pictorial Representation of the MDA BMDS

Multiple systems are currently deployed or in development that have the ability to detect and track ballistic missiles during boost, midcourse, and terminal phases. Coupled with the existing system that provides the capability to engage these threats during all ballistic phases, the U.S. has a robust system design that has a successful track record during test intercepts of ballistic targets.

d. Shortcomings of Current Systems

As previously described, the current BMD systems rely heavily on the ability of remote, internal, and on-board sensors to predict and relay the flight path trajectory of the ballistic threat. The anti-ship threats that are being introduced have been designed to exploit limitations in the current deployed capabilities. Using the example threat given in the problem statement, the threat can be traveling in excess of Mach 10 at the time of reentry and can maneuver during the terminal portion of flight, altering its aimpoint and ultimately forcing a defense system to estimate a false trajectory. Given the current capabilities, the ability of the system to predict the ultimate flight path of these threats becomes impossible.

Another shortcoming of the current systems is that, for sea-based intercepts, they rely exclusively on the availability of ships configured with the Aegis BMD Weapon System and loaded with SM-3 or SM-2-Block IV missiles. Only 3 cruisers and 15 destroyers are configured to conduct Aegis BMD missions as of 2009, so these assets must be strategically located to provide adequate coverage. While the SM-3 Block IA is a full-rate production missile, it is only capable of conducting midcourse intercepts. The Sea-Based Terminal (SBT) terminal-phase intercept capability is provided by use of the modified SM-2 Block IV, also known as the SM-T missile. The modifications that were made to the SM-2 Block IV to achieve the SBT capability transformed the weapon from an Anti-Air Warfare (AAW) interceptor to a BMD interceptor. These changes enabled the missile to intercept high-velocity ballistic threats in the last moments of their flight. The SM-T missile is no longer in production, constraining the SBT capability to the remaining inventory in the near term. A far-term SBT capability using a different missile is under development, but will not be fielded for several years. Given the minimal system availability, a significant operational risk exists for most CSGs when operating within the expected range of ASBM threats.

Based on the capabilities deployed to date, if ASBM threats are put into full-rate production, a fundamental shift would be needed in the current operational CONOPS for the U.S. Navy. Without a robust and reliable system to counter these threats, U.S. Navy CSGs would be required to drastically reduce their ability to operate within close vicinity of countries that have the threat production capabilities.

e. Priority of New Features

The ASBMD System will perform the detection-through-engagement portion of the sequence for an ASBM threat. The specific benefits of the ASBMD System will be its ability to track and eliminate or avoid maneuvering threats during the midcourse or terminal phases of flight. The Navy will benefit from a robust architecture that can provide engagement-quality data to a system that can be used to eliminate the threat during the later phases of flight.

The ASBMD team has prioritized the key system features, taking into consideration existing systems that can perform portions of the mission. As stated earlier, multiple systems are being developed that have the ability to detect and engage ballistic missiles during both the boost and midcourse phases of ballistic missile flight; therefore, the priority of the proposed system and analysis is the tracking and engagement of ASBM threats during the post-boost phases of flight. Specifically, the team has prioritized engagement of the threat during the midcourse phase of flight as the highest priority of the proposed system; a midcourse intercept would eliminate the threat before it can conduct its maneuver.

For operations within the terminal phase of flight, there are two key system functions—tracking and engagement—that have also been prioritized for assessment. The ASBMD team prioritized tracking of the reentry vehicles as the highest priority, and then the engagement of the threats as the second highest. The ASBMD System is dependent on the ability of the system to provide engagement quality data to engage and eliminate the threats; therefore, accurate tracking of the threats is of the utmost importance.

f. Functional Analysis Results

The ASBMD capability will be achieved by a system of systems that, to meet its mission requirements, is comprised of a minimum set of components. Components considered and analyzed included: radar, electro-optic (EO)/infrared (IR) sensors, passive electronic warfare sensors, communications/link architecture, command and control systems, decoys, electronic countermeasures, and one or more weapon systems.

A preliminary functional analysis resulted in a list of the primary system functions, as follows:

- **Search**: The system will be capable of conducting search functions in self-defense and BMD modes.
- **Detect**: The system will be capable of detecting an incoming threat organically (using ownship sensors). The system will also be capable of initiating engagement sequences based on remote sensor detection and track hand-off.
- **Acquire Track**: The system will be capable of conducting organic track acquisition and communicating that track to the BMDS. The system will also be capable of launching on remote track data (with eventual acquisition of the track organically) or full engagement on remote track data (with no organic track acquisition).
- **Planning**: The system will be capable of communicating with BMDS resources for determination of the best use of local radar and weapon resources.
- **Identification**: The system will be capable of identifying the threat type via on-board sensor discrimination and will not engage on countermeasures.
- **Engagement**: The system will be capable of executing an engagement against the incoming threat.
- **Kill Assessment (KA)**: The system will provide KA data to the operator and the BMDS so that a determination of kill and the potential for reengagement can be assessed.

The system must be capable of surviving and operating in the tactical environment and will meet all requirements for system certification and fielding. Ships with this capability can be deployed in any operational area necessary to provide coverage in the ASBMD mission area. The system, as designed, must interface with the larger BMDS for the purposes of battle management and command and control. It will interface with its battlegroup or ships-in-company for local fire control, radar resource, and weapon management.

Currently, there is no single solution to address the ASBM threat. In designing a system-of-systems solution, a key objective of this project was to consider technologies that would complement a layered approach that takes advantage of remote and forward-based capabilities as well as organic/ownship capabilities. Any leveraging of existing technology will require that the systems are made more robust to meet requirements for sensor function, detection, and BMDS interfaces. The final aim of the system design is to propose a reliable, compatible, and interoperable ASBMD functionality to support defense of critical assets and mission areas to the Navy.

2. Design Reference Mission Profiles and Scenarios

a. Purpose

As defined by Pace (2000), a DRM defines the specific projected threat and baseline operating environment for a given system; these may range from a single-purpose weapon system to a multi-mission platform, or to a multi-system, multi-platform system of systems. The ASBMD DRM provides a notional description of deployed operations for the mission as described in the ASBMD CONOPS. It is primarily an engineering/design tool used to support systems engineering activities by identifying significant, design-driving operational elements and characterizing them to the level of detail necessary to assess their design impact. The DRM is intentionally modular to allow the team to tailor or modify the scenario and its components over time in order to update operational and warfighting requirements and prospective solutions. To this end, the DRM is envisioned as an evolutionary document that can be revised throughout the acquisition process. The DRM is comprised of two distinct components: Design Reference Mission Profiles (DRMP) and Design Reference Mission Scenarios (DRMS); each component will be detailed in the following sections.

b. DRM Profiles

The DRMP is a matrix of the best, expected, and worst values for each of the operational conditions for the ASBMD system. The DRMP helped bound the operational capabilities of the system by defining the overall timing requirement for each of the sub-functions of the ASBMD system.

The example DRMP is shown below in Table 2.

Table 2. DRMP for the ASBMD System

Note: The DRMP is a matrix of the best, expected, and worst values for each of the operational conditions to which the concept architecture will be exposed. The DRMP helps to ensure that the system requirements cover the operational context of the system.

Event	Required Equipment	Factors			
		Condition	Best	Expected	Worst
Missile Launch	N/A	# of Missiles	1	2	4
		# of Locations	1	1	2
Missile Detection	Organic/Nonorganic Detection System	Time to Detect	1s	10s	No Detection
		Ship Time to Detect	1s	20s	No Detection
Missile Tracking	Organic/Nonorganic Tracking System	# of Missiles	1	2	6
Compute Fire Control Solution	Organic/Nonorganic System	Time to Compute	1s	3s	10s
Transmit Kill Order	Communication Network	Time to Transmit	1s	5s	10s
Missile Engagement	Participating Units	Weapons Available	5	3	1
Missile Kill Assessment	BDA Capable System	Operational	Yes	Yes	No
Missile Re-Engagement	Participating Units	Weapons Available	Yes	Yes	No

c. DRM Scenarios

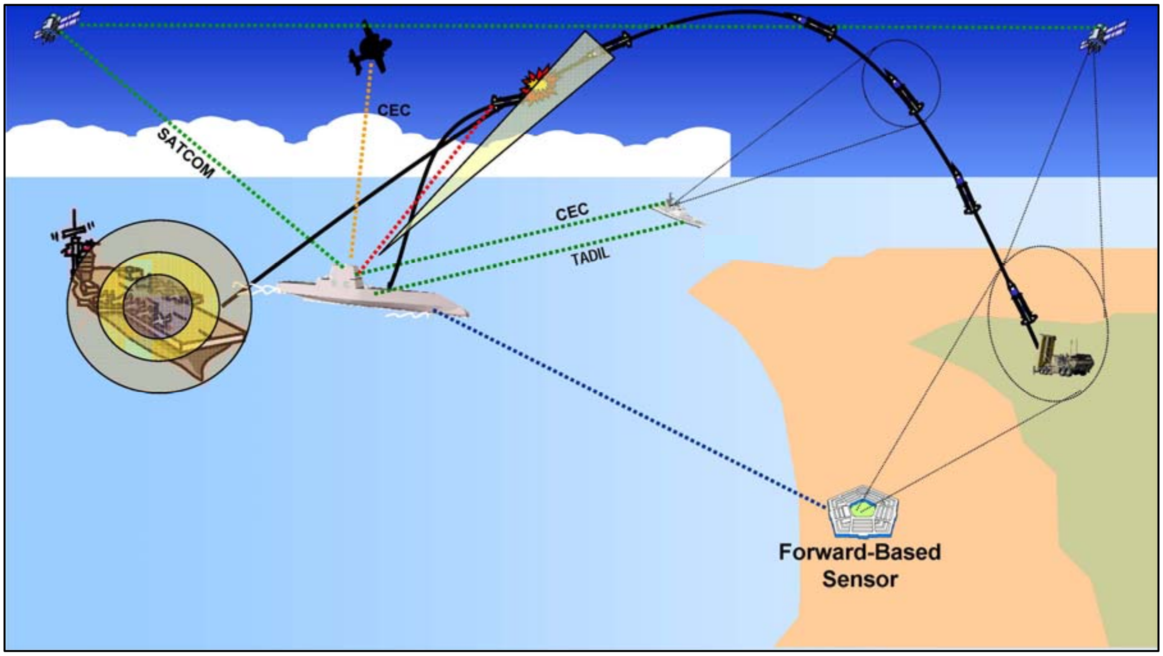
The DRMS are graphical representations of the DRMP criteria. The DRMS that the team created, along with the general explanation of each, are shown below.

The best scenario in DRM terms is one in which the ideal conditions for operation of the system are present. For ASBMD, the best case scenario consists of the following conditions:

- A single threat is launched from a known launch site.
- All participating defense systems/units are online and fully operational.

- Environmental factors do not impact performance.

Figure 9 depicts the best case scenario for the ASBMD system.



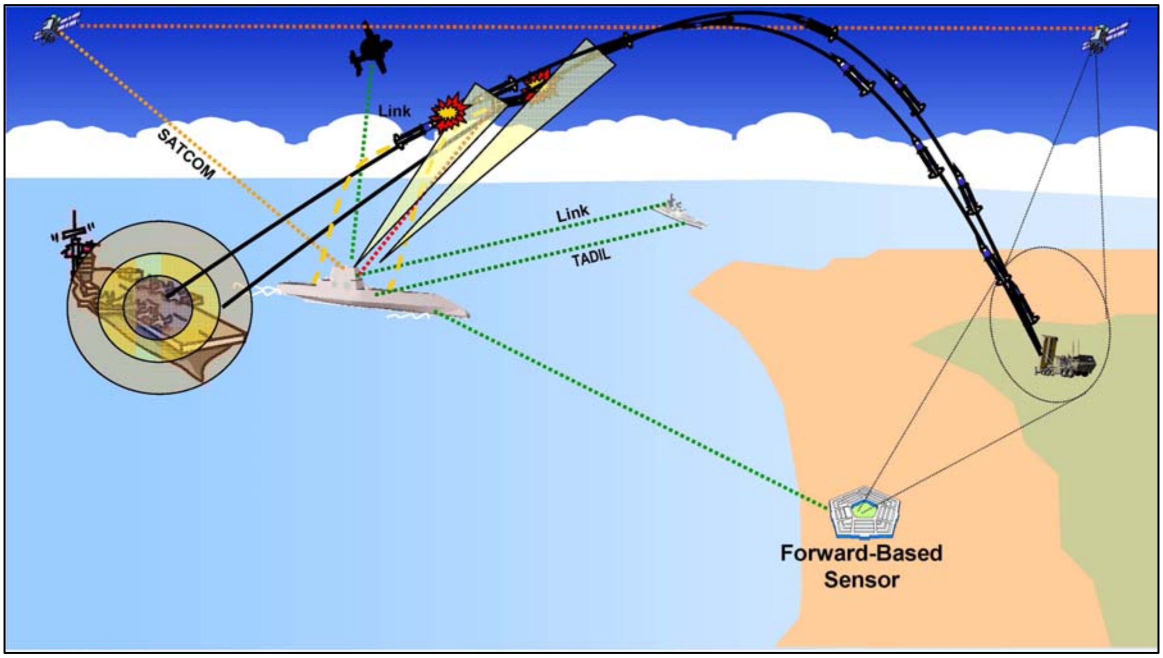
Note: The best case DRMS represents the minimal threat environment that the system will encounter. Using the best case DRMS will help bound the minimum capability required of a system in the optimal environment.

Figure 9. DRMS 1 (Best) for ASBMD

The expected scenario is depicts the conditions that the ASBMD System is most likely to encounter in the tactical environment. Conditions in this scenario are neither ideal nor dire. The conditions for the expected scenario are as follows:

- Multiple incoming threats are launched from one launch site.
- Satellite coverage is provided for one launch site.
- The CSG experiences average environmental conditions and their associated performance impacts.
- Three defense units are participating: Satellite, Forward-Based Sensor, and Firing Ship.

Figure 10 depicts this scenario.



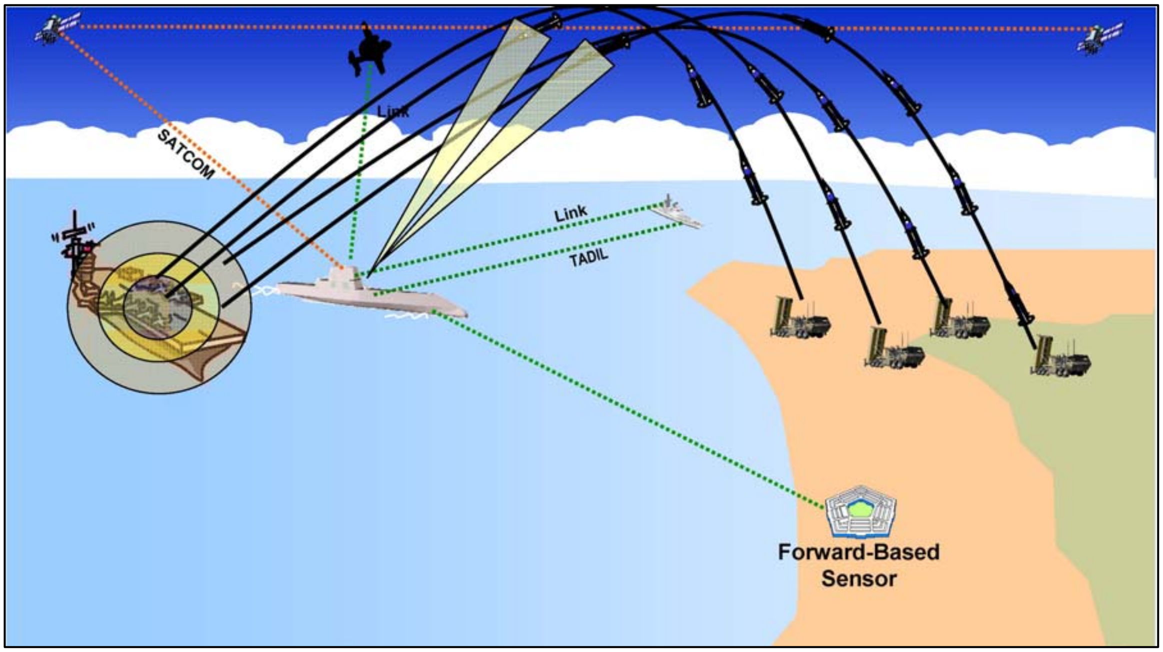
Note: The expected case DRMS represents the nominal threat environment that the system will encounter. This scenario is used to derive the objective values for many of the system performance requirements.

Figure 10. DRMS 2 (Expected) for ASBMD

The worst case scenario is a depiction of the worst operational environment that the ASBMD System is expected to encounter. The conditions for this scenario are as follows:

- Multiple incoming threats are launched from multiple launch sites.
- Participating units experience performance degradation due to adverse environmental conditions.
- Detection and tracking of threats is unreliable.

Figure 11 shows this scenario for ASBMD.



Note: The worst case DRMS represents the most taxing threat environment that the system will face. This scenario is used to determine the upper bounds of the system capabilities, including bounding values for computer processing and network loading requirements.

Figure 11. DRMS 3 (Worst) for ASBMD

3. Initial Capabilities Document

a. Purpose

The primary function of the ASBMD ICD, provided as Appendix C, was to describe the need for a material approach to fill the functional gap within the current BMDS that is created when ASBM threats are introduced into the arsenals of enemy combatants. This document defines the existing capability gap in terms of the functional areas affected and also describes why non-material changes alone are not adequate to fully provide the needed capability.

b. Functional Requirements

The following is a list of high-level functional requirements that was used as the basis for the follow-on system analysis and decomposition. It is an excerpted list of requirements provided as part of the ICD, and should not be viewed as a complete list of requirements that the system must meet.

- The ASBMD System shall be capable of sending, receiving, and processing intelligence reporting messages to be used for situational awareness related to ballistic missile flight path. (This includes, but is not limited to, the ability to receive and process Global Command and Control System Maritime (GCCSM), Tactical Data Link (TDL) (Link-11, Link-16), and Data Distribution System (DDS) messages.)
- The ASBMD System shall process received intelligence messages and create radar search sectors to be used by both on-board and off-board sensors.
- The ASBMD System shall be capable of tracking no less than 10 vehicles during the midcourse and/or terminal phases of missile flight path. Tracking shall include the production and dissemination of engagement quality data.
- The ASBMD System shall be capable of near simultaneous engagement of no less than two ballistic vehicles.
- The ASBMD System shall be capable of performing Launch on Remote (LoR) using fire control quality data from the BMDS network.
- The ASBMD System shall be compatible with the ship's requirement and capability to perform both self-defense (i.e., AAW) and BMD missions.
- The ASBMD System shall have a Mean Time Between Failures (MTBF) that is greater than or equal to the MTBF of the existing BMDS architecture into which the ASBMD System will be integrated.
- The ASBMD System shall have the ability to perform high fidelity object discrimination.
- The ASBMD System shall have the ability to perform localization.
- The ASBMD System shall have the capability to perform threat identification.

c. Measures of Effectiveness and Measures of Performance

MOEs and MOPs are quantitative measures that give some insight into how effectively a unit must perform under the operational conditions defined in the CONOPS and detailed in the DRMs. The MOEs for this project were defined primarily through the use of stakeholder inputs, as described earlier in this chapter. The ASBMD team defined the MOPs using the nominal values that were obtained during the initial investigation and analysis portion of the project. The key ASBMD System MOEs and MOPs are identified in Tables 3 and 4, respectively. As with the system requirements, these lists should not be considered complete, as they are excerpts from the documents that were used to help bound the system.

Table 3. ASBMD MOEs

Note: MOEs are defined by stakeholder inputs. They are used to measure the ability of the concept architectures to meet the operation needs of the overall system.

MOE	Description	Objective
P_D	Probability of detection	0.95
P_F	Probability of false alarm	0.005
P_{Kill}	Probability of kill	0.97
P_{id}	Probability of correct identification	0.9997
P_{dis}	Probability of correct discrimination	0.9997
$MaxTgt_{eng}$	Maximum number of targets engaged	2.0
P_{info}	Probability of information exchanged	0.9999
$MaxTgt_{trk}$	Maximum number of targets simultaneously tracked	10.0

Table 4. ASBMD MOPs

Note: MOPs are defined by stakeholder inputs. They are used to provide a measurement of the ability of the system to perform in a system of systems context.

MOP	Description	Objective
T_{trk}	Track formulation time	0.5 sec
T_{det}	Organic detection time	6 sec
T_{eng}	Engagement time	60 sec
T_{re-eng}	Re-engagement time	15 sec
T_{kill}	Time to conduct kill assessment	10 sec
N_{eng}	Number of simultaneous engagements	2

4. Functional Analysis and Allocation

Functional Analysis is the process by which the team took the identified key system requirements (*How's*) and the need statements (*What's*) and combined them into a Quality Function Deployment (QFD) matrix. Each need statement was weighted by using the inputs solicited during the stakeholder analysis portion of the project. Next, the requirements were rated against the needs statements; each requirement was assigned a numerical rating between one and ten that corresponds to the level of influence that it has in fulfilling the identified needs. The mapping of requirements to mission needs is depicted in Table 5. The team used this process to assist in the allocation of requirements to the identified functions of the system. Each function will be detailed in the following sections of this document and is depicted in Table 6.

Table 5. Functional Analysis

Note: Functional Analysis ensures that each identified functional requirement is mapped to an identified need. Each need is weighted to help drive the functional prioritization of the system.

Functional Analysis								
		Requirements (*How's*)						
Needs (*What's*)	**Weights**	Capable of processing received intelligence messages and creating radar search sectors for use by on-board and off-board sensors	Capable of performing launch on remote using fire control quality data from the BMDS network	Capable of performing both self-defense and BMD missions	Capable of an MTBF that is greater than or equal to the MTBF of the existing BMDS	Capable of sending, receiving and processing intelligence reporting messages to be used for situational awareness	Capable of near simultaneous engagement of no-less-than two ballistic vehicles	
Protect other assets from ballistic missiles	0.275	8	7	8	5	8	9	
Interoperable with BMDS	0.15	9	8	4	5	9	3	
Stand-alone BMD capability	0.15	3	3	9	3	3	9	
Destroy ballistic missiles with a high probability of kill	0.275	7	7	9	5	6	9	
Operate across a wide range of environmental conditions	0.15	5	5	7	8	9	7	
Sum	**1**							
Weighted Performance		16.4	16.0	20.6	16.0	19.4	20.7	**109.1**
Percentage		0.151	0.147	0.189	0.147	0.178	0.190	

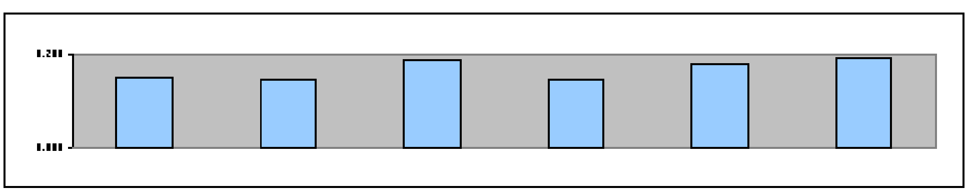


Table 6. Functional Allocation

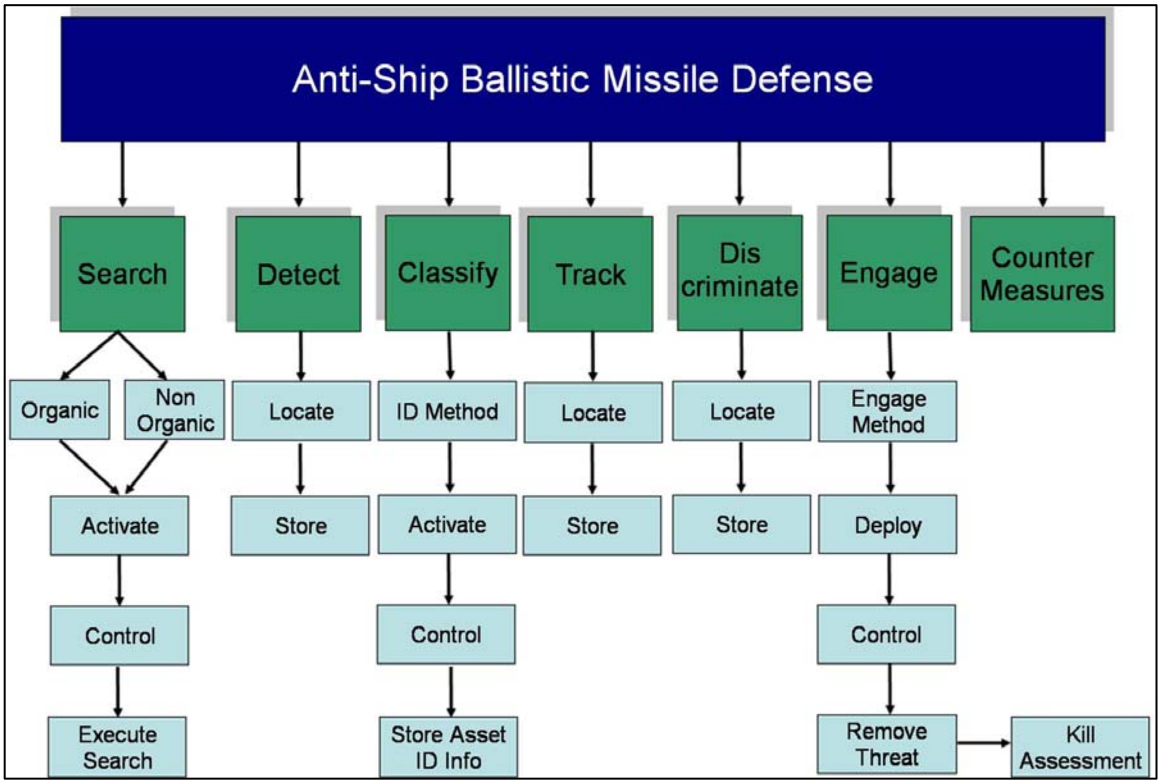
Note: Functional Allocation is the mapping of system functions to the known components of the functional architecture. This mapping ensures that the system under analysis is sufficiently bounded and that there is no unintentional overlap of functions.

	Components				
Functions	**Nonorganic Assets**	**Organic Radar**	**Fire Control System**	**Data Transfer System**	**BMDS**
Receive/Transmit Intelligence Cueing				X	
Detection	X	X			
Classification	X	X			
Tracking	X	X			
Discrimination	X	X			
Identification		X			
Decide and Assess	X				X
Engage Ballistic Missile			X		
Perform Kill Assessment	X		X		

5. Functional Flow Diagrams

The proposed ASBMD System is scoped as a system of systems that provides a set of value-added functions within the existing BMDS. The system's objective is to provide increased capabilities to defend against and eliminate ASBM threats. The proposed system will be fully integrated, interrelated, and interoperable with the existing BMDS. As a result, the ASBMD System will be an information environment within an existing combat system comprised of interoperable computing and communication components.

As stated earlier, the ability of an ASBM threat to maneuver during its terminal phase of flight is what differentiates it from a typical ballistic missile. Due to the distinct operational attributes of the ASBM threat, the unique functionality of the ASBMD System will be limited to the tracking and elimination of these threats during the post-boost phases of flight. The individual system functions required to complete an engagement sequence were defined in the requirements analysis and then documented via functional flow diagrams to show the interrelation of system functions and the information flow between them. Figure 12 depicts the high-level, notional functional decomposition of the ASBMD System. The detailed decomposition of each individual system function is described in this section.

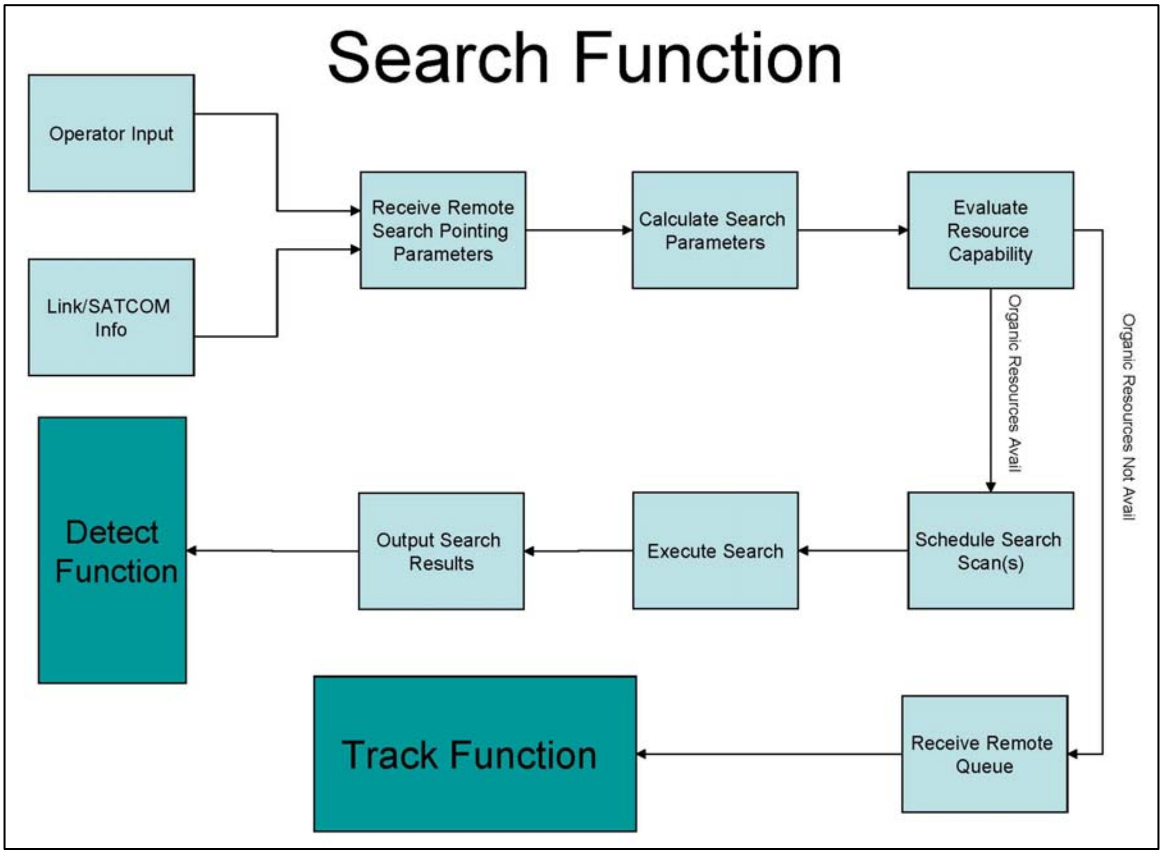


Note: Creating functional decomposition diagrams ensures that all functions in the system are described both individually and as a part of the overall system architecture. The hierarchical decomposition model enables more concise decomposition of system functions.

Figure 12. Notional ASBMD System Decomposition

a. Search

The basic flow of the search function is depicted in Figure 13. The search function initiates upon receipt of a cueing signal from either an off-board source (i.e., an external, BMDS network sensor) or the human operator. The cueing parameters are then converted to radar parameters that are used to build the sector of space that will be searched. After calculation of the radar parameters and required resources, the system evaluates the ability to perform the requested search function with organic resources. At this point in the functional flow, the system takes one of two actions: Either it determines that organic resources are available and will carry out the search function, or, in the absence of organic resources, the system waits for remote search data from the BMDS to be passed to the tracking function. In this document, this type of track data transfer from the BMDS will be referred to as Launch on Remote (LoR).

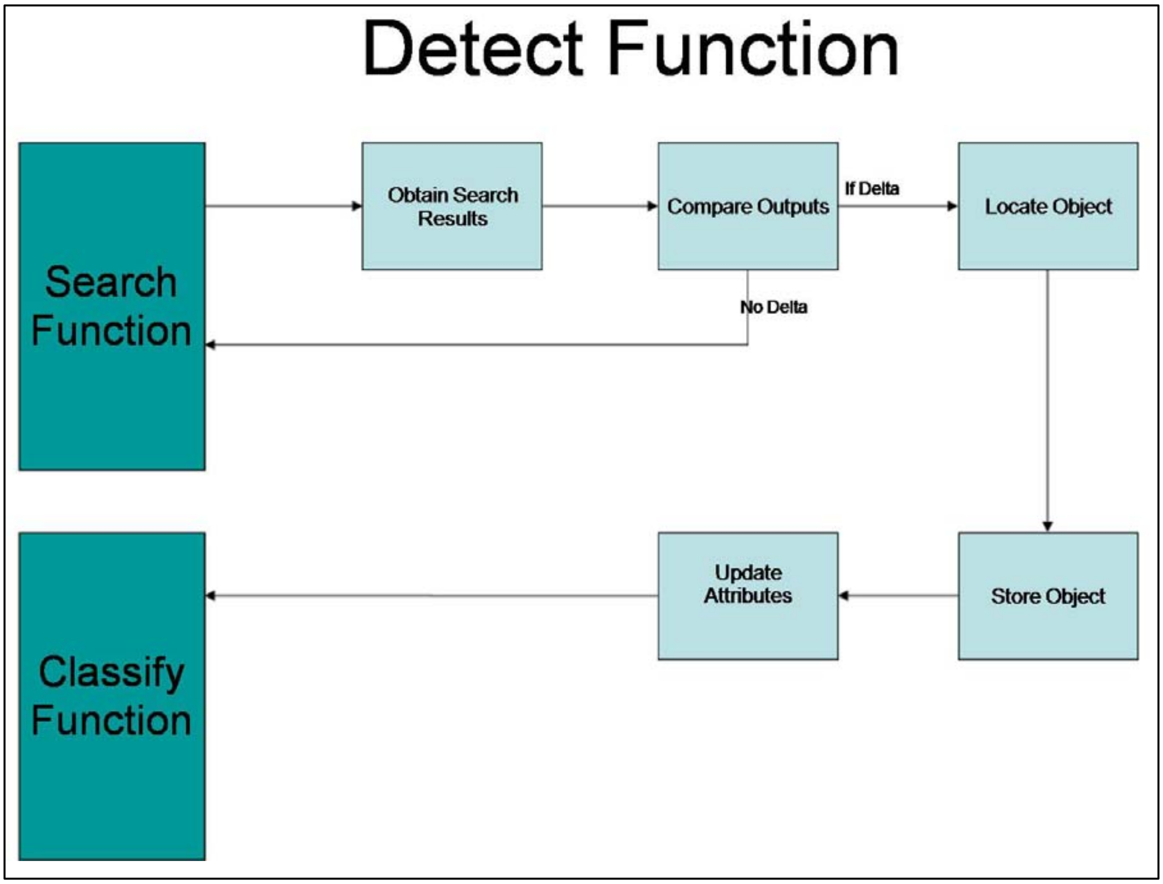


Note: The search function of the system takes operator input or data from off-board sources and directs organic sensors to transmit radio frequency (RF) to a specific point or area in space.

Figure 13. Search Functional Flow Diagram

b. Detect

The detect function is shown in Figure 14. The detect function begins when search results are received from either organic or remote sensors. The results from the search function are compared against the current file of existing objects, and the system determines if any attributes are new or have changed. If changes or new objects are noted, the location information is sent to the classify function.

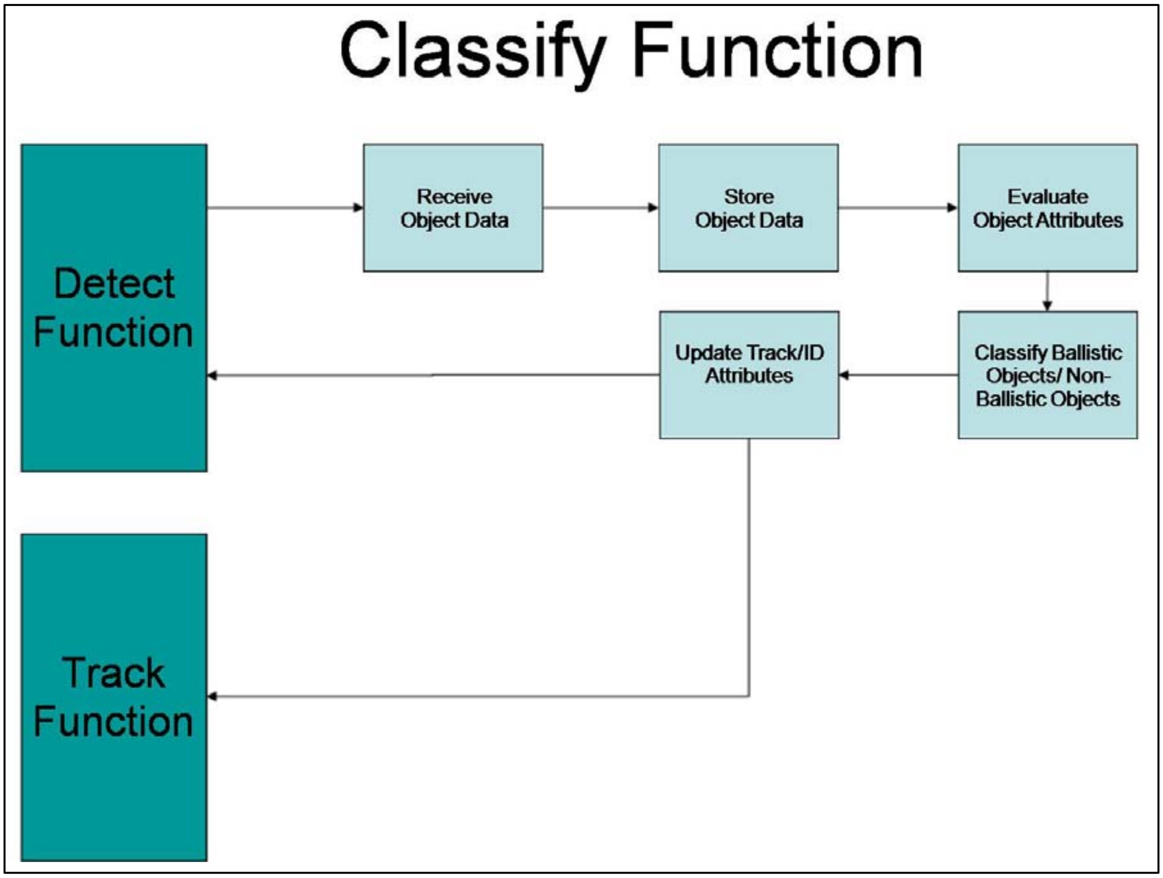


Note: The detect function receives search results in the form of an RF return map and compares it with the existing RF map to determine if a new object exists.

Figure 14. Detect Functional Flow Diagram

c. Classify

The classify function is shown in Figure 15. The classify function receives object attributes (i.e., altitude, speed, Radar Cross Section (RCS), etc.) from the detect function and compares them with algorithms to determine if they represent ballistic or non-ballistic objects. Upon determination of the classification of the objects, the classify function updates the object attributes including the identification and passes the information to the track function.



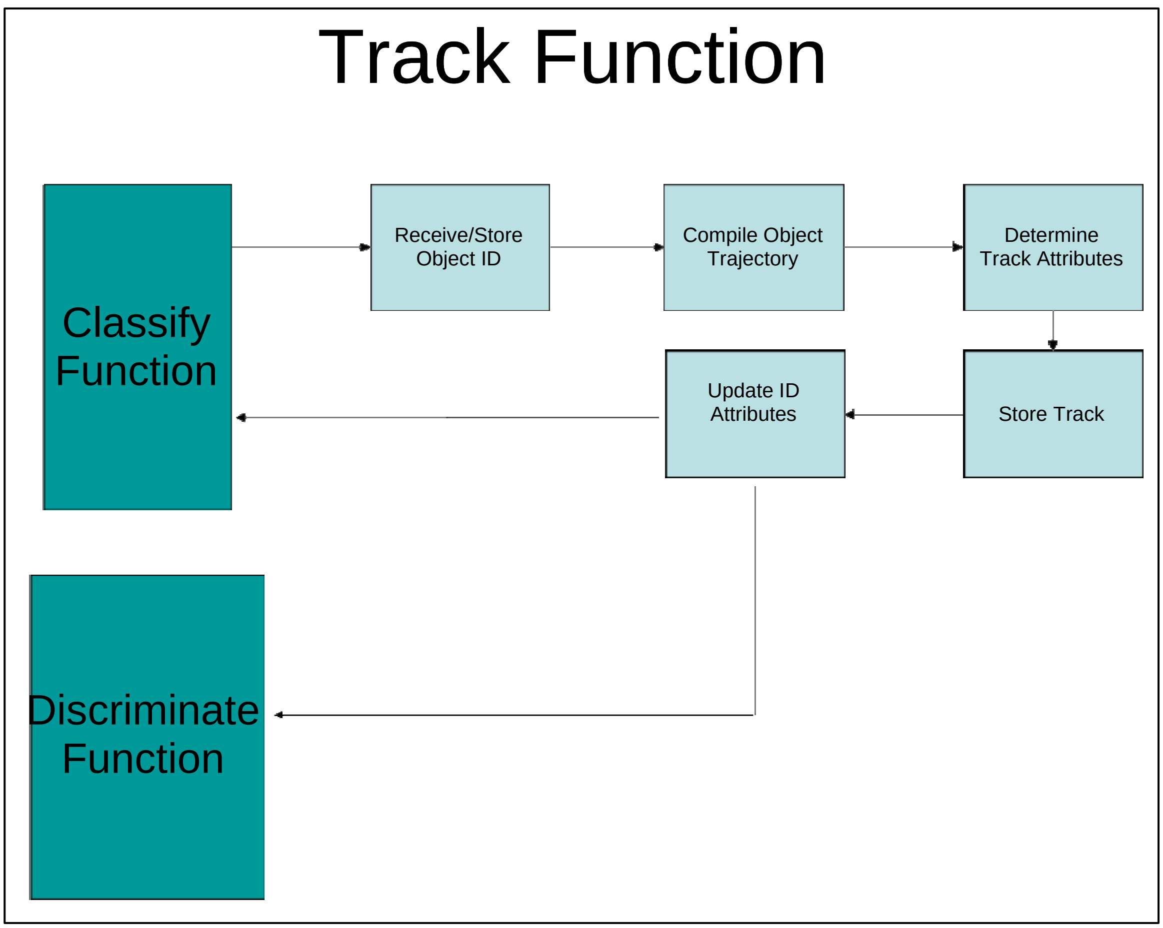
Note: The classify function uses the object data attributes (velocity, altitude, and bearing) to determine the classification of an object as a ballistic object.

Figure 15. Classify Functional Flow Diagram

d. Track

The track function is shown in Figure 16. The track function receives objects from the classify function and computes the object trajectory. After determining and updating the track attributes, the track file is updated and stored. The updated tracking data is sent to the discrimination function.

The track function is key to the capability of the ASBMD System and is independent of all other system functions. The track function can be executed using remote or organic track data. Compilation of the object trajectory is used to determine the ability of the system to engage the object.

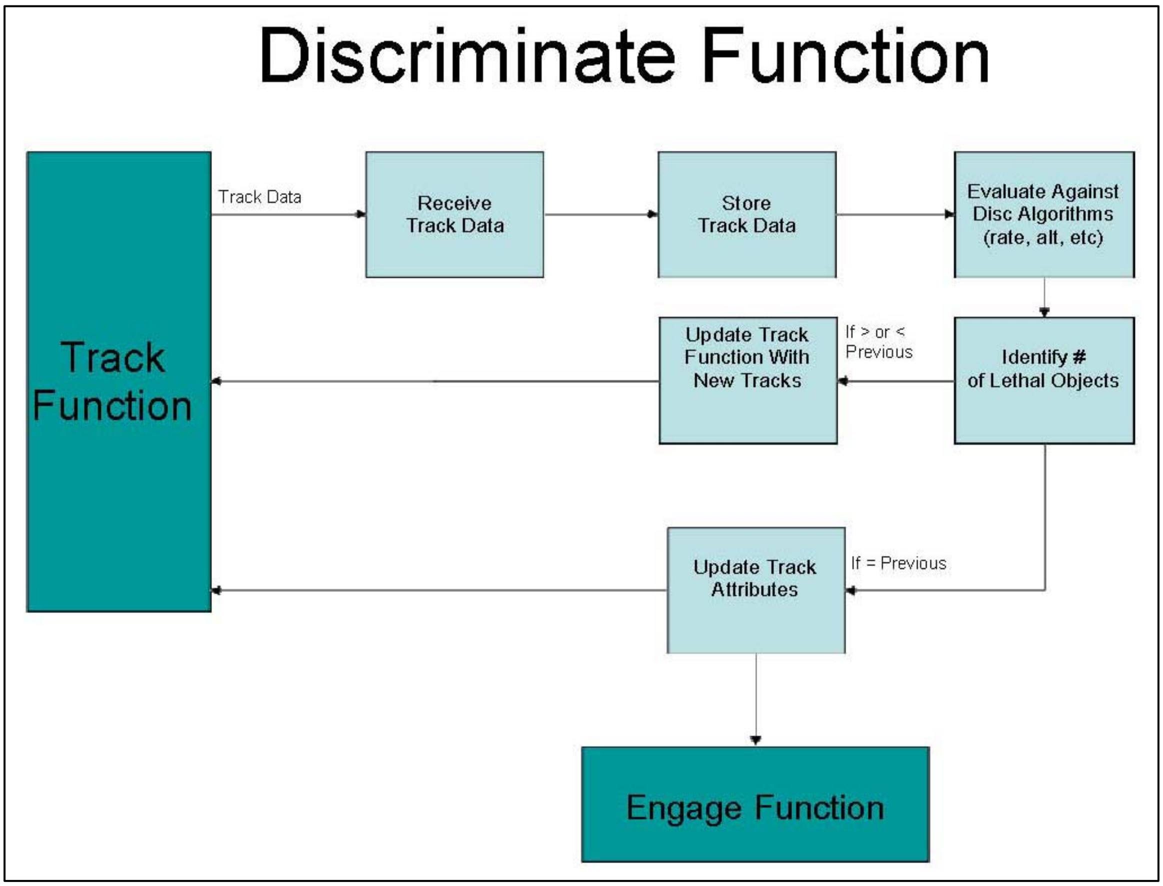


Note: The track function receives the output of the classify function and determines additional attributes, such as trajectory, and updates the track file with the current object.

Figure 16. Track Functional Flow Diagram

e. Discriminate

The discriminate function is shown in Figure 17. The discriminate function receives track data from the track function and evaluates it, using predetermined discrimination algorithms. The output of the evaluations will be the identification of the number of lethal objects in the current track gate. If the output of the evaluation determines that there are more lethal objects than previously identified, the discriminate function will notify the track function of new objects to be tracked. If the output of the evaluation determines no new objects, the discriminate function will update the attributes of the existing tracks and report back to both the track and engage functions.



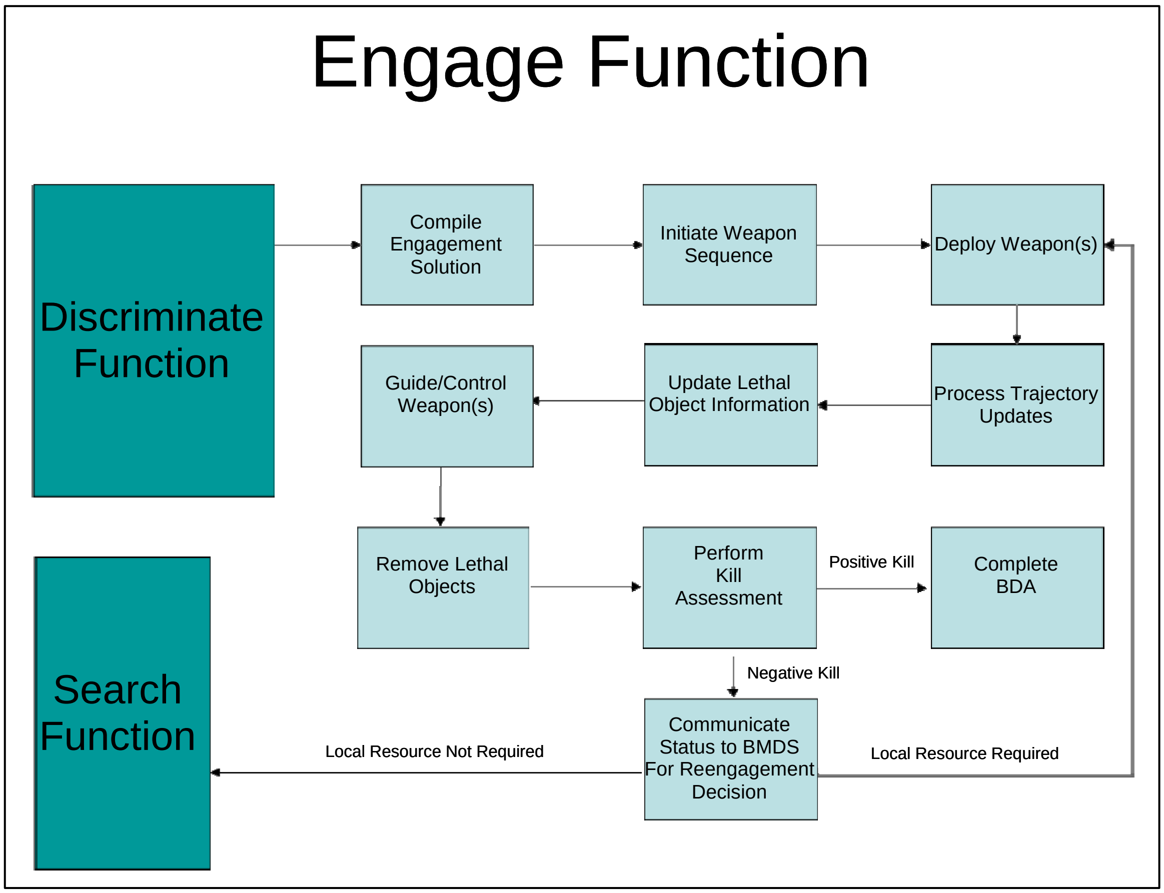
Note: The discriminate function receives and stores track data and then evaluates each received update against the unique discrimination algorithm. This ensures proper identification of the number of discrete objects that are being tracked and stored.

Figure 17. Discriminate Functional Flow Diagram

f. Engage

The engage function is shown in Figure 18. The engage function receives track information from the discrimination function and, upon operator initiation, will compute and disseminate the fire control solution for the selected target.

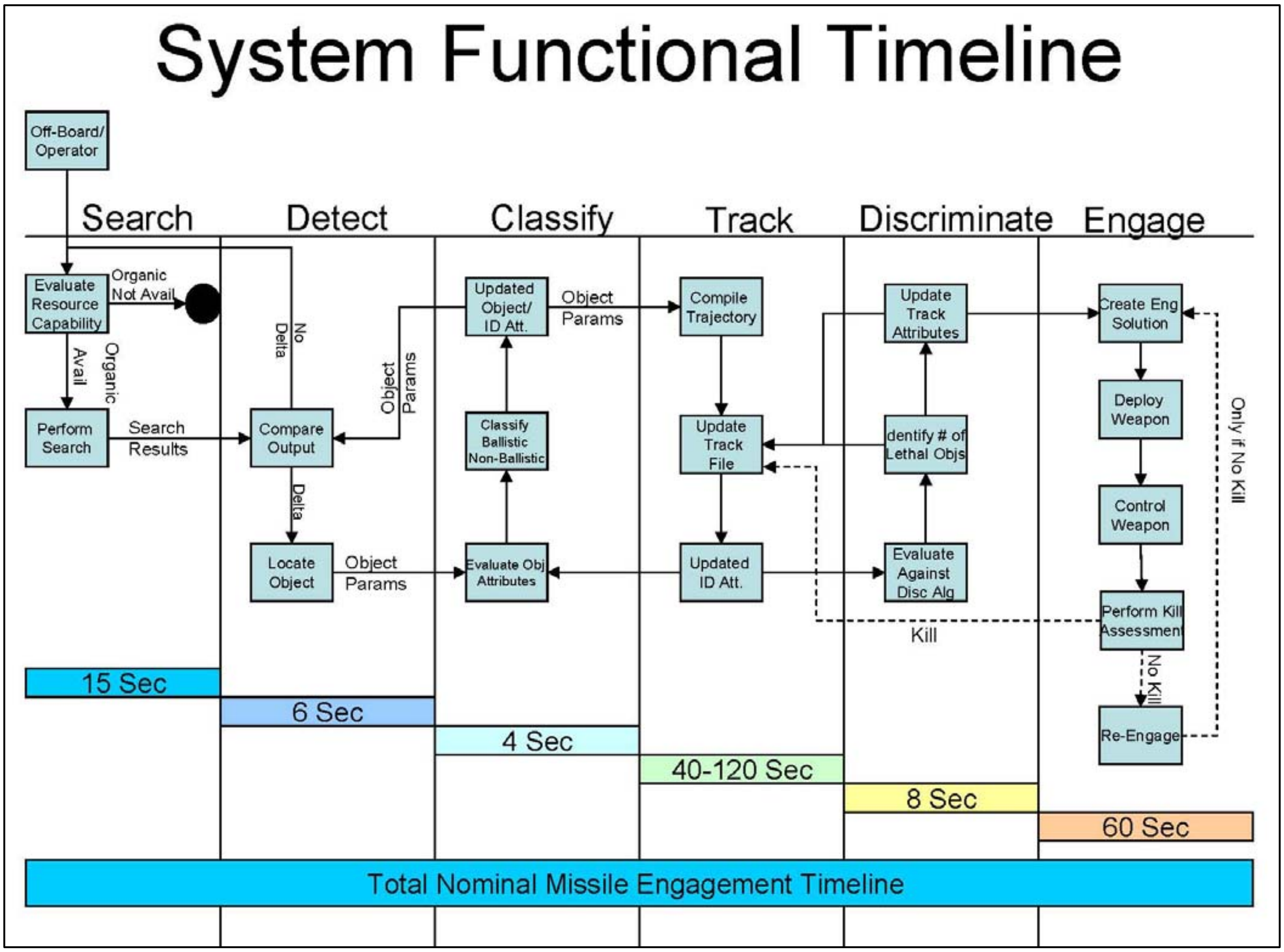
After operator approval, the weapon will be deployed, and the engage function will compute and carry out the guidance and KA portion of the engagement. The engage function is also responsible for creating and communicating the current status of the engagement to the larger BMDS.



Note: The engage function receives operator or system commands to create and execute a fire control solution against an identified object.

Figure 18. Engage Functional Flow Diagram

Following completion of the functional flow diagrams, the team compiled a system functional timeline to assess the timing requirements for completion of each system function and the information flow between functions throughout the complete engagement sequence. Figure 19 is a representation of the information flow within the ASBMD System and a notional timeline for this information flow within the ASBMD system. The timeline is based on the flight times of a nominal MRBM. This timeline was used to develop the criteria for the timing model employed during the AoA.



Note: Functional timeline analysis ensures that each function is allotted a specific portion of the timeline while maintaining the overall system timeline. Detailed functional interaction as depicted ensures a consistent system flow of information. This timeline was used to develop the criteria for the timing model employed during the AoA.

Figure 19. ASBMD Information Flow and Functional Timeline Diagram

D. SYSTEMS ANALYSIS SUMMARY

As described in the preceding sections of this chapter, the team created a number of system analysis artifacts for the purpose of defining and analyzing conceptual system architectures that could address the problem statement. Stakeholder inputs were solicited for the purpose of deriving high-level system requirements. These requirements were decomposed during FSA. The output of this functional decomposition was a detailed set of functional requirements and engagement timing criteria that were applied in the AoA, described in Chapter III.

III. ANALYSIS OF ALTERNATIVES

A. OVERVIEW

Analysis of Alternatives (AoA), as defined by Ullman, (2006), is the analytical comparison of multiple alternatives to be completed before committing resources to a designated project. DoDI 5000.02 (2008, December 8) establishes the basis for developing an AoA and defines the objectives of the AoA. The practice of comparing multiple alternative solutions has long been a part of engineering practices in the DoD. There is, however, a natural human tendency to propose a single alternative for investigation or development and justify this option rather than compare multiple options with the goal of choosing the best fit. Thus, government agencies, such as DoD, have found it necessary to encourage those proposing projects to use an AoA structure to properly evaluate their options. The ASBMD team has conducted an AoA using a modified process similar to that used in many DoD agencies. This chapter details the modified process that was selected.

The objective of this AoA was to answer specific questions that were required to ensure that the chosen system met the requirements of the project. The outcome of the AoA is a single, recommended architecture that meets the functional requirements, schedule, and cost constraints of the system. Although the outcome is a single core system, the recommended architecture includes multiple elements or systems that will be integrated into a single architecture to combat the identified threat group. The details of how the system is integrated will be explained in Chapter IV.

The purpose of the AoA for this project was to answer the following questions:

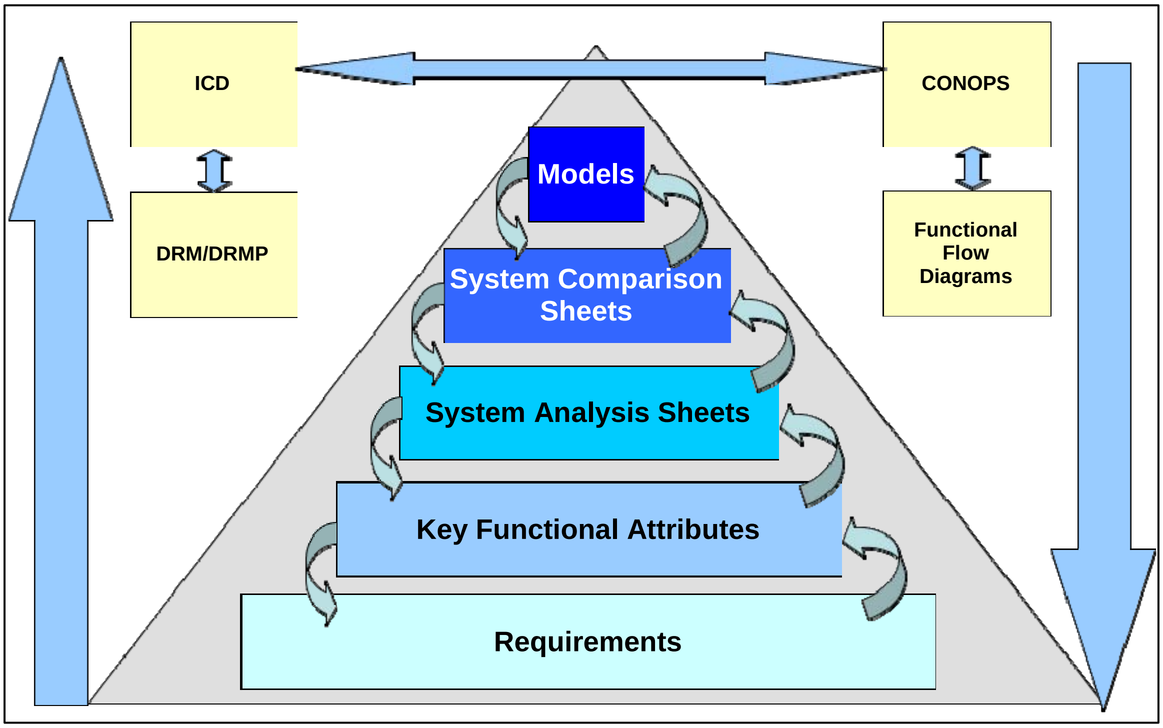
1. What is the most cost-effective, sea-based alternative for defending CSGs against the emerging ASBM threat group? (This refers to the most cost-effective approach that meets the key functional requirements identified during the CONOPS and functional analysis portion of the project.)

2. Which alternative introduces the least amount of risk in all cost, schedule, and performance aspects?

3. Which alternative allows for the shortest fielding and deployment schedule? (This addresses the emergent need aspect of the problem.)

B. PROCESS

The ASBMD team created a modified analysis technique, as depicted in Figure 20. As the figure shows, the process is iterative, and there is a natural increase in detailed analysis artifacts and their fidelity, as the process flows up the pyramid. The key to the process is the development of a well defined set of baseline documents at the start of the analysis. Baseline documents in this case are the documents that the team created during the system functional analysis portion of the product; they consist of the CONOPS, ICD, DRMs, and functional flow diagrams. Although the key is to maintain stable baseline documents, the process is designed to have feedback loops that drive updates to the preceding steps as additional details are defined. For example, as the team identified the key functional attributes (KFAs), the analysis demonstrated the need to add another level of detail to the requirements that were developed during the CONOPS and ICD phases of the project. These modifications are not functional changes to the requirements, but they ensure that the attributes being developed and analyzed are correct and consistent with the scope of the project. Updating requirements as the technical assessment progresses ensures that traceability is maintained throughout the project. Each step in the process will be detailed in the following sections of this chapter. The outcome of the AoA is a detailed set of analysis artifacts that were applied in the concept architecture and integration portions of the project.

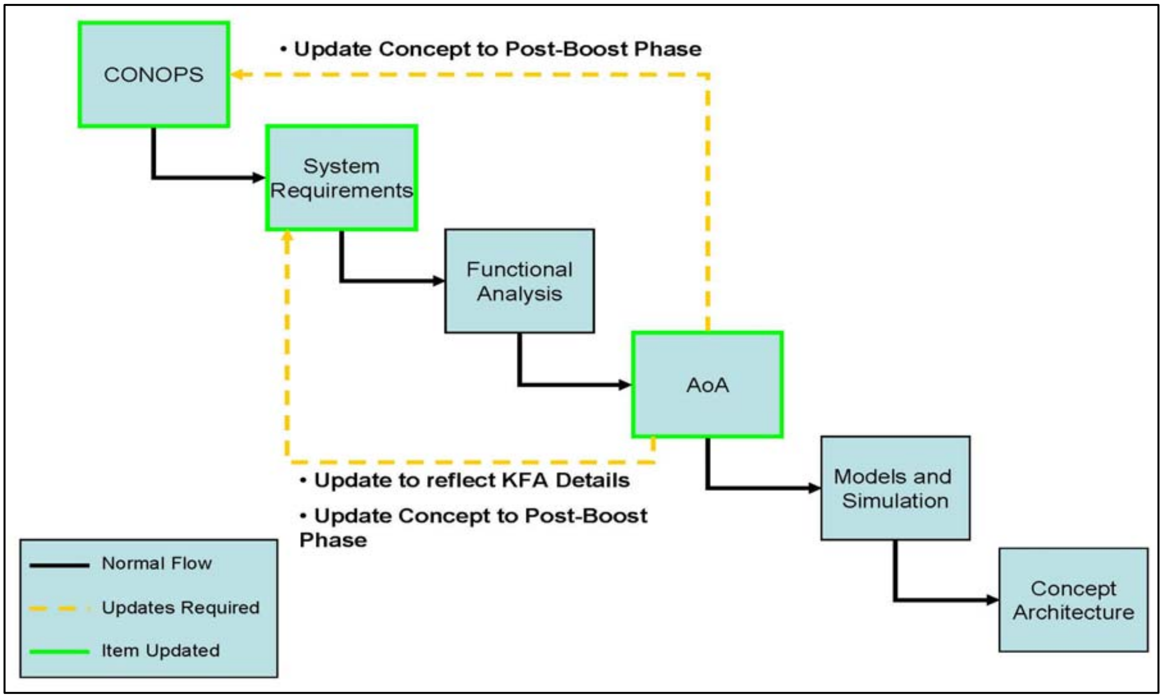


Note: The AoA process designed by the ASBMD team ensured that a complete and consistent concept architecture was created that was reinforced by detailed analysis artifacts. The ASBMD team used the AoA process to ensure that traceability was thorough and complete through all of the analyses and artifacts.

Figure 20. ASBMD Analysis of Alternatives Process

1. Requirements Refinement

The success of this process depends on the early definition and refinement of the requirements and functions of the system. Since the requirements and their associated documents (CONOPS, ICD, etc.) are the basis for the analysis and the ultimate selection of an alternative, it is imperative that they are made clear and concise as early as possible in the analysis process. Requirements changes are inevitable; therefore, a clear line of feedback (as depicted in Figure 20) to all parent documents is key to ensuring that the engineering of the system is consistent and correct. The AoA process began with a set of high-level requirements that were derived from the CONOPS and ICD. Each requirement is associated to the key functions that were identified in Chapter II. Verification that the derived requirements remained aligned with the key functions continued throughout the AoA. As each step of the process was started and subsequently completed, the engineer assigned to a specific function assessed the requirements and associated documentation to ensure that they were still correct, complete, and concise. Although the process is continuous, the number of modifications and clarifications to the requirements reduces considerably as the assessment advances up the levels of the pyramid. This is attributable to each step building on the analysis performed and the artifacts produced for the preceding steps. The majority of the requirements changes occurred during the creation of KFAs; this is due to the analysis having determined the need for additional requirements details to support the functional requirements of the system. A depiction of this update process is shown in Figure 21. This represents the iterative refinement aspect of the requirements development process originally depicted in Figure 7.



Note: Updates were applied to system requirements and associated documentation as needed throughout the analysis process to ensure correctness and completeness.

Figure 21. Process Flow for Requirements Refinement and Documentation Updates

2. Key Functional Attributes

The next step in the process was the creation of KFAs. KFAs are the system attributes that are required to effectively evaluate system performance against the requirements that were identified during the ICD phase that were further detailed during the requirements refinement step. These are the system attributes that must be analyzed to determine the functional capabilities of candidate systems that are chosen for assessment during the AoA. The KFAs that the team identified were those attributes that, when analyzed, would provide a clear and objective view of the capabilities of the candidate systems. For example, for the search function, the team identified the scan rate, search volume, and angular resolution as the functional attributes that would be used to evaluate each candidate system.

The ASBMD team identified KFAs for each functional area depicted in Table 7. As previously described, the feedback loop from each step in the process to the preceding steps ensures a consistent flow and commonality across all functions and requirements. During the analysis and creation of the KFAs, the team identified multiple KFAs that demonstrated a need for the requirements to be refined. The requirements refinement ensured sufficient detail to support the KFAs that were identified.

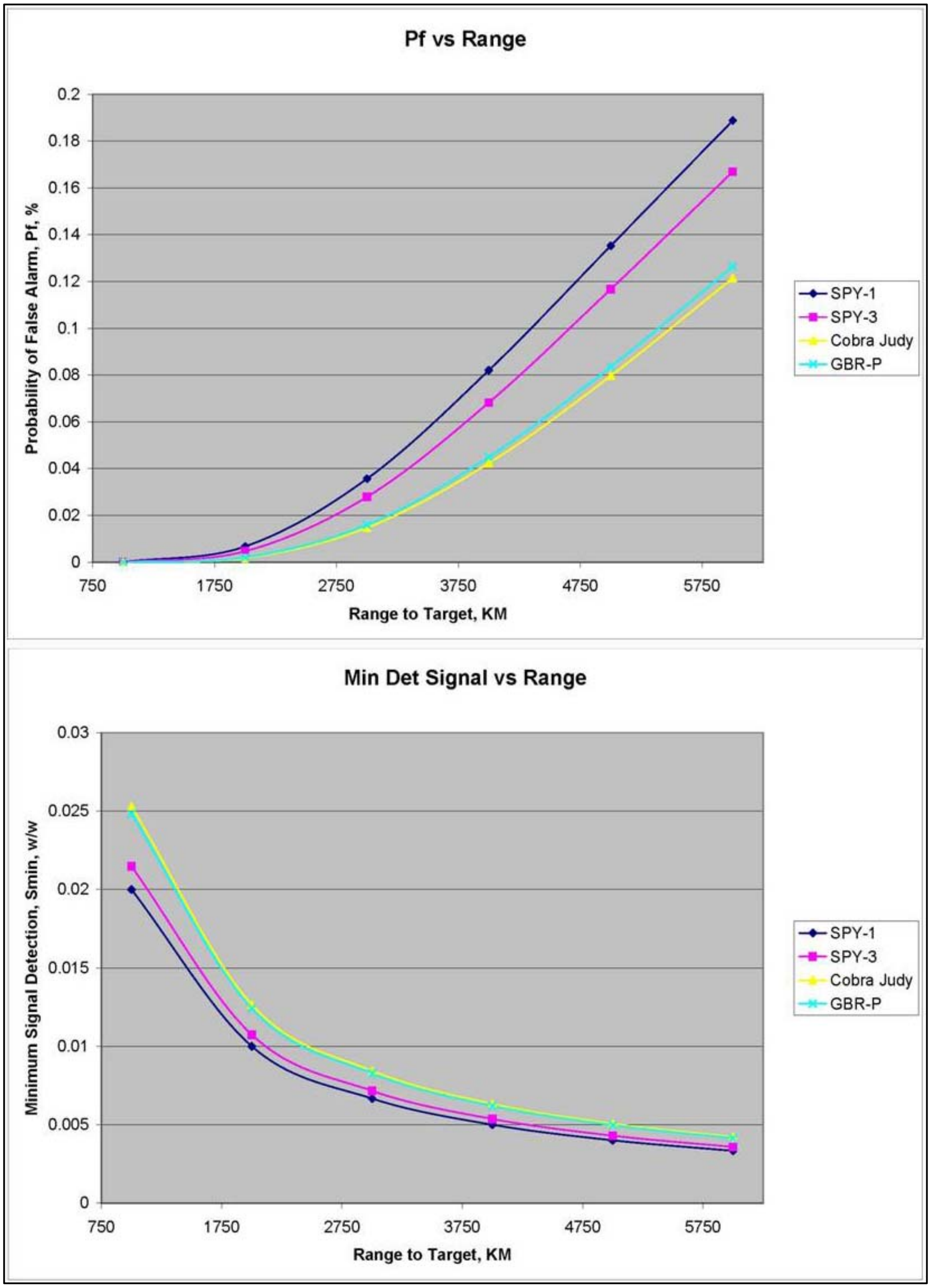
Table 7. Key Functional Attributes

Note: The ASBMD team created KFAs to identify the attributes that, when analyzed, would provide detailed analysis artifacts to assist in the decision of the final elements or systems that would comprise the concept architecture. KFA development was an important factor in the further refinement of system requirements and timing analysis. KFAs were weighted by stakeholder inputs and became criteria for system evaluation during the AoA.

Analysis Area	Recommended Attribute Analysis
Search	Search Rate (Scan Rate)
	Search Volume Capabilities
	Range
	Angular Resolution
Detection	Signal-to-Noise Ratio
	False Alarm Rate
	Probability of Detection (Adjusting Target and Environmental Attributes)
	Radar Range Calculation for Maximum Detection Range
Tracking	PRF and Tracking Errors
	Effective Aperture and Resolution Calculations
	Effects of Tracking Ranges Given Tracking and Turning Gate Changes
	Transition-to-Track Timeline Analysis
Intercept Variants	General Systems Capability Analysis
	Kill Timeline Analysis by Varying Range
	Maximum Effective Ranges

3. System Attribute Analysis

The system attribute analysis step of the AoA process is the point where the team began the identification of the analysis artifacts that would be used to evaluate each KFA identified in the earlier steps of the AoA process. Analysis artifacts identified by the team included tables, graphs, and charts that would provide clear, easily understood documentation to assist in the final architecture decision. After creation of the KFAs, the team defined a list of candidate artifacts that were used to perform an analytical comparison of the candidate systems that would be defined in the successive steps of the process. For example, as depicted in Figure 22, to evaluate the search function of the candidate systems, the team created artifacts to evaluate maximum detection range vs. RCS and minimal detectable signal vs. range. These analysis artifacts were used to assist in the one-to-one comparison of each concept architecture in the system comparison phase. Additional system attribute analysis sheets were created for each system function; a compilation of these analysis sheets is provided in Appendix E.



Note: System attribute analysis provides the detailed analysis technique that the team used to evaluate each candidate element or system. The analysis artifacts were used to assist in the one-to-one comparison of each concept architecture.

Figure 22. System Attribute Analysis Sheets Example

4. System Comparison

Following creation of the KFAs and system analysis sheets, the team defined a list of candidate elements and/or systems for each defined function. This list was derived from the documents created during the initial system research and analysis phases of the project, in conjunction with the operational experience of each team member. Although the list may appear somewhat limited, the team tried to bound the size of the list to contain only those options that were feasible and met the functional, cost, and schedule requirements of the project. Each team member then performed a detailed analysis of each candidate system to gather the required information to evaluate the KFAs. To ensure that the project was kept unclassified, the detailed analysis and information gathering included only information that was readily available via public domain sources. After data were gathered, each team member created specific system analysis sheets for each candidate system. Creation and evaluation of the system analysis sheets allowed the team to rank each system according to how well it performed its function. The team was also able to identify pros and cons for each system to assist in the ranking. After a detailed analysis was performed, the data were combined into a single system comparison spreadsheet, as shown in Table 8. The outcome of this step is a consolidated list of elements and/or systems that were evaluated on their ability to meet the performance requirements, as well as a one-to-one comparison based solely on how each system performed against the KFAs. A full system-of-systems comparison occurred later in the process and considered other aspects of the project, such as risk assessment and cost/schedule requirements.

Table 8. System Comparison

Note: The team used system comparison sheets to perform comparisons of each system identified to meet the associated requirements. The sheets displayed the functional and operational pros and cons for each system, which the team found useful in determining the final architecture.

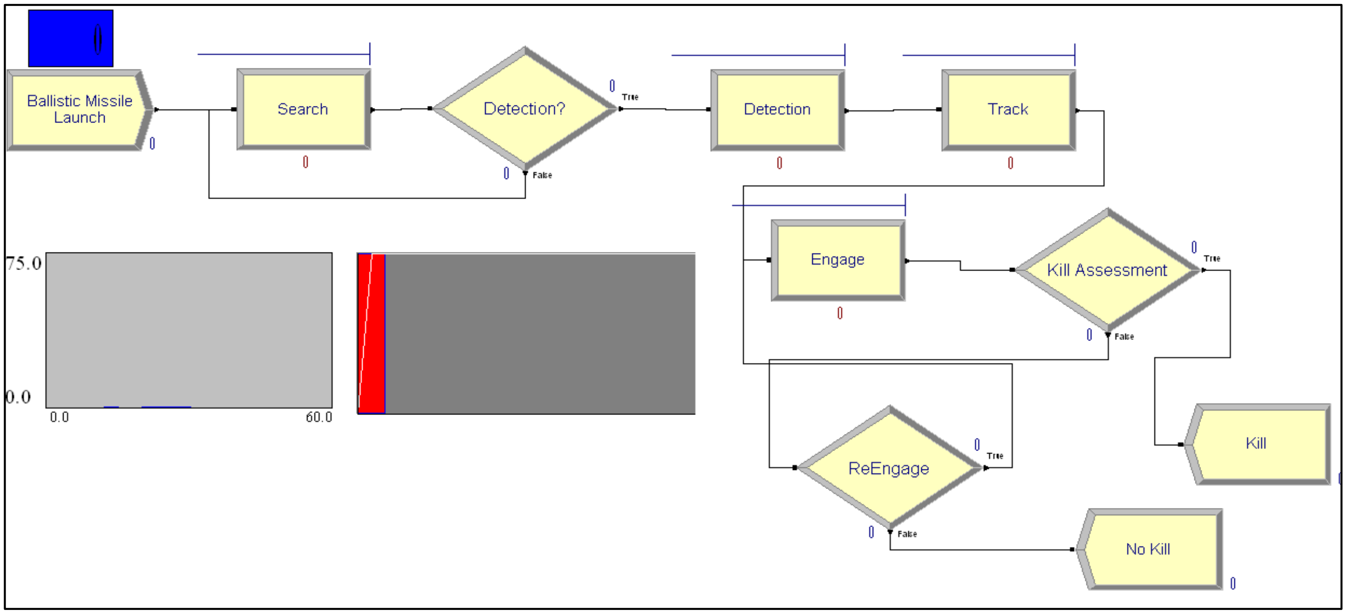
Function Name (Search/Detection)						
Options	Performance Parameters				Requirements	Pros / Cons
	Max Range/ Accuracy	Max Power	A_e (Effective Aperture Size)	S_{min}		
SPY-1 B(D)	* 1460 KM	3 MW	20 m^2	-13 dB	ASBMD System shall be capable of searching a designated search sector of not less than 30 degrees at a distance of not less than 750 km in less than 2 seconds, when cued by either off board intelligence or the onboard operator.	**Pro:** Mature, proven system capability **Con:** Shorter maximum range limits the maneuverability options of the Fleet **Con:** Heavily reliant on intelligence data to allow for resource focusing
SPY- 3	** 2527 KM	4.5 MW	23 m^2	-23 dB	ASBMD System shall be capable of searching a designated search sector of not less than 30 degrees at a distance of not less than 750 km in less than 2 seconds, when cued by either off board intelligence or the onboard operator.	**Pro:** Greater search range and accuracy capabilities than the SPY-1 **Pro:** Greater peak power and A_e size allows for search and detection of smaller RCS **Con:** Unproven system that is still under development **Con:** Power usage to excite radar elements exceeds that of current ship capabilities **Con:** Unable to uplink with current weapon inventory
Cobra Judy	** 2681 KM	7 MW	26.4 m^2	-20 dB	ASBMD System shall be capable of searching a designated search sector of not less than 30 degrees at a distance of not less than 750 km in less than 2 seconds, when cued by either off board intelligence or the onboard operator.	**Pro:** Greatly increases search and detection ranges **Pro:** Allows greater operational maneuverability **Con:** Large power consumption requirements **Con:** Unable to control current weapons **Con:** Too large to fit onto current operational naval vessels
GBR-P	** 3297 KM	8 MW	20.4 m^2	-23 dB	ASBMD System shall be capable of searching a designated search sector of not less than 30 degrees at a distance of not less than 750 km in less than 2 seconds, when cued by either off board intelligence or the onboard operator.	**Pro:** Increased search and detection ranges **Pro:** Increases operational capability of fleet **Con:** Power consumption is too great **Con:** Weight and size are restrictive **Con:** RCS signature much too large for naval vessel **Con:** No weapon control capability
All calculations assume 30 degree search sector. * Derived from Aegis BMD briefing. ** See specific Radar Calculation Sheets.						

5. Model Creation

After candidate systems were identified and a detailed analysis was performed for each system, the team created high-level system models using the Arena modeling tool set. Although this was not the only modeling tool used during the analysis process, the team chose Arena as the primary modeling tool due to the team's familiarity with the program and the its capabilities. Arena is a useful tool when modeling both high-level systems and subsystems from a timing perspective. It allows easy manipulation of the key timing drivers identified by the user. This was important to the team because system timing was recognized early in the analysis process as a critical dependency in this assessment. The graphical interface provides ease in the creation of metrics and charts that measure and monitor KSAs. Early in the project, the team conducted and documented a modeling proficiency demonstration using Arena. The purpose of this exercise was to illustrate the team's ability to use Arena to generate a high-level system simulation of BMD functions over the course of a ballistic missile threat flight from detection to intercept.

The modeling output examples described below are examples of the functional modeling analysis conducted by the team. Functional modeling was the process of creating a model that contained each system function that was identified during the functional decomposition phase. As the project progressed and the team identified specific candidate systems/elements that could perform the identified functions, the system-specific timing values and behaviors of candidate systems were inserted into the model. Because each candidate system was required to fulfill the identified system functions, the team did not create a separate model for each candidate system. However, the team used the model to prove or disapprove any assumptions that the team had for each candidate system.

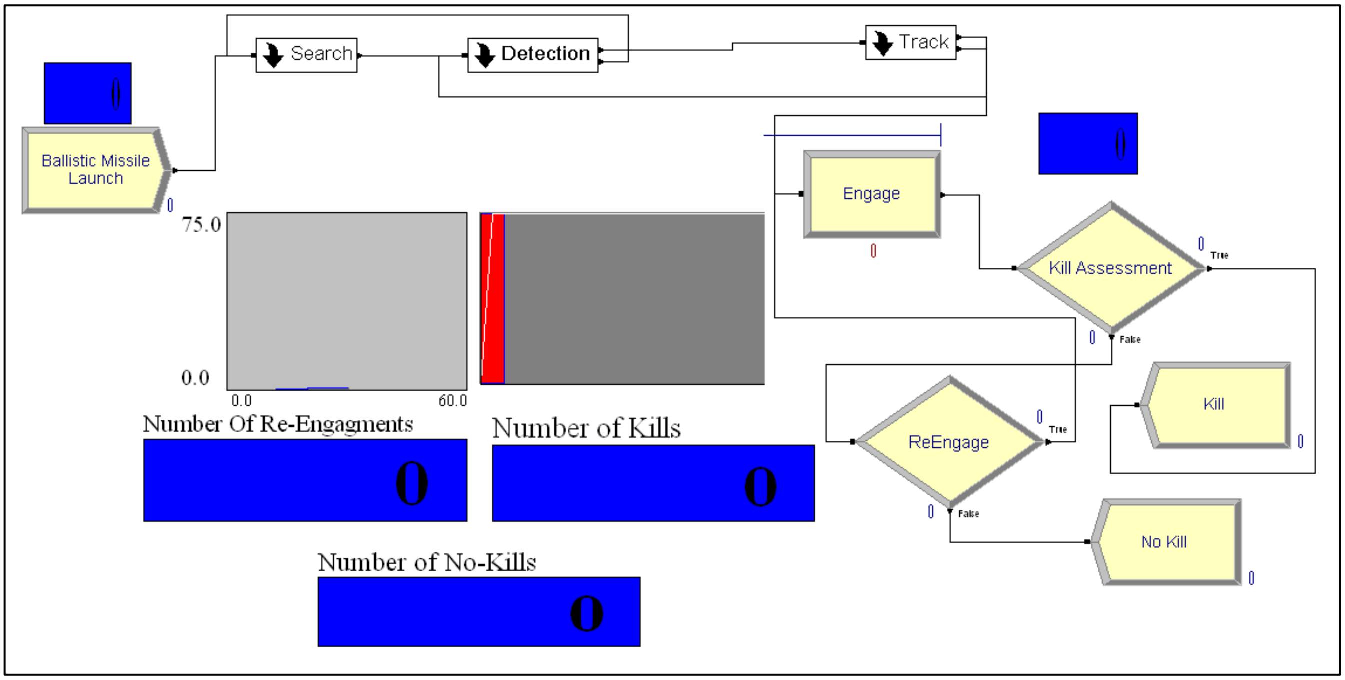
Two separate levels of Arena models were created for this step of the process. These models are shown in detail in Appendix E. The gross system model depicted in Figure 23 was used primarily to evaluate system timing and to identify major impediments to system integration.



Note: The gross system model is used to identify the ability of the concept architecture to meet the overall system timing constraints. This model assisted in understanding the ability to integrate each element or system into a system of systems.

Figure 23. Gross System Model

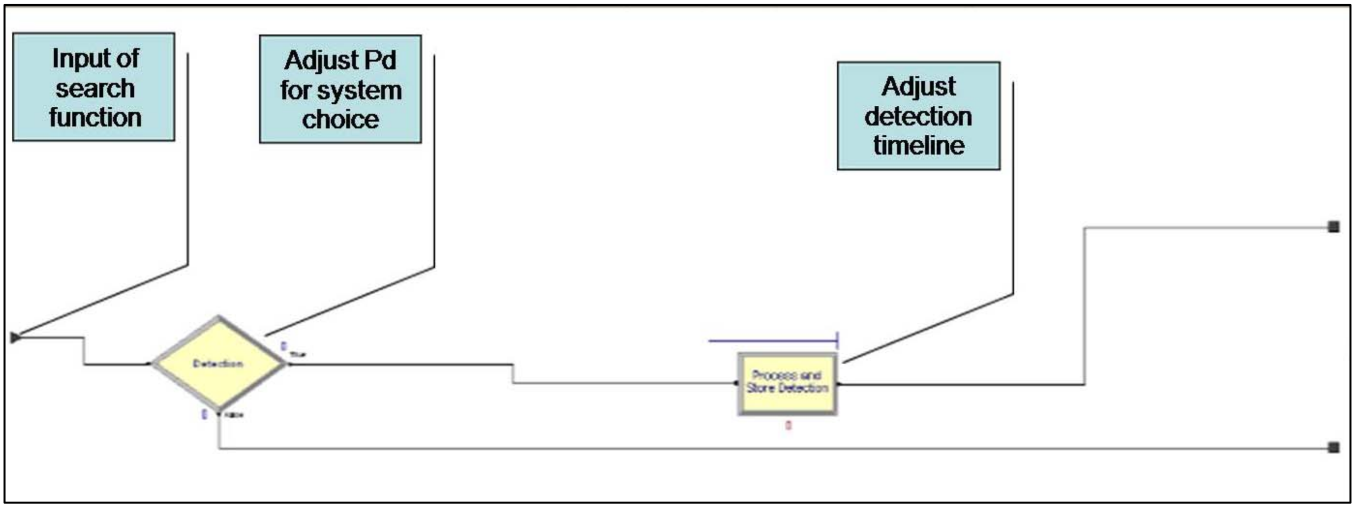
After timeline analysis was performed using the gross model shown in Figure 23, the team created multiple sub-models to assist in the evaluation of the candidate systems. Each candidate system was evaluated individually, using the model depicted in Figure 24. This allowed the team to understand the dependencies created as each system was integrated. The models were used to ensure that the systems, when integrated, met the overall performance requirements for the system of systems under varying conditions. The team modified attributes, such as RCS, range, probability of kill (PK), probability of detection (Pd), and flight times, to ensure that the systems still met the overall system requirements. Subsequent sections of this document will describe the steps taken to narrow the candidate systems using interoperability as one of the main requirements.



Note: The detailed system model is used to identify and understand the dependencies created as each system was integrated to create a system of systems solution.

Figure 24. Detailed System Model

When the candidate architectures were narrowed to two, the model depicted in Figure 25 was employed to help ensure that the selected solution met the overall system requirements when integrated at the system-of-systems level. The outcome of the model analysis provided additional details that were used to assist in the final architecture decision. The results of the model analysis were used to generate the system-of-systems analysis and are described in section C below.



Note: Sub-models were used to ensure that the chosen elements or systems met the timing requirements of the overall system. The sub-models also assisted in identifying the key interactions required to integrate into a systems-of-systems architecture.

Figure 25. Functional Sub-Model Breakout Example

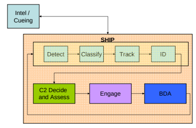
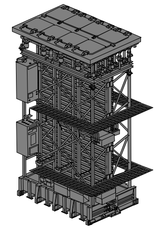
C. SYSTEM-OF-SYSTEMS ANALYSIS

As previously discussed, the AoA process covered only the analysis of the individual candidate elements and/or systems; the system-of-systems analysis portion of the project is where the team performed the detailed comparison of each of the candidate architectures integrated at the system-of-systems level. This process examined each system's ability to meet not only the performance requirements, but also its ability to meet the identified cost and schedule constraints. The outcome of this analysis was multiple system configurations that could meet the identified functional requirements. The configurations were ranked according to the capability to be deployed quickly and cost effectively and were compiled into a ranked list. This list illustrates that one solution can be deployed quickly, while continued development of an alternate solution can introduce greater capability at a later time.

1. Concept Architecture Analysis

The next step was the formulation of end-to-end, system-of-systems concept architectures that could be used to combat the ASBM threat. The team used the analysis artifacts that were created during the AoA process described above to identify the best fit solutions for each function. After determining the system or element that was the best fit for each function, the team used a mixture of engineering analysis, experience, and discussion to derive multiple combinations of elements that could be integrated into a coherent system of systems. The team used the models described in section B of this chapter to ensure that, when integrated, each candidate architecture could meet the overall timing defined in the system requirements.

The team then created the concept architecture analysis comparison sheet, depicted in Figure 26, to document the elements/systems that were integrated into candidate architectures.

	 OPIR Assets AN/TPY-2 AN/SPY-2	 C2BMC/ Interoperability	 Aegis Fire Control Zumwalt Fire Control	S-Band Link X-Band Link Missile Data Links and Beacon Track		
	Network Sensors	**Network Interoperability**	**Shipboard FC System**	**Data Link**	**Launcher Mechanism**	**Interceptor**
1	External Sensors	C2BMC Link 16 CEC-D	Modified Zumwalt Fire Control AN/SPY-3	X-Band Link	MK-57	SM-3 Dual Band
1a	External Sensors	C2BMC Link 16 CEC-D	Modified Zumwalt Fire Control AN/SPY-3	N/A	Rail Gun	Mod 1 Ballistic Round
1b	External Sensors	C2BMC Link 16 CEC-D	Modified Zumwalt Fire Control AN/SPY-1	S-Band Link	MK-57	SM-3 Dual Band
1c	External Sensors	C2BMC Link 16 CEC-D	Modified Zumwalt Fire Control AN/SPY-3	N/A	Laser System	N/A
2	External Sensors	C2BMC Link 16 CEC-D	Modified Aegis Fire Control AN/SPY-1	S-Band Link	MK-41	SM-3 Dual Band
2a	External Sensors	C2BMC Link 16 CEC-D	Modified Aegis Fire Control AN/SPY-3	X-Band Link	MK-41	SM-3 Dual Band
3	External Sensors	C2BMC Link 16 CEC-D	Modified Zumwalt Fire Control Modernized GBR-P	X-Band Link	MK-57	SM-3 Dual Band
3a	External Sensors	C2BMC Link 16 CEC-D	Modified Aegis Fire Control Modernized GBR-P	X-Band Link	MK-41	SM-3 Dual Band

Notes:
1. System configurations were not evaluated if they were ruled out in earlier processes or were immediately deemed not interoperable (system comparison, cost analysis, stakeholder discussions, etc.).
2. Fire control and weapons would be shipboard only due to range from land sensors.
3. No tail chase scenarios were identified; therefore, this requirement was not driven to the system architectures.
4. External sensors are defined as BMDS networked sensors, to include AN/TPY-2, additional AN/SPY-1 assets, airborne sensors, and Overhead Persistent Infrared (OPIR) assets.
5. Launch on Remote (LoR) will be the base scenario when external sensors are available.
6. Specified Fire Control Systems are hull-specific and are not interchangeable (i.e., Aegis = DDG 51 class hull, etc.).

Note: Architecture comparison sheets document each of the elements or systems that could be combined to meet the overall requirements of the ASBMD system.

Figure 26. Concept Architecture Analysis Comparison Sheet

The six elements/systems are defined as follows:

Network Sensors:

- This term refers to the sensors that are already included in the BMDS network (AN/TPY-2, AN/SPY-1, Upgraded Early Warning Radar (UEWR), and Overhead Persistent Infrared (OPIR)).

Interoperability:

- Command and Control Battle Management and Communications (C2BMC) is the core interoperability and element coordination architecture for the BMDS.

- Link 16 is the high speed, L-Band digital data link currently in service throughout U.S. Navy systems and networks.

- The Cooperative Engagement Capability–Distributed (CEC-D) system is an updated Cooperative Engagement Capability (CEC) system that adds the capability to process space tracks, including updated algorithms to allow processing of tracks with very large velocities. The CEC-D system has an initial operational capability (IOC) of early 2010.

Shipboard Fire Control Systems:

- AN/SPY-1 is the is the primary air and surface radar for the Aegis Combat System installed in the USS *Ticonderoga* (CG 47) and USS *Arleigh Burke* (Guided Missile Destroyer (DDG) 51)-class warships. It is a multifunction, phased-array radar capable of search, automatic detection, transition to track, tracking of air and surface targets, and missile engagement support.

- AN/SPY-3 is an active, phased-array X-band radar designed to meet all horizon search and fire control requirements for the next generation of

U.S. Navy ships. It supports new ship design requirements for reduced RCS, significantly reduced manning requirements, and total ownership cost reduction. The multifunction radar is designed to assume the functions of five separate radar systems that are currently in service. SPY-3 is scheduled to IOC in 2012.

- Ground-Based Radar–Prototype (GBR-P) is an X-band phased array radar and fire control sensor that provides precision discrimination and interceptor fire control support capability to the BMDS. There is currently only one GBR-P installation, located at Kwajalein Atoll. While the full ground-based concept would not be suitable for this assessment, what was considered is a modernized, shipboard-scale X-band phased array radar that is capable of providing the same in-flight interceptor communications system (IFICS) and in-flight target update (IFTU) support featured in the GBR-P system.

Data Link:

- S-Band Data Link is used by the AN/SPY-1 radar for acquisition and midcourse communication with Standard and Evolved Sea Sparrow Missile variants. The S-Band Data Link is primarily used by legacy Aegis systems.

- X-Band Data Link is used by the AN/SPY-3 radar for acquisition and midcourse communication with Standard and Evolved Sea Sparrow Missile variants. The X-Band Data Link is the preferred ownship missile communication mechanism for systems being designed for use in a littoral environment due to its improved clutter rejection and anti-jamming capability.

Launcher Mechanism:

- MK-41 Vertical Launching System (VLS) is the currently fielded, canister-based, fixed shipboard launcher. It is capable of firing a variety of ordnance items and, if appropriately configured, is able to simultaneously support multiple missions, including both Anti Air Warfare (AAW) and BMD.

- MK-57 VLS is an open-architecture-compliant launcher developed for the DDG 1000 platform. It is designed to accommodate existing VLS encanistered missiles but provides for the growth in volume and weight expected for future missile systems. It is scheduled to IOC in 2012.

- Rail Gun is a weapon system that moves a projectile along a pair of metal rails using two sliding or rolling contacts. The contacts permit a large electric current to pass through the projectile, which interacts with the magnetic field around each rail to accelerate the projectile. Although the U.S. Navy has tested a rail gun that is capable of accelerating a 3.2 kilogram (kg) projectile to greater than Mach 7, no Navy platform can currently support the space and infrastructure needs (i.e., provide power and cooling) that would allow further development and deployment of this functionality.

- Laser weapons system is a megawatt-class chemical oxygen iodine laser (COIL) that could be modified for integration in U.S. Navy ships. In BMD applications, this type of laser is primarily designed to destroy ballistic threats in their boost phase. A shipboard laser weapon system is not feasible for BMD scenarios due to proximity to the launch site that would be required for a boost phase intercept; however, MDA has developed and tested the Airborne Laser (ABL) platform for boost phase intercept capability.

Interceptor:

- SM-3 is the U.S. Navy's midcourse ballistic missile interceptor. The certified SM-3 Block IA is currently in service. SM-3 Block IB, which features enhanced capabilities and would be the desired candidate for consideration in the ASBMD scenario, is scheduled for IOC in 2011. The Block IB design includes an advanced, two-color, infrared seeker for enhanced discrimination capabilities. Its Throttleable Divert and Attitude Control System (TDACS) will provide the kill vehicle with greater agility, which is advantageous for use against maneuvering threats.

- Rail Gun Mod 1 Ballistic Round is a lightweight projectile designed for use with the developmental rail gun concept.

Although many systems could have been analyzed, the team included only those that met the functional capabilities and performance parameters identified during the functional analysis and system comparison phase. This resulted in the creation of candidate architectures that were more feasible and could potentially meet the performance criteria and system requirements, including cost and schedule constraints.

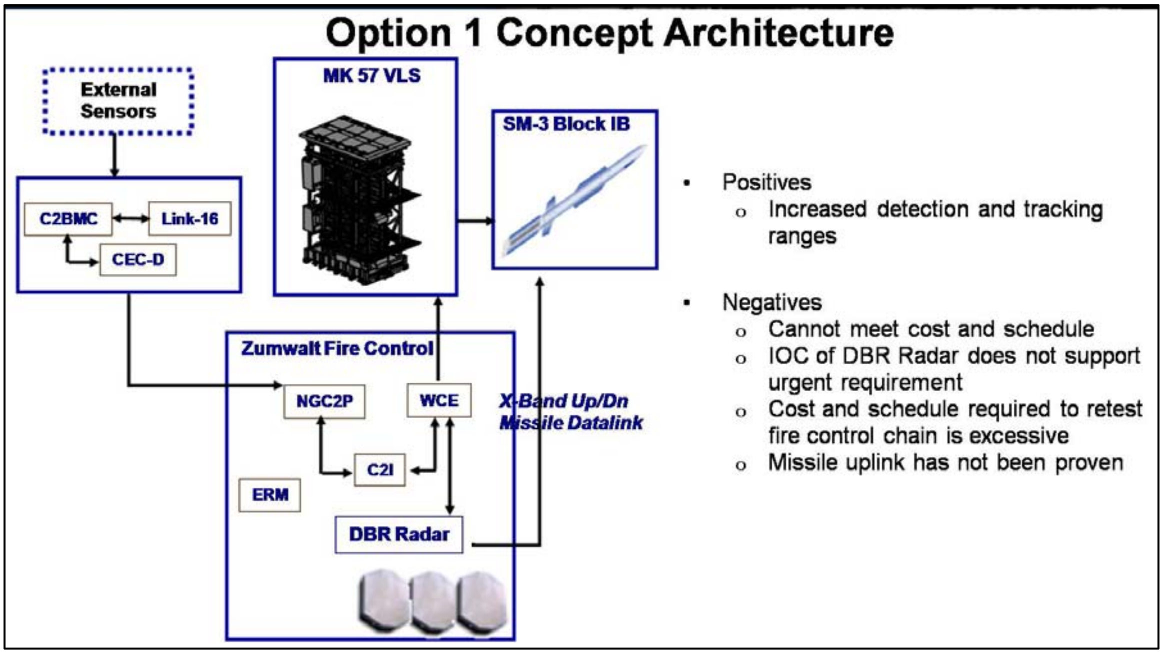
2. Selection of Concept Architecture Options for Evaluation

During this portion of the process, the team performed detailed analyses of each candidate architecture that was identified during the earlier steps of the assessment. The detailed analysis included identification of the pros and cons for each architecture. The pros and cons included both technical and programmatic issues and were identified using available literature and working-level knowledge of the team members. After detailing and analyzing each candidate architecture, the team narrowed the concept architectures based on all artifacts that had been created up to that point in the process. Those artifacts included the KFAs, models, systems attribute sheets, and system requirements. Based on system availability, ability of the systems to meet stakeholder requirements, and performance of the systems in the models, the team ranked the concept architectures and provided detailed rationale to justify why each concept architecture option was or was not chosen. The ranking of the top concept architecture options and the associated rationale for each are depicted in Table 9. Next, the team created the architecture diagrams for the top three ranked choices to provide a graphical representation of each option. The diagrams are shown in Figures 27, 28, and 29; these contain the pros and cons for each system.

Table 9. Ranking of Concept Architecture Options

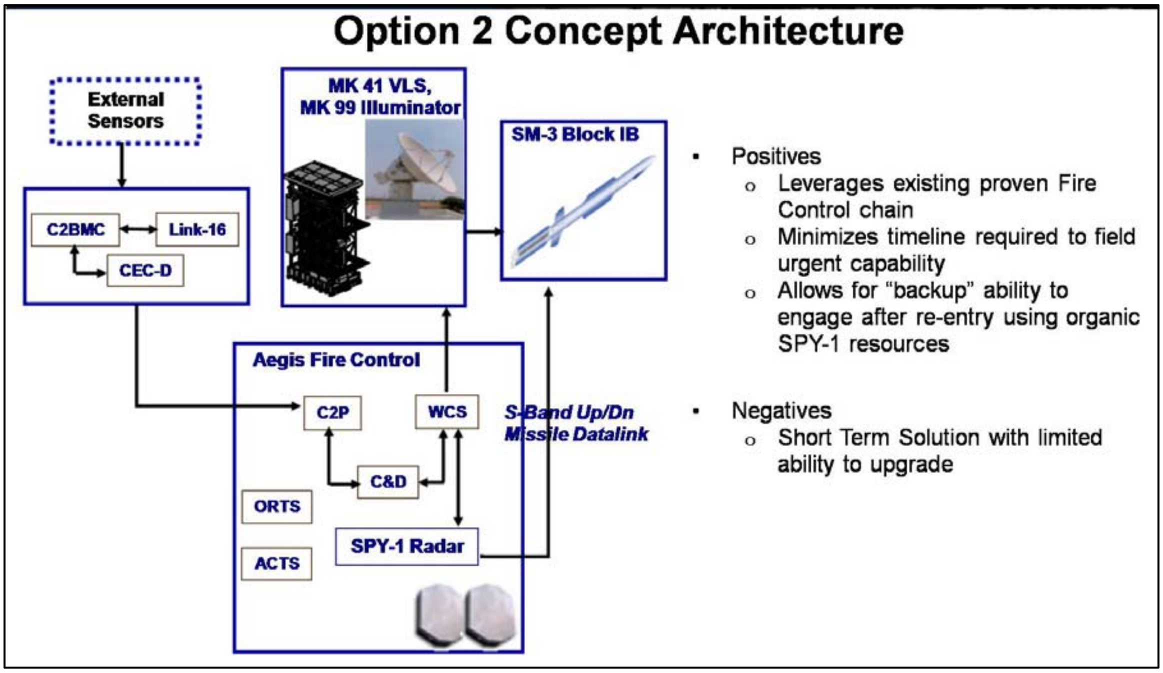
Note: Ranking of the systems assists in focusing the detailed analysis and artifact creation to only those options that meet the high-level requirements, cost, and schedule constraints. The options labeled “not ranked” (NR) were eliminated due to their inability to meet one or more of these constraints.

Option #	Architecture Descriptor	Evaluation Priority/Rank	Rationale
1	Zumwalt Fire Control with Updated Discrimination and Tracking Algorithms	**3**	• Zumwalt IOC is ~2014. • Option requires changes to SPY-3 and Combat Systems. (Near field range testing required.)
1a	Zumwalt Fire Control with Updated Discrimination and Tracking Algorithms, Weapons Control Changes for Rail Gun	**NR**	• Zumwalt IOC is ~2014. • Very high development, integration, and testing costs • Schedule constraints
1b	Zumwalt Fire Control integrated with SPY-1 Radar guidance and control	**4**	• Zumwalt IOC is ~2014. • Very high development, integration, and testing costs with integrating new radar into existing Fire Control • Schedule constraints
1c	Zumwalt Fire Control with Updated Discrimination and Tracking Algorithms, Weapons Control Changes for Laser System	**NR**	• Zumwalt IOC is ~2014. • Laser System IOC is beyond 2015. • Very high development, integration, and testing cost • Very high risk of technology/capability not being sufficient
2	Modified Aegis Fire Control with updated Discrimination and Tracking Algorithm	**1**	• Quick development and deployment with minimal integration and testing cost • Minimal schedule impact. • Availability could meet need dates.
2a	Modified Aegis Fire Control integrated with SPY-3 Radar for guidance and control	**2**	• Platform cannot support the power and cooling requirements of SPY-3. • Integration and testing timeline does not support need dates.
3	Modified Zumwalt Fire Control integrated with Modernized GBR-P System for guidance and control	**NR**	• Option involves a very long and costly development, integration, and testing timeline that would not meet need dates. • Complex integration effort required to use GBR-P for ordnance control.
3a	Modified Aegis Fire Control integrated with Modernized GBR-P System for guidance and control	**NR**	• Option involves a very long and costly development, integration, and testing timeline that would not meet need dates. • Platform cannot meet the cooling and power requirements of the GBR-P System.



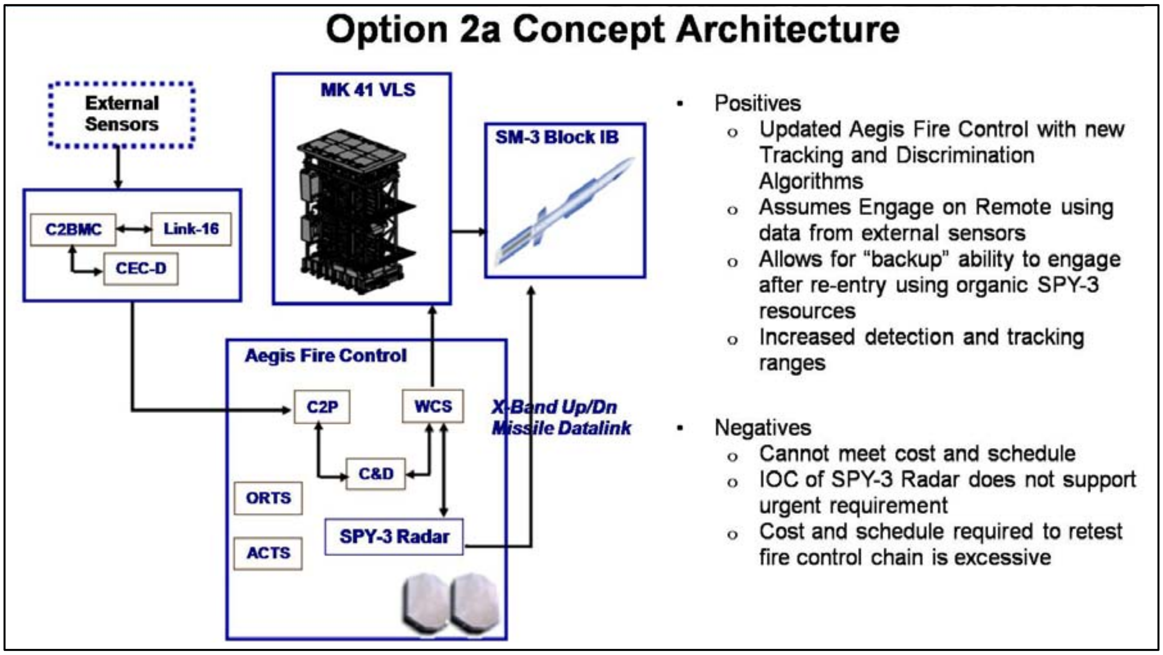
Note: The Option 1 concept architecture depicts the integrated solution using the Zumwalt Combat System as the baseline configuration. This figure identifies the pros and cons for this architecture.

Figure 27. Option 1 Concept Architecture



Note: The Option 2 concept architecture depicts the integrated solution using the Aegis Combat System as the baseline configuration. This figure identifies the pros and cons for this architecture.

Figure 28. Option 2 Concept Architecture



Note: The Option 2a concept architecture depicts the integrated solution using a hybrid Zumwalt and Aegis Combat System as the baseline configuration. This figure identifies the pros and cons for this architecture.

Figure 29. Option 2a Concept Architecture

3. One-to-One Comparison of Ranked Concepts

The final step of the AoA portion of the project was to compare the ranked concept architectures to ensure a complete understanding of the magnitude of the impacts associated with employment of the concept architectures. For example, some of the architectures would result in software-only changes, while others would result in hardware and software changes that could impact the ability to meet the schedule constraints of the project. The comparison analysis resulted in development of a capabilities and limitations sheet, shown in Table 10. Each concept option would provide the required capability to combat the threat identified in the problem statement, but the limitations of implementing some concept architectures could result in integration challenges that would render the entire BMDS system less agile or capable. The next activity that the team undertook during this step was conduct of a performance and capability comparison assessment summary for the ranked concept architectures. This is a side-by-side comparison of the top three architectures identified in the earlier steps. Table 10 shows the top three ranked options that the team chose and a one-to-one functional comparison of these options. The key attributes used to evaluate the options are also shown in Table 11; key attributes included engagement mode, engagement performance, and maneuverability. The architectures were also evaluated against cost and schedule requirements to ensure that the chosen architecture met all of the requirements created during the ICD and CONOPS portion of the project.

Table 10. Concept Architecture Capabilities and Limitations

Note: The comparison analysis performed resulted in a capabilities and limitations definition for each candidate architecture. The required capability to combat the threat was identified in the problem statement, but the limitations of implementing some concept architectures could result in integration challenges that may render the entire BMDS system less agile or capable.

	Option 1	Option 2	Option 2a
Operational Flexibility	• Allows LoR and EoR due to compatibility with C2BMC and addition of CEC-D. • Not backwards compatible with SM-T.	• Allows EoR and LoR due to compatibility with C2BMC via Link 16 capability.	• Allows LoR and EoR due to compatibility with C2BMC and the addition of CEC-D. • Not backwards compatible with SM-T.
Implementation and Operational Deployment	• Zumwalt system manages onboard assets and sensors and manages missiles in flight via X-band link. • Midcourse guidance updates based on remote data from external BMDS sensors.	• Aegis system manages onboard sensors and missiles via S-Band link. • Midcourse guidance updates based on remote data from external BMDS sensors.	• Aegis system manages onboard sensors and missiles via S-Band link. • Midcourse guidance updates based on remote data from external BMDS sensors.
Fire Control Loop Integrity	• Achieved via local/organic SPY-3 radar and/or external/remote sensors via the BMDS network.	• Achieved via local/organic (AN/SPY-1) radar and/or external/remote sensors on the BMDS network.	• Achieved via local/organic SPY-3 radar and/or external/remote sensors via the BMDS network..
Raid Capability	• AN/SPY-1 can provide additional radar resources for search, tracking, and discrimination. (Requires new C2BMC radar control functionality.)	• SPY-3 can provide additional radar resources for search, tracking, and discrimination. (Requires new C2BMC radar control functionality.)	• AN/SPY-1 can provide additional radar resources for search, tracking, and discrimination. (Requires new C2BMC radar control functionality.)

Table 11. Side-by-Side Functional Comparison

Note: The side-by-side functional comparison assists in identifying the most capable candidate architecture when compared against common functional performance criteria.

		Option 1 Zumwalt/SPY-3	Option 2 Aegis Baseline	Option 2a Aegis/SPY-3
Primary Engagement Mode		Engage-on-Remote (EoR)	EoR	EoR
One-on-One Engagement Performance		**Similar**		
Battle Space Performance One-on-One	**Launch Window**	**Better**: Uses SPY-3 with fully populated array		**Better**: Uses SPY-3 with fully populated array
Raid Capacity	**Small Raid**	**Similar**		
	Large Raid		**Better**: Radar resources greater for in-flight missiles	
Missile Data Link Margin/ Information Assurance (IA)		**Better**: Uses P3I link with X-band		**Better**: Uses P3I link with X-band
Cost		**Higher**: Requires additional hardware and advanced program testing	**Best**: Leverages existing resources	**Higher**: Requires additional hardware and advanced program testing
Schedule and Programmatic Risks		**Higher**: More challenging development, integration and testing effort	**Lower**: Shorter build test and certify timeline = lower cost	**Higher**: More challenging development, integration and testing effort

Table 12 demonstrates the impact of modifications that each system introduces to the architecture. Significant changes require additional time and funding to implement. Therefore, options requiring extensive changes were deemed unable to meet the schedule constraints of the project.

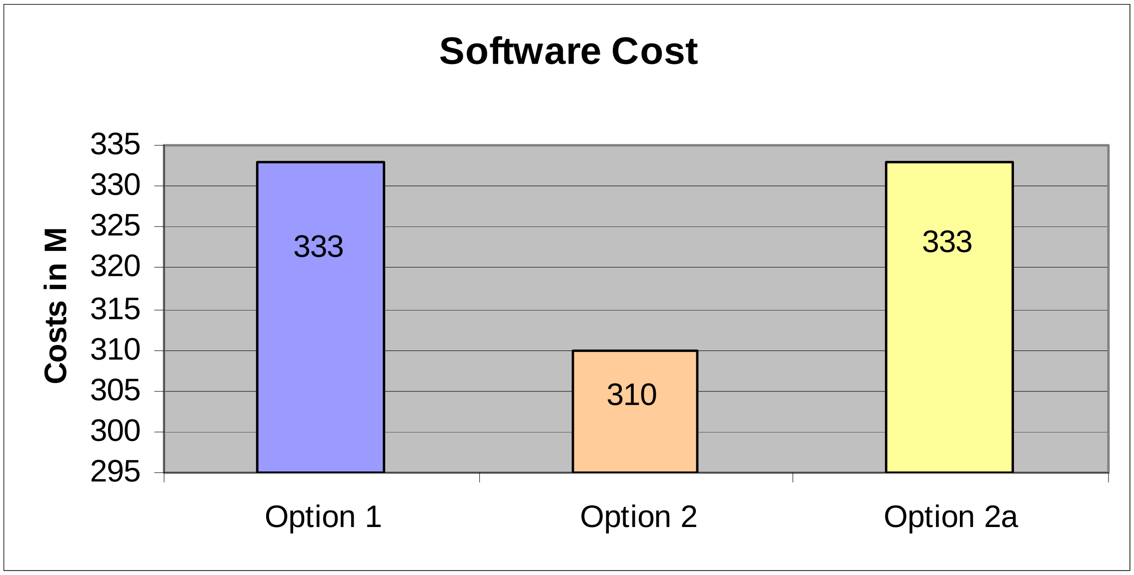
Table 12. Comparison of Candidate Architectures by Impact of Modification

Note: The impact of changes that each system introduces to the architecture is a key consideration in making the final decision. Significant changes require more time and funding to implement. Therefore, most concept architectures requiring extensive changes were deemed unable to meet the schedule constraints of the project.

Area of Modification	Impact of Modification		
	Option 1 Zumwalt/SPY-3	Option 2 Aegis/SPY-1	Option 2a Aegis/SPY-3
External Sensors	None	None	None
Missile	Moderate	None	Moderate
Core Combat Systems	Negligible	Negligible	Negligible
Launcher	None	None	None
Radar	Significant	None	Significant

D. COST ANALYSIS

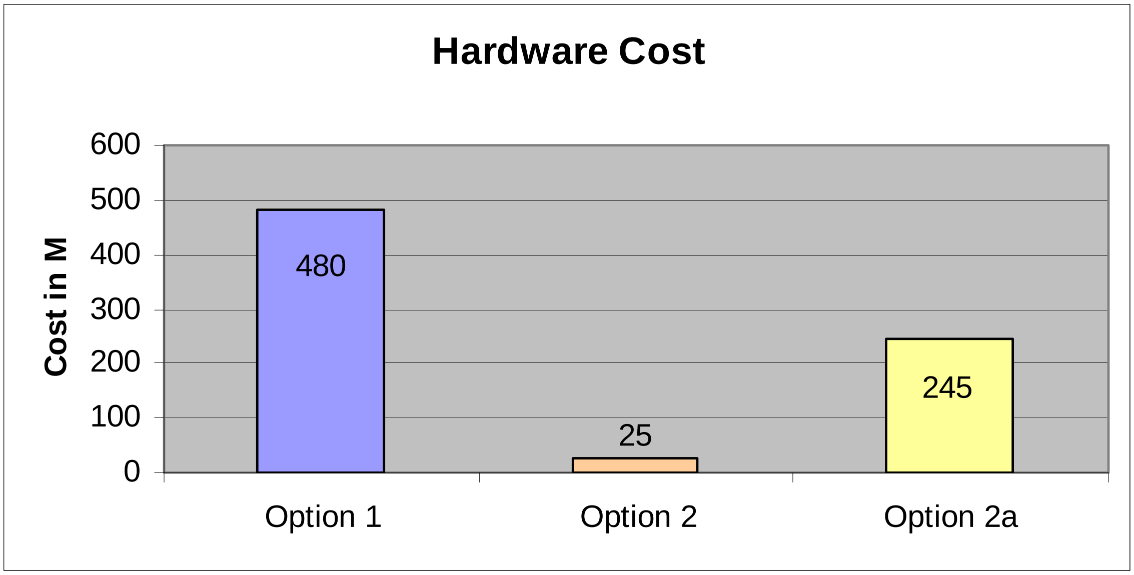
When evaluating cost, comparing candidate alternatives is important to determine their relative costs with respect to a baseline set of requirements or capabilities. The three candidate options were evaluated to determine the total cost of implementation. To ensure that a fair comparison was performed, the team separated the costs for each option into two separate categories. The first category that the team evaluated was the cost for software-related changes, including requirements, design, code, and testing needed to upgrade or develop the required capabilities. The estimated software-related costs for each of the candidate architectures are shown in Figure 30.



Note: Software cost of the selected architecture helps to identify the resources required to field the system. The cost analysis was a significant variable in the concept architecture decision-making process.

Figure 30. Software Cost

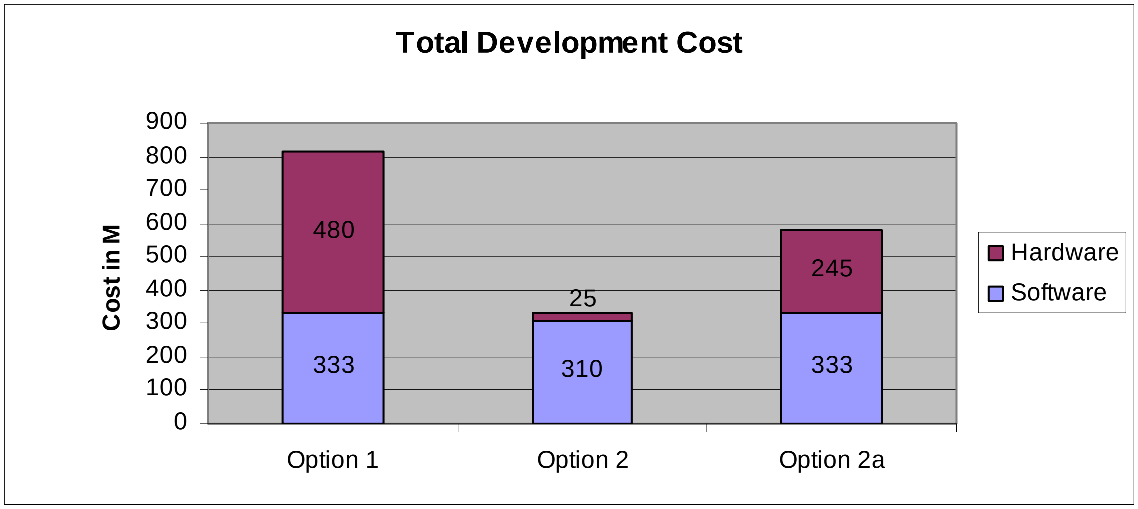
The second category of cost analysis was associated with hardware-related changes. Some options required few hardware changes, as most of their required updates were only changes to software algorithms. Figure 31 shows the comparison of the estimated hardware-related changes for the candidate architectures.



Note: The hardware cost for the selected architecture is key to ensuring that the selected architecture can meet the schedule requirements of the system. High hardware cost is always accompanied by testing and certification costs, which are significant schedule drivers.

Figure 31. Hardware Cost

Following these individual software and hardware cost comparisons, the team conducted a total cost comparison that evaluated software, hardware, and system integration costs for each option. The comparison of the total cost to implement each option is shown in Figure 32. As depicted in this figure, Option 2 was determined to have the lowest total development cost.



Note: Total development cost is the total cost required to field the concept architecture. For the purpose of this study, the total cost is the sum of the hardware and software costs.

Figure 32. Total Development Cost

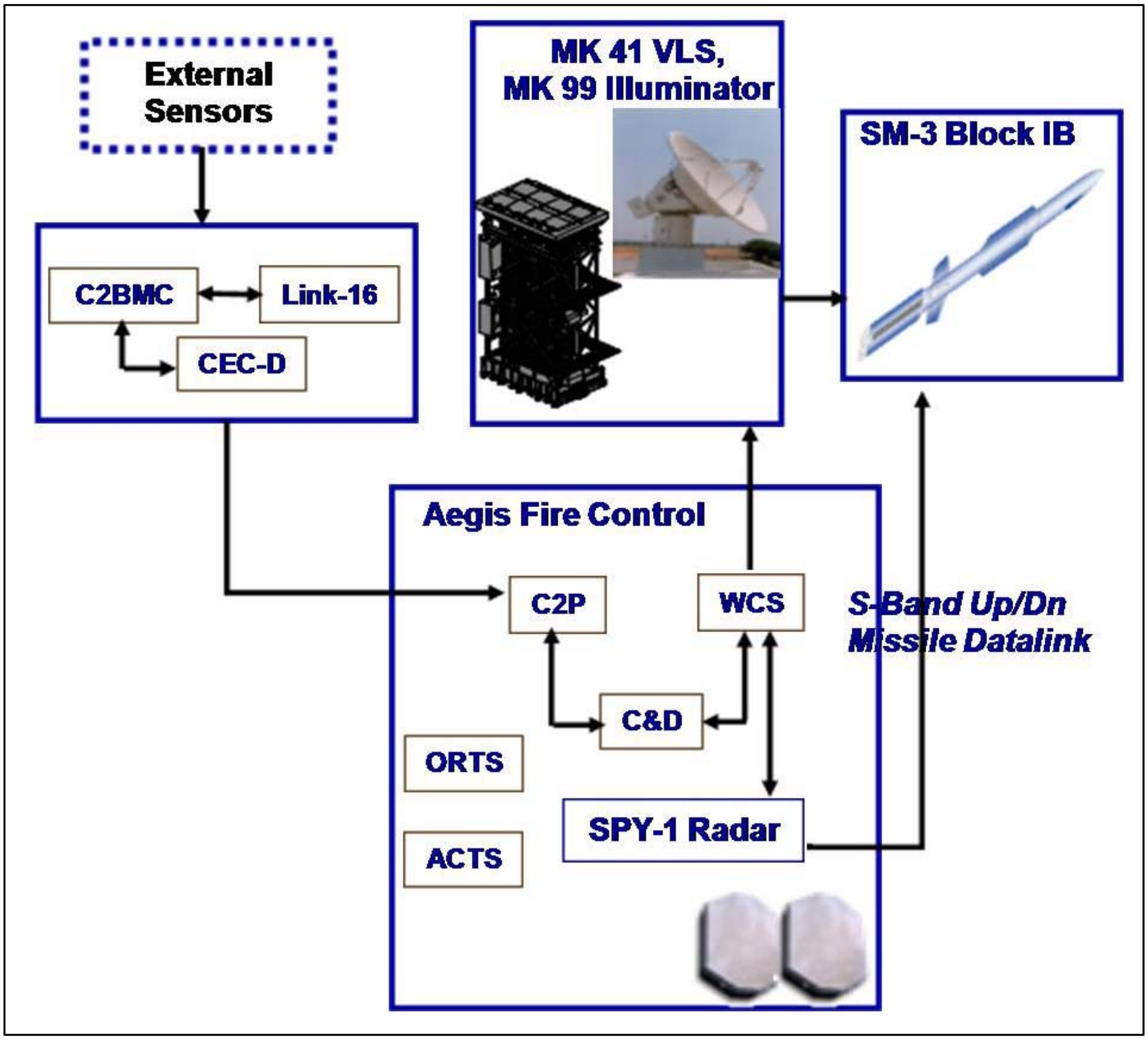
E. RISK MANAGEMENT SUMMARY

Risk management is a concept used to assess and handle events that might adversely impact a system development effort. Mitigating these impacts increases the likelihood of a successful system development effort. The ASBMD team utilized the risk management process described in the *Risk Management Guide for DoD Acquisition* (DoD, 2006, August). Team members identified the risk root causes in the areas of project management and systems engineering, and each root cause was analyzed for the likelihood of the event occurrence and the consequence to the effort upon occurrence. The team developed and reviewed risk mitigation plans in an iterative manner throughout the project and used them to monitor progress toward closure of each risk. Risk assessment was a significant aspect of the AoA process, as each system and end-to-end architecture option was considered in context of its potential to introduce risk to the system or mitigate system risk. Several architecture options were eliminated from further evaluation in the AoA because they introduced cost and schedule risk to the ASBMD system, either due to lack of maturity or to an assessed inability to integrate effectively with the BMDS. The team used this information to aid in the selection of the option that best met system requirements while posing the least perceived risk to system integration, fielding, and performance. More information about the risk management process and its use by the ASBMD team is available in Appendix F.

F. FINAL SELECTED SOLUTION

1. Core Solution Architecture

As previously described, each candidate architecture option was ranked and evaluated based on its ability to meet the identified functional and programmatic requirements of the ASBMD System. The selection of the core solution architecture from the final three evaluated options was based on the primary objective of eliminating the ASBM threat during the midcourse phase of ballistic flight. This approach requires the system solution to communicate efficiently and effectively within the BMDS network and on the capability of receiving and processing data from all network sources. Stakeholder concerns related to interoperability and performance were balanced by the team with the cost and schedule constraints associated with the needs statement. These factors were applied during the AoA to determine the best system of systems solution for the ASBMD system. The side-by-side functional and programmatic comparisons, cost analyses, and risk assessment of the final three options clearly show that Option 2 was the best fit for the ASBMD System requirements. Figure 33 shows this option’s configuration in detail and depicts the overall architecture of the core solution.



Note: The selected core architecture consists of the Aegis Combat System and the SM-3. This architecture relies heavily on a software baseline upgrade to introduce the ability to eliminate the ASBM threat.

Figure 33. Selected Core Architecture

G. AOA SUMMARY

As described in this chapter, the purpose of the ASBMD AoA was to determine the single recommended architecture that meets the functional requirements, schedule, and cost constraints associated with a solution to the problem statement. The recommended solution—Option 2—includes multiple systems that, when integrated, will function as a single combat system to defeat the ASBM threat. The discussion of how the system is integrated follows in Chapter IV.

IV. INTEGRATED SYSTEM SOLUTION

A. PURPOSE

As described in Chapter III, the team implemented the modified AoA process and conducted a detailed analysis to identify the candidate architecture that could be used to fill the stated capability gap. The team provided detailed pros and cons for each system and element of each candidate architecture to help select the final configuration that best met the functional and programmatic requirements. The team described methods used to narrow the candidate architectures into a single set of systems or elements that could fulfill each function identified as part of the functional area analysis portion of the project. Chapter IV will detail the final recommended architecture in a system-of-systems context and will further identify a total fleet solution to ensure layered capabilities. The fleet solution creates a more robust system that is considered by the team to be capable of defeating the identified threat, even under off-nominal conditions. The recommended architecture, Option 2, was chosen by considering all technical and operational aspects of the problem and identifying risks that result from the implementation of the solution.

B. ADDITIONAL ARCHITECTURE CONSIDERATIONS (LAYERED DEFENSE CAPABILITIES)

1. Operational Employment

As described earlier in this report, the team defined a core architecture that could defeat the threat set using the existing BMDS assets, while not degrading existing BMDS capabilities. As the project progressed, it became clear that a layered defense approach, including additional architectures, would be required in order to best defend against the unique capabilities of the ASBM threat. The team's primary approach was to engage and destroy the target exoatmospherically to ensure that the target was not able to begin its reentry maneuver. The team recognized, however, that additional terminal phase defense capabilities should be considered in concert with a midcourse capability, in the event that the target is not intercepted in the midcourse phase and reenters the atmosphere. A logical consideration for a backup terminal phase intercept capability was the SM-T missile.

The team performed a PK analysis to determine the ability of current fleet assets to meet the PK requirements of the project. The team analyzed the SM-3, SM-T, and mixed-salvo options to determine the PK for each scenario. Due to the classification of the data required to compute the PK for both the SM-3 and SM-T, the team used alternate analysis techniques to obtain representative data. The techniques included using notional timing data for AAW functions of similar systems, including the KA timeline for both the Aegis and Zumwalt fire control systems. The team also used engineering-level discussions with both Government and contract engineers that are experienced with the representative systems to obtain the data needed to assist in the comparative analysis. Using the described analysis techniques, the team performed a detailed analysis of the effects of multiple CONOPS changes to increase the ability of the concept architecture to combat the threat.

The first CONOPS modification identified was the need to alter the firing policy to raise the PK of the exoatmosheperic portion of the engagement. A graphical representation of the results of the firing policy vs. PK analysis for both the SM-3 and SM-T missiles is depicted in Table 13. The only ordnance currently in the fleet that can intercept this threat exoatmospherically is the SM-3 missile; the team initially investigated the effects of the firing policy changes using the SM-3 Missile. The SM-T portion of the analysis was conducted to determine the feasibility of its use as a complementary system to the selected core architecture for a layered defense capability.

Table 13. Firing Policy vs. PK Analysis for SM-3 and SM-T Missiles

Note: The ability to increase the PK by modifying the firing policy or by salvo size is key to meeting the required timelines of the ASBMD System.

Missile Type	PK (Rating) Exoatmospheric			PK (Rating) Endoatmospheric			PK (Rating) Mixed		
	Shoot	Shoot-Shoot	Shoot-Shoot-Shoot	Shoot	Shoot-Shoot	Shoot-Shoot-Shoot	Shoot	Shoot-Shoot	Shoot-Shoot-Shoot
SM-3	Fair	Fair/Good	N/A	N/A (Not Capable of Endo. Intercept)			N/A (Not Capable of Endo. Intercept)		
SM-T	Poor	Poor	Fair	Good	Good	Excellent	Depends on the Mix/Not Evaluated		
***Mixed**	Fair	Fair/Good	N/A	N/A	N/A	Good	Fair	Fair/Good	Excellent
* Mixed assumes that the first two salvos will be SM-3s, and third salvo is SM-T.									

As Table 13 shows, the PK of the concept architecture against the identified threat was increased by employing a shoot-shoot firing policy. As a follow-on to this analysis, the team also investigated a layered defense CONOPS change using a mixed load-out of SM-3 and SM-T missiles. The scenario evaluated called for the ship to perform the initial engagement, using a dual-salvo SM-3 policy while the target was still in the exoatmosphere and to perform the KA. If a positive no-kill was received, the ship would then fire a SM-T as a backup attempt to intercept the target in the upper endoatmosphere prior to its terminal phase maneuver. Unfortunately, the analysis performed by the team during the AoA phase of this project showed that the time required to perform the KA was greater than the available time in this scenario.

As a work-around to this limitation, the team evaluated the effects of using a mixed salvo with a shoot-shoot-shoot-look policy on the PK of the system. The CONOPS for this solution would be for the ship to perform an initial dual-salvo SM-3 engagement when the threat is at apogee. The system would continue to engage the threat and launch an SM-T missile at a time in the engagement window calculated to ensure that the intercept would be achieved before the target has begun its final terminal maneuver. The team looked at the inclusion of the SM-T as a complementary solution that applies only to the Option 2 architecture, since it is not functionally compatible with all candidate architectures evaluated during the AoA process. When analyzed, it was determined that this layered solution provided a greater probability of mission success at a significantly lower cost (refer to Table 13). Although the SM-T is no longer in production, the team concluded that the remaining inventory (~ 80 missiles) was sufficient to support the near-term fleet requirements, given the current projected threat production capability (Office of Naval Intelligence, 2009, July). Thus, the use of this tactic was the most effective and practical fit for the system solution. Note that SM-T performance against maneuvering threats has not been assessed and requires additional study. For the purposes of this assessment, the assumption was made that the SM-T would intercept the threat early in the terminal phase, prior to its maneuver.

With respect to combat system integration and fire control, the SM-T uses the common S-Band missile uplinks for acquisition and midcourse guidance and employs an on-board active seeker during terminal phase. This eliminates the need for detailed analysis of the capabilities (e.g., range and power) of the MK-99 fire control illuminators.

2. Additional System Considerations

The team investigated additional complementary solutions that could be integrated with any of the candidate architectures and employed to assist in the elimination of the threat. A key operational criterion of the threat group is that it uses a global positioning system (GPS) as a guidance source during the midcourse and terminal phases of flight. The team investigated use of a GPS transponder, deployed on a vehicle in the upper endoatmosphere, to disrupt communication with the combatant's GPS satellite and effectively “walk” the threat away from the CSG by feeding the threat bad GPS data. Because all GPS variants essentially use the same phase shift keying modulation scheme (most are biphase shift keying (bpsk)) and have a similar power output, consistent interference techniques could be developed that exploit the reliance of a broad range of threats on a variety of GPS systems. Use of omnidirectional GPS antennas on the interference source vehicle would help ensure timely acquisition of the spoofed GPS signal by the threat.

Employment of this concept assumes that several conditions would be met:

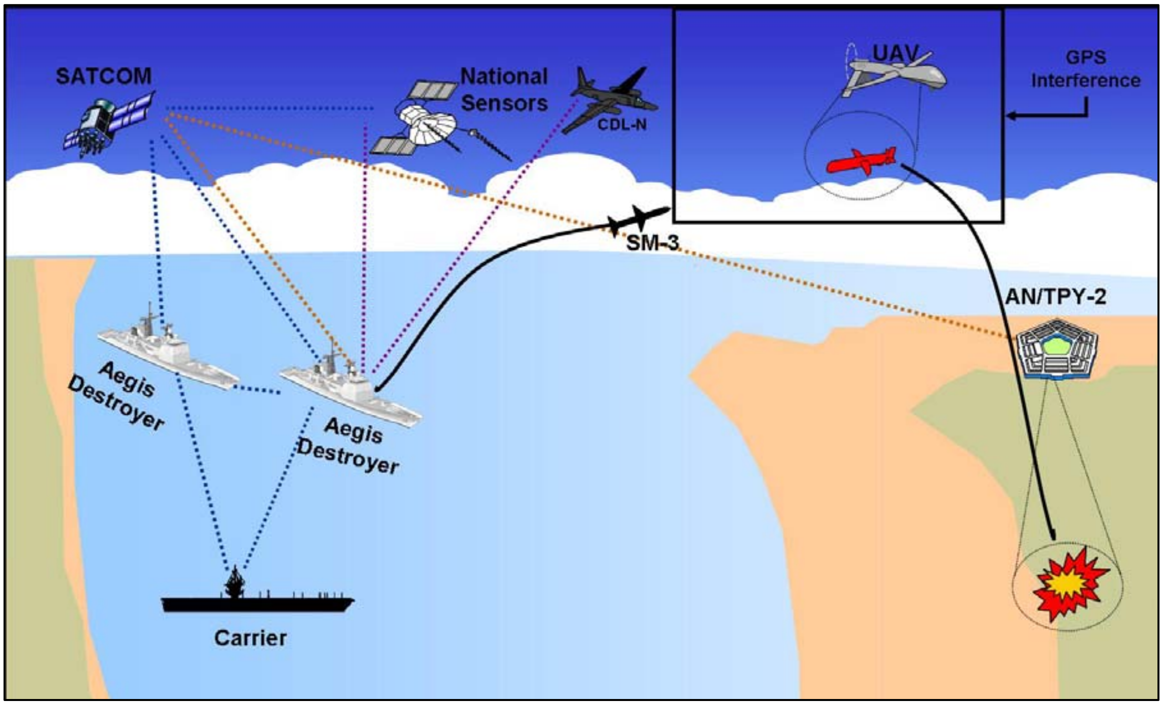
- The CSG receives intelligence data indicating a probable or imminent launch, and the appropriate mission plan is developed with enough notice to launch and position the vehicle.
- The vehicle is capable of operating in the upper endoatmosphere, has sufficient range to reach the required altitude, and can operate in thin atmosphere.
- The vehicle has sufficient endurance to perform loiter maneuvers for a period of multiple hours once on station and at the desired altitude.
- The vehicle is capable of powering the GPS transponder, and the GPS signal strength will be greater than that of the combatant's GPS satellite (−130 dBm). A moderately higher signal (approximately 20 dB higher) would be sufficient to overwhelm the threat GPS signal.

Once the threat encounters and acquires the false GPS signal, it is anticipated that the threat would attempt a course correction. Any course adjustments this late in flight would be occurring while the threat is moving very fast. Even if the dummy GPS signal were lost and the satellite were reacquired, it is unlikely that the threat would have sufficient time to reposition itself to close on the intended target (i.e., a carrier). Further, the GPS vehicle could be maneuvered away from the flight path once the threat acquires the signal, drawing the threat away from the CSG and ideally to a location where it could impact the ocean or be put within lethal range of conventional shipboard weapons.

Other potential options for this concept could include a launch of multiple vehicles carrying GPS transponders to create an interference source over a wide operational area. Use of multiple Tomahawk Land Attack Missile (TLAM) vehicles in this manner, spread over an operational area with different loiter patterns, would be sufficient to disrupt multiple threats. This could potentially increase the coverage area, especially if intelligence indicates the likelihood of multiple launches from a single site, multiple active sites, or that the active launch units are mobile. This technique may also be effective in dealing with multiple threats launched in a raid configuration and could solve the potential discrimination issue of threat evaluation and weapons assignment (TEWA) by exploiting the GPS dependency of all threats in the raid.

Because the vehicle-borne GPS transponder solution was approached as a complementary architecture that could supplement any of the possible selected core system architectures, it was also desired that the vehicle be a low-cost and easily integrated option. Ideally, an existing vehicle that is common to CSGs and could be retrofitted with a GPS transponder would be selected for this task. This would add additional capability to the system at a fraction of the cost and time required to develop a new vehicle expressly for this purpose.

The team first analyzed the feasibility of using an Unmanned Aerial Vehicle (UAV) to fill this role. The MQ-8B Fire Scout UAV was the specific unit considered due to the inventory approved for the recent initial deployment on Guided Missile Frigates (FFG) and planned deployment on the Littoral Combat Ship (LCS) and DDG 1000 platforms. The concept was to launch the UAV well in advance of the arrival of the threat; the UAV would loiter in the flight path between the expected launch point and the battlegroup while operating the GPS transponder. A graphical representation of this concept is shown in Figure 34.

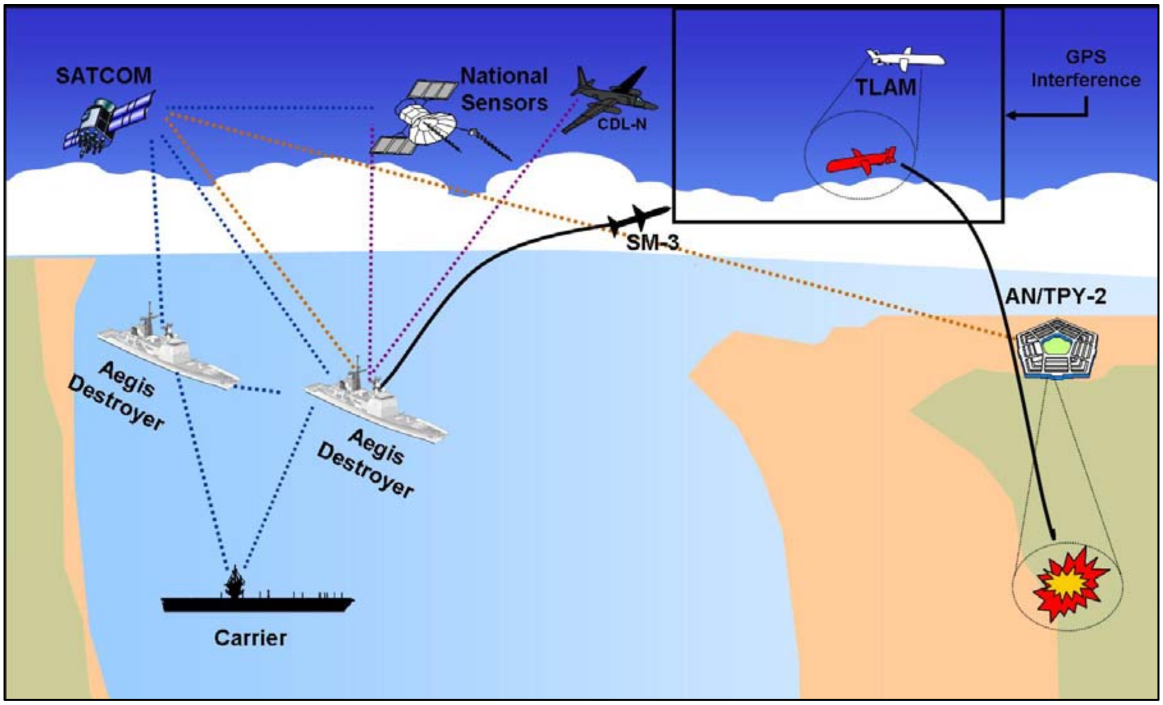


Note: The use of a UAV to carry a GPS-interference source across the flight path of the incoming threat was analyzed as a potential complementary architecture to augment any of the candidate ASBMD architectures. It is shown here in complement to the selected Aegis Combat System architecture.

Figure 34. UAV GPS Interference Option

This capability appeared feasible, because when the CSG is operating within the threat's capability range, the group should have consistent and quality intelligence reporting on the anticipated launch sites. The intelligence would allow for advance planning and UAV launch staging for faster response and on-station times prior to a threat launch. An analysis of this option concluded that the MQ-8B Fire Scout was unsuitable for this type of mission since it does not have the capability to achieve and maintain the required altitude, due to the environment that the UAV would encounter in the upper endoatmosphere. Additionally, the MQ-8B top speed only supports a maximum notice scenario. It is unlikely that the MQ-8B could be readied, launched, and positioned in time-critical scenarios to support this mission. The lack of widespread fielding or available launch platforms for the MQ-8B further limited consideration of it as a viable option for this capability.

The second option that the team investigated was the use of a TLAM as the GPS-transponder vehicle. This option is depicted in Figure 35.



Note: The use of a TLAM to carry a GPS-interference source across the flight path of the incoming threat was analyzed as a potential complementary architecture to augment any of the candidate ASBMD architectures. It is shown here in complement to the selected Aegis Combat System architecture.

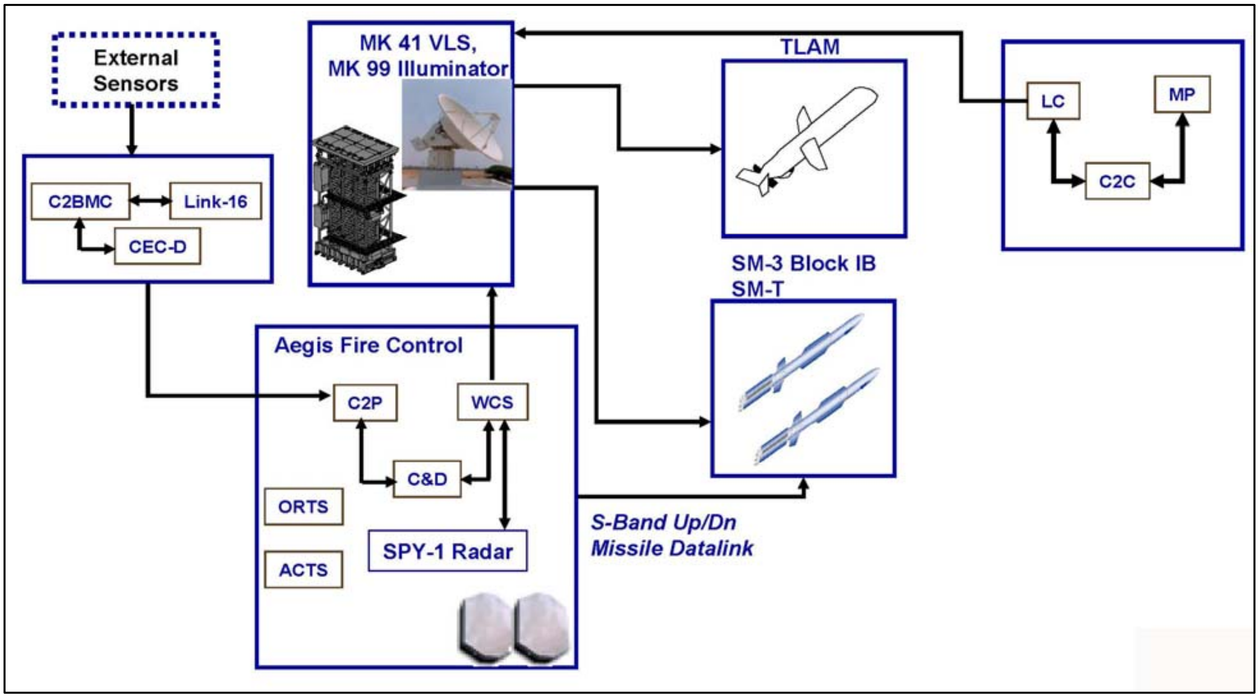
Figure 35. TLAM GPS Interference Option

The team concluded that the TLAM option was more technically feasible than the UAV option, since the newer TLAM (Block IV)—while not designed for use in the upper endoatmosphere—is capable of achieving the desired altitude. The TLAM has a built-in loiter mission that can be sustained for as long as its remaining fuel permits. Because the TLAM is not designed to operate in the upper endoatmosphere, it would be necessary to bring the missile up to the required altitude at a lower speed than typically employed for its flyout to minimize the risk of compromising the structural integrity of the missile. The ability to have advanced knowledge of the threat launch is again very critical to this option. The nominal mission planning and launch time for a new, no-notice mission is approximately 10 minutes for a Block IV TLAM. For a predefined Block IV mission scenario, the required time is reduced to 5 minutes. Operating at a lower speed, the

TLAM could have a nominal flight time of approximately 15 minutes (i.e., a 20-nautical mile (nm) range at a 165,000-foot altitude) to allow the TLAM to be positioned on station in time to begin its loiter and disrupt the threat. Although a total, on-station readiness window of 20 to 25 minutes is good, this demonstrates the need for intelligence indicators of a pending threat launch. It is not a viable option for backing up the core architecture in scenarios where no advance notice is received.

3. Fully Integrated Operational Solution (Based on Option 2)

A graphical representation of the fully integrated recommended solution, based on Option 2 and including the SM-T and TLAM complementary solutions, is depicted below in Figure 36. As discussed in Chapter III, the fully integrated solution meets the key functional requirements, as well as cost and schedule constraints of the project.



Note: The fully integrated architecture for the ASBMD system, based on Option 2, includes the core Aegis Combat System and the SM-T and TLAM complementary systems. The ability to fully integrate these elements into a system of systems is key to mission success in the ASBMD scenario.

Figure 36. Fully Integrated ASBMD System Architecture

As depicted in Figure 36, if the equipped ship receives advanced intelligence cueing, the crew would create and execute a TLAM mission plan to launch the TLAM for the interference mission. If no advance intelligence data were available, the launch of the TLAM would not be used as part of the engagement. After launch of the threat, the equipped ship would begin receiving BMD data across the BMDS network. The data would include a composite system track that is made up of fused Link-16 and CEC data from remote, forward-based sensors. Since the fire control algorithms have been optimized, the Aegis Weapons Control System (WCS) would recommend a launch time that would ensure that the time to intercept of the first dual-salvo SM-3s would be at the point that the threat has just reached apogee. This optimization is key to mission success since it ensures that the threat is intercepted at the point in flight where the target presents the largest cross section before the SM-3 intercepts.

Upon launch of the first salvo of SM-3 missiles, the ship would begin planning the launch of the second salvo, consisting of the SM-T interceptor to ensure the layered defense capability that was described in section 2 of this chapter. As the first salvo of SM-3 missiles breaches the atmosphere, the TLAM would begin transmitting GPS interference along the flight path of the threat. Ensuring that the SM-3s have exited the atmosphere before initiating the GPS interference is critical to mission success, since the interference could also impact the guidance of the SM-3. Prior to the actual engagement of the first salvo of SM-3, the updated Aegis fire control system would determine a need to launch the SM-T missile and ensure intercept in the upper endoatmosphere before the threat has begun its terminal maneuver. Upon engagement of the threat by the first salvo (i.e., dual-salvo SM-3s), the system would use both organic and BMDS nonorganic data to perform a KA. If the KA returns a positive kill, the threat has been eliminated, and the fire control system would terminate the SM-T portion of the mission and self-destruct the SM-T missile. The mission would be considered complete. If the system determines that the threat remains active, a status of no-kill would be reported, and the system would continue to consummate the SM-T portion of the engagement sequence. This weapon requires organic radar control commands until the threat’s terminal phase of flight. Therefore, resources would be prioritized to ensure sufficient guidance could be provided until the SM-T is within range of the threat. Following the SM-T engagement, the same KA described above would occur.

Although the specific firing policy updates to the CONOPS are not employed today, the selected system solution would be compatible overall with current fleet CONOPS and could be implemented with minimal impact and additional resources. The current fleet CONOPS provides for at least one BMD-equipped Aegis cruiser or destroyer within each CSG. Implementation of the ASBMD architecture would not change the current CONOPS but would require that the Aegis ship be equipped with the recommended system solution. The operational implementation of this system would include the plan to backfit the current BMD-equipped Aegis cruisers and destroyers to ensure a sufficient number would be available to support the CSG CONOPS. The ASBMD capability should be fielded in accordance with the BMD baseline installation, fielding, and maintenance plan so that the system could be deployed at minimal cost. If desired, the ASBMD architecture could be backfit in additional ships as new BMD ships are brought online, in accordance with the baseline installation schedule.

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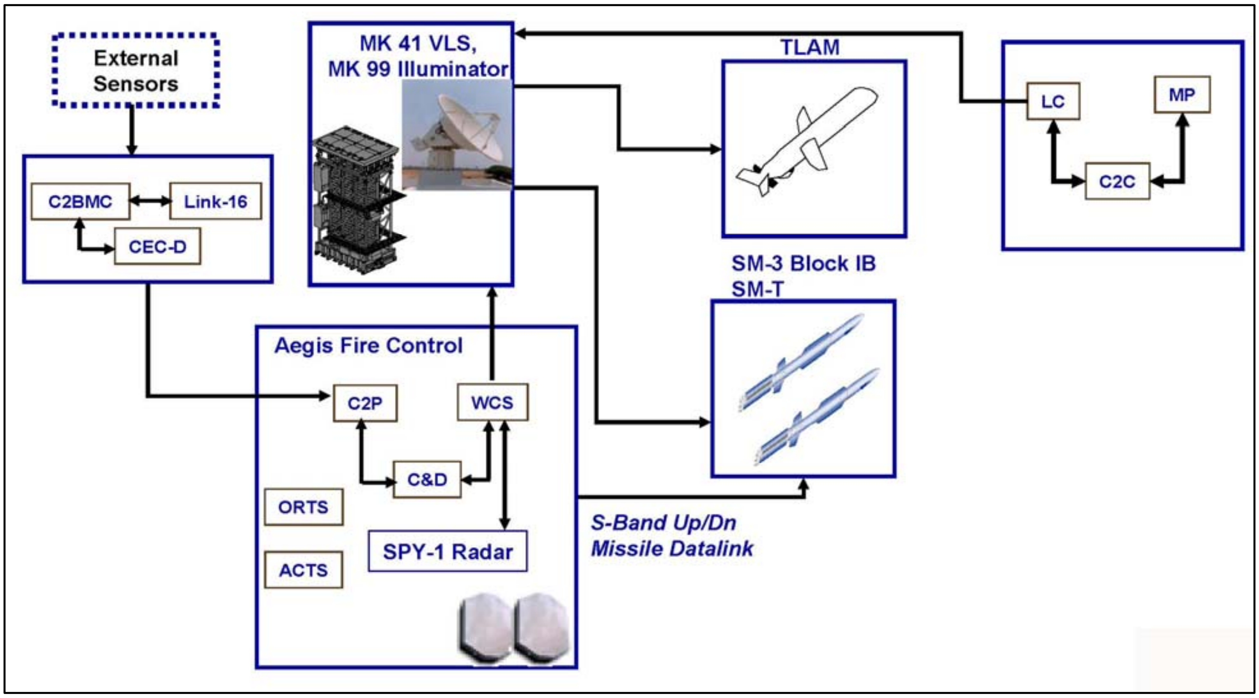
V. CONCLUSIONS AND RECOMMENDATIONS

A. OVERVIEW

The ASBMD team applied and maintained compliance successfully with a rigorous, tailored systems engineering process. The team created and followed a comprehensive and challenging schedule to ensure that research and development of the ASBMD System solution met the timelines identified at the beginning of the project. As defined in Chapters II and III, the team followed a tailored version of the systems engineering "V" model and focused on creation of a key set of analysis artifacts and program documentation. The objective was to design and communicate a robust system architecture that could fill the capability gap created by the introduction of the ASBM threat set.

Following requirements analysis and functional decomposition, the team developed and analyzed eight core system solution candidates and two possible complementary solutions. Using the key system requirements and schedule constraints as the bounding factors for the solution space, the team was able to quickly narrow the concept architectures down to three. Through the process of technical feasibility screening, the team was able to determine the single, best fit architecture concept, as described in Chapter IV. The recommended solution is based on Option 2 and includes the layered defense capabilities provided by the complementary SM-T and TLAM systems, as shown below in Figure 37.



Note: The fully integrated architecture for the BMDS system, based on Option 2, includes the core Aegis Combat System, as well as the SM-T and TLAM complementary systems. The ability to fully integrate these elements into a system of systems is key to mission success in the ASBMD scenario. (This figure was previously presented as Figure 36.)

Figure 37. Fully Integrated ASBMD System Architecture

These analyses focused on maximizing the detection and tracking capabilities of the selected architecture. The maximization of the detection and tracking ranges lengthens the engagement window and ultimately increases the ability to protect the CSG. Using the core architecture, as described in Chapter IV, provides the ability to deploy quickly, enhance the capability of the BMDS, and use existing assets without major modification to the current fleet CONOPS. The core option also has negligible impact to the total lifecycle cost of the existing systems, since it can be provided as an upgrade to the current fielded assets and then installed during the next scheduled installation and checkout (INCO) or maintenance availability.

The complementary systems defined in Chapter IV, if implemented as designed, would have negligible impact to the current BMDS network, but would require a fleet CONOPS update to facilitate the early warning and launch requirements to support the use of the system as described. The total lifecycle cost of the existing weapon system would still be unaffected with this solution, since the capabilities already exist within the current fielded assets.

B. FOLLOW-ON RECOMMENDATIONS

The recommended core architecture was paired with two complementary architectures, SM-T and GPS, to further layer the defensive capability of the ASBMD system. While both of these complementary concepts were deemed feasible by the ASBMD team for application in this manner, this determination was made via engineering assessment and has not been demonstrated through detailed analysis or test. No performance characterization has been conducted for either technology in this scenario; however, further study of both applications for consideration in a BMD architecture is recommended.

In addition to the ASBMD team's recommended solution, the team also recognized that it would be beneficial to continue to pursue the long-term development and testing of Option 1, as defined in Chapter III. Pursuit of Option 1 would ensure that the latest technology is developed with the ASBMD mission in consideration and would extend the fleet's ability to combat the ASBM threat with future platforms. As discussed in Chapter III, the SPY-3 radar would advance search and track capabilities beyond that of the SPY-1 radar currently employed in the Aegis Combat System. The Zumwalt Combat System would also bring advanced tracking and discrimination algorithms into service and will provide additional capability that would assist in lengthening the battlespace and engagement timeline for the ASBM threat.

The cost analysis for Option 1 was included in Chapter IV. Since the Zumwalt program is already under development and is currently funded through its IOC, an ASBMD capability for Zumwalt would need to be added to the Zumwalt Combat System and SPY-3 Radar. This would require additional funding, but could be integrated prior to IOC at a lower cost than if the decision to implement this capability in Zumwalt is made following delivery of the platform.

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Naval Postgraduate School (NPS)
Capstone Project
Masters of Science in Systems Engineering (MSSE)

ANTI-SHIP BALLISTIC MISSILE DEFENSE (ASBMD)

APPENDIX A

PROJECT MANAGEMENT PLAN

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Appendix A

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Appendix A

ILLUSTRATIONS

TABLES

Appendix A

ABBREVIATIONS AND ACRONYMS

ASBMD	Anti-Ship Ballistic Missile Defense
BDA	Battle Damage Assessment
C2I	Command, Control, and Intelligence
CJCSI	Chairman of the Joint Chiefs of Staff Instruction
CONOPS	Concept of Operations
DF	Dong-Feng (“East Wind”)
DoDAF	Department of Defense Architecture Framework
DoDI	Department of Defense Instruction
FOC	Full Operational Capability
ICD	Initial Capabilities Document
IOC	Initial Operational Capability
ID	Identification
IPT	Integrated Product Team
JCIDS	Joint Capabilities Integration and Development System
km	Kilometer(s)
KPP	Key Performance Parameter
KSA	Key System Attribute
LCC	Life Cycle Cost
MCDM	Multiple Criteria Decision Making
MOE	Measure of Effectiveness
MOP	Measure of Performance
NPS	Naval Postgraduate School
OIPT	Over-arching Integrated Product Team
PM	Program Manager
PMP	Project Management Plan
QFD	Quality Function Description
RDT&E	Research, Development, Test, and Evaluation
RMG	Risk Management Guide

SEP	System Engineering Process
TOC	Total Ownership Cost
UML	Unified Modeling Language
US	United States
WIPT	Working Integrated Product Team

Appendix A

1 INTRODUCTION

1.1 PROJECT DESCRIPTION

The members of this team have been tasked with investigating a system solution to counter the evolving Land-Based Anti-Ship Ballistic Missile threat. Current reports indicate that multiple countries and organizations have funded research and development of missile systems specifically designed to target sea-going vessels, including U.S. warships and aircraft carriers. This plan identifies the key tasks that the team will accomplish to research and identify a recommended architecture for a robust system of systems solution that may be developed to counter such threats.

1.1.1 Problem Statement

A recent article in the *U.S. Naval Institute's Proceedings Magazine* has suggested that China is developing ballistic missiles that can be used against moving targets, such as ships. One such technology is said to be able to cover a range of 2,000 kilometers (km) and operate at a speed of Mach 10. This type of threat from China, or any other nation, could greatly impact the current concept of operations of U.S. Navy ships. While there are currently some individual solutions capable of providing partial defense in specific mission scenarios, no comprehensive system has been developed to counter this threat post-launch. To fulfill this need, the Anti-Ship Ballistic Missile Defense (ASBMD) team will propose a notional architecture for a system of systems that could be used to effectively counter this threat.

Figure A-1. Modern Carrier Strike Group Underway
[From Strategypage.com, 2008]

1.2 ORGANIZATION STRUCTURE

The ASBMD team has decided to structure ourselves into Integrated Product Teams (IPTs), headed by a Team Lead. Each IPT Lead is a member of the Overarching-Level Integrated Product Team (OIPT) headed by the Project Manager (PM). This philosophy is expressed pictorially below in Figure A-2. The IPT structure directly maps to the Systems Engineering approach that we have chosen. The Systems Engineering philosophy will be discussed later in this document. IPTs will be established as necessary to perform the analysis and meet project objectives within each project phase. As an IPT completes its assigned tasking, the IPT Lead will report out to the OIPT/PM and members will populate or update their portion of the Capstone report. Upon completion and review of the relevant sections of the Capstone report, the IPT team members will be reassigned as necessary to support other tasking. The OIPT is responsible for identifying the Working IPT (WIPT) requirements throughout each project phase.

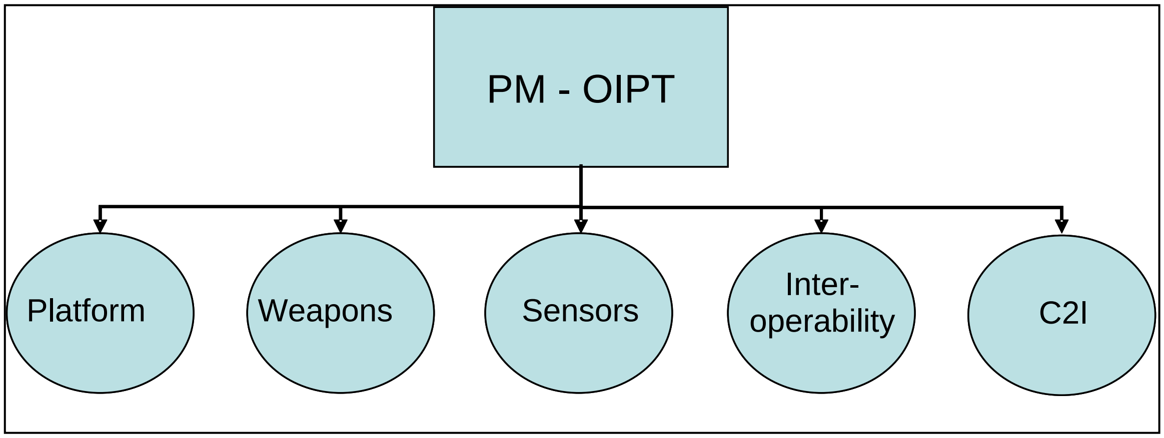

Figure A-2. ASMBD OIPT Structure

1.2.1 Team Membership

Table A-1 provides the names and contact information for each of the ASBMD team members.

Table A-1. ASBMD Team Member Contact Information

Name	Organization	E-mail Phone	Role
Hobgood, Jean	NSWCDD/K54	jean.hobgood@navy.mil (540) 653-2968	Technical Editor, Risk Manager
Madison, Kim	NSWCDD/W63	madisonkg@gmail.com (540) 653-6745	Data Librarian
Nedd, Steven	TACOM	steven.nedd@us.army.mil (584) 574-7928	Modeling Specialist
Pawlowski, Geoff	NSWCCD 2110	geoffrey.pawlowski@navy.mil (301) 227-3661	Cost Analyst
Roberts, Michael	NSWCDD/W51	michael.w.roberts@navy.mil (202) 406-4250	Lead System Analyst
Rumberg, Paige	NSWCDD/Q51	paige.rumberg@navy.mil (540) 653-3478	Team Lead, Scheduler

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2 SYSTEMS ENGINEERING APPROACH

2.1 OVERVIEW

A tailored Systems Engineering Process (SEP) will be utilized in the performance of this Naval Postgraduate School (NPS) Capstone Project. The SEP process chosen by the ASBMD team will be based on the V model, one of the SEP frameworks outlined in the NPS System Engineering Curriculum. A representation of the V model being used by the ASBMD team is shown in Figure A-3.

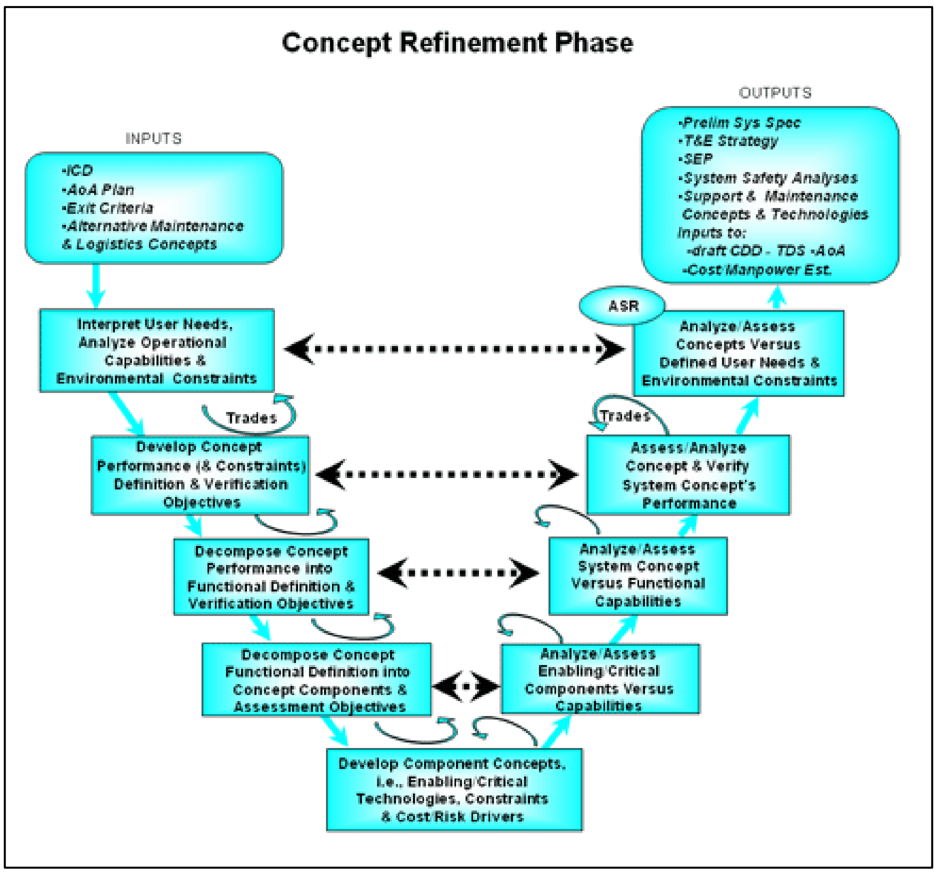

Figure A-3. ASBMD SEP Approach

2.2 TEAM APPROACH

The tailored version of the V model, shown in Figure A-3, will be used by our team to develop a notional system architecture that can be used to effectively defend against anti-ship ballistic missiles. At a fundamental level, the rationale for using a Systems Engineering V process is founded on the idea that it can provide an organized approach to problem resolution, according to the Sage and Armstrong text, *Introduction to Systems Engineering*.

The focus of this project, as our team has defined it, will be to address the Concept Refinement phase of the Defense Acquisition Process. Specifically in this phase, we will be focusing on developing high-level Concept of Operations (CONOPS), requirements, and system-level architecture artifacts. We feel that the SEP V process is appropriate for our use, because the project focuses on performing early acquisition phase conceptual definition and the supporting functional analysis.

2.2.1 Initial Research

With the problem statement identified during the initial phase of the project, and the overall goal of the project outlined, the initial research will be conducted covering all aspects of the problem. The team will be leveraging both public domain documentation and personal experiences to understand the detailed functional aspects of the problem. The team will research the capabilities and functional makeup of the basic threats that were identified in the initial problem statement. Understanding the threats and existing system capabilities will assist us in defining the system that can effectively combat the threats. Each of the topics chosen will be related to the SEP to ensure that the boundaries of the problem statement are maintained.

2.2.2 Stakeholder Analysis

During the stakeholder analysis phase, the individuals with a vested interest in a system that can achieve the objectives described in the problem statement will be identified and categorized according to their influences on the system. The output of this phase will be a weighted scale that will ensure that stakeholder needs have precedence in the decision-making process. Stakeholder inputs will be collected by surveys, interviews, or focus groups; these inputs will be used to derive system requirements and needs. The team will use the Quality Function Deployment (QFD) model and/or Pareto Analysis to both ensure that the customer inputs are understood, and to prioritize inputs so that the most significant issues are examined. Weighting of system requirements will allow the team to tailor the analysis phase so that only the most viable alternatives are evaluated.

2.2.3 Problem Formulation

In this phase, the project team will refine the problem definition to confirm that it remains scoped within the timeline and boundary of the project as we have defined it. This process will involve the performance of functional analysis to understand what the system must accomplish, and the development of a functional architecture that outlines the sequence and structure of the tasks identified during functional analysis.

2.2.3.1 Perform Functional Area Analysis

As stated in Blanchard and Fabrycky's *Systems Engineering and Analysis*, the functional area analysis portion of any system engineering process is a critical step. In this task we will use the functional need statement, derived from the stakeholder analysis performed in earlier steps, to define the system needs and basic requirements from the system level down to the applicable level of detail. Per the direction provided during the NPS Systems Engineering curriculum, the objective of functional analysis is to specify the "what's" that need to be accomplished. We plan to use Figure A-4 as a starting point for our functional hierarchy. This notional functional hierarchy will be updated to depict the overall actions required to effectively and efficiently meet the threat detailed in the problem statement. As discussed earlier, this functional hierarchy is notional and will change as the team further defines the scope of the project.

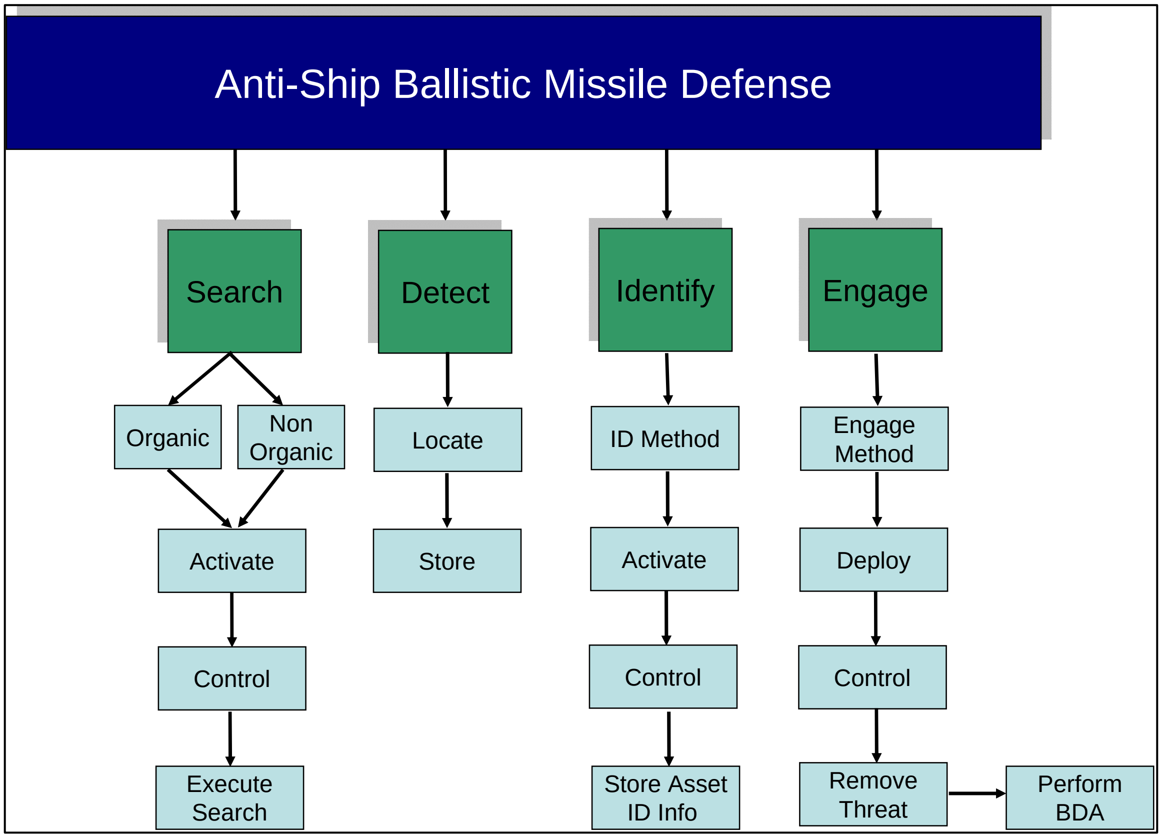

Figure A-4. ASBMD Functional Hierarchy (Notional)

2.2.4 Analysis of Alternatives

Upon completion of the problem formulation and the functional architecture determination described above, our team will determine the physical architectures and generate various system alternatives. During this phase, the team will also begin developing the models that will be used to analyze the various alternatives of the system. This work will help drive the feasibility analysis and metrics that will be used in the justification for a final recommended decision.

2.2.4.1 Developing Alternatives

Morphological charts and the QFD diagrams created earlier will be used to assist the project team in the development of alternatives. This is the point in the process where the "what's" are developed into "how's."

2.2.4.2 Generate Metrics to Measure Effectiveness/Performance

During this activity, the team will be generating metrics as we compare the alternative systems defined during the Analysis of Alternatives phase to both the operational- and performance-related requirements. The objective of the developed metrics will be to provide quantitative evaluation of the effectiveness and performance of the various alternatives. The outcome of this effort will be a measurement of how completely each of the alternatives meets the defined performance requirements.

2.2.4.3 Develop Models and Simulations

During this task, the team will develop models and simulations using different modeling techniques for the purpose of evaluating tangible alternatives and as a method of understanding the system of systems, functional decomposition, hierarchy, and overall system effectiveness. Furthermore, Arena, Excel, MATLAB, UML and other tools will be used throughout the design process to assess risk, cost, schedule, and system performance. The goal is to produce a system architecture that can provide a solution to the problem statement that best meets the needs identified from the stakeholder analysis.

2.2.5 System Concept Refinement/Finalization

The final phase of our modified SEP is to perform System Concept Refinement and Finalization activities. The goal for this phase is to carry out the final decision analysis of the alternatives with reference to the Measures of Effectiveness (MOEs) and Measures of Performance (MOPs) obtained from metrics analysis and the modeling and simulation exercises. It will involve cost analysis, risk analysis, sensitivity analysis, trade-off study, and finally, the recommendation of the preferred alternatives.

2.2.5.1 Cost Analysis

The goal for cost analysis is to estimate the total Life Cycle Cost (LCC), or Total Ownership Cost (TOC), of the various identified alternative systems. The LCC is defined as the cost of the Research, Development, Test, and Evaluation (RDT&E); procurement of prime equipment, support equipment and spares; operations and support of prime equipment, support equipment and spares; and disposal of the system. Out year costs will be discounted to reflect the declining value of the dollar over time and allow alternatives to be compared to one another using net present value.

2.2.5.2 Risk Analysis

Risk analysis will be conducted to identify the risk drivers associated with developing this Capstone project. The goal is to identify cost, schedule, and technical risks so that they can be controlled, and that the consequences of courses of action can be determined as early in the process as possible. The ASBMD team will perform this risk management during all phases of the development of our project. All risks that we identify will be analyzed and scored according to risk management procedures defined in the DoD Risk Management Guide (RMG). All risks are evaluated and categorized according to the probability (likelihood) of failing to achieve a particular outcome and the consequences (impact) of failing to achieve that outcome.

Initial risk analysis performed by the ASBMD team has identified six current risks. Four of these risks are related to meeting our project schedule and two are related to being able to find a feasible technical solution. An Excel spreadsheet is maintained by the team and contains a current status of all risks being tracked by the team and the mitigation plans for each one. Figure A-5 shows the current risk matrix for the ASBMD team.

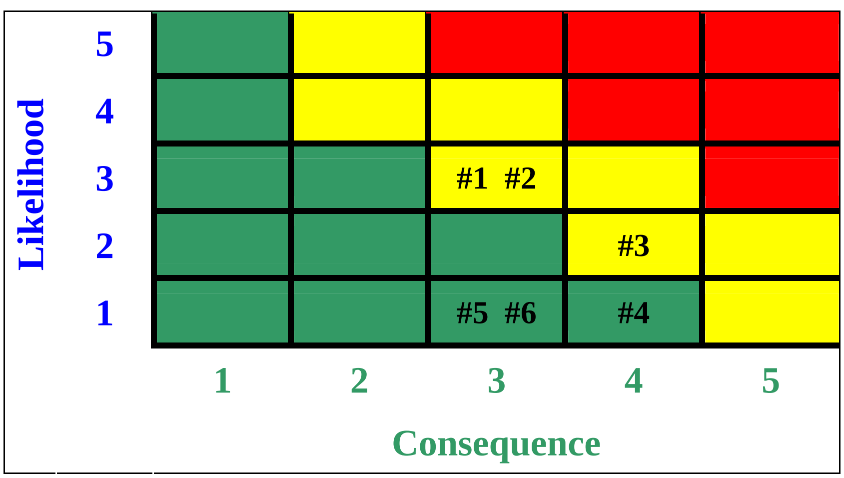

Figure A-5. Current ASBMD Risk Management Matrix

Table A-2 describes the risks currently being tracked by the team.

Table A-2. Current Risk Description for ASBMD

Risk #	Description	Type
1	The team will not be able to generate a list of viable alternatives to counter the threat in a timely manner, so the analysis of alternatives will be delayed.	Schedule
2	The team will not decide on a list of Key Performance Parameters (KPPs) in a timely manner, so the analysis of alternatives will be delayed.	Schedule
3	Modeling and simulation tools will not be developed in time for their use in the analysis of alternatives.	Schedule
4	Final project report and briefing will not be completed on time.	Schedule
5	The team will not be able to find a feasible solution to meet the stated need.	Technical
6	The chosen solution is not able to be integrated with existing systems.	Technical

2.2.5.3 Sensitivity Analysis

A basic sensitivity analysis will be conducted to verify the quality of the mathematical models. The assigned weights used for decision-making criteria will be varied to determine the areas that are the most influential in the outcome of the system decision. Sensitivity analysis will identify the sources of uncertainty that affect the study's conclusions most. This will ensure the quality of the models and increase confidence in the assessment.

2.2.5.4 Trade-off Study

A trade-off study is the activity of finding the solution to a problem that best satisfies a series of technical measures and/or cost functions. These measures will describe the desirable characteristics of a given solution. Multiple Criteria Decision Making (MCDM) methodology such as min-max methods, min-max regret methods, and weighting methods (decision matrix), may be used to compare each of the alternatives.

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3 MILESTONES AND DELIVERABLES

3.1 OVERVIEW

As described above, when using the SEP approach there are several key milestones and associated deliveries that the team will need to make to ensure that progress is being made. As detailed in section 2.2, this project will focus on the Concept Refinement Phase of the Defense Acquisition Process. The ASBMD team will create high level excerpts from each of the key documents identified in the Integrated Defense Acquisition, Technology, and Logistics Life Cycle Management Evolutionary Acquisition Program, using the DoD Instruction 5000.2 as the guide. The high level view of the Defense Acquisition Process focusing on the areas that we are going to address is shown below in Figure A-6.

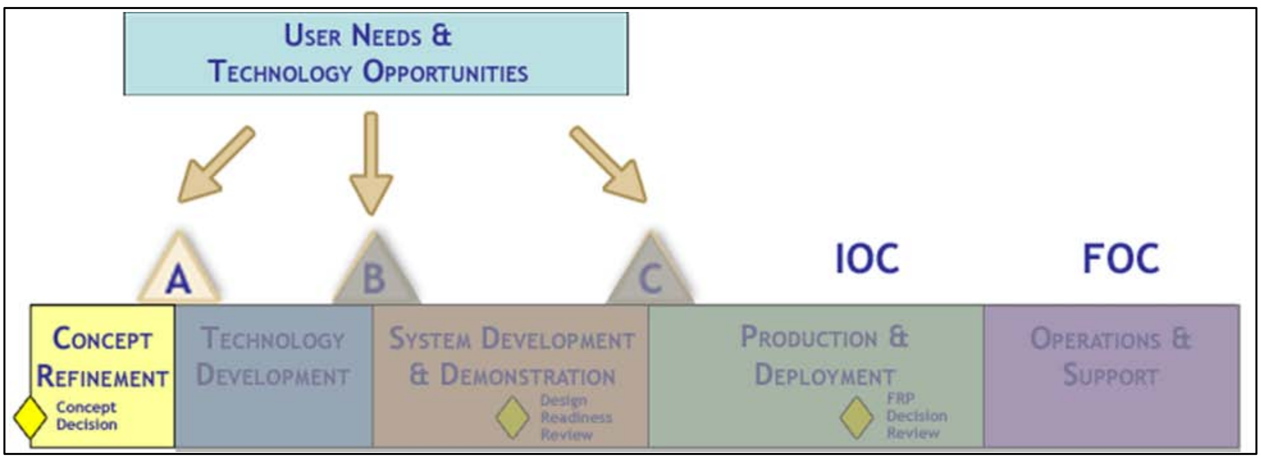

Figure A-6. ASBMD Focus within the Defense Acquisition Process [Lifecycle Framework View]

3.2 DELIVERABLES

The following products will be provided by the ASBMD team for this Capstone project as a stand-alone document as well as being excerpted in the team's final report:

- **Problem Statement**: Statement outlining the current system capabilities and threat assessments; provides details of the current system functional gap that our team has chosen to address.

- **Project Management Plan (PMP)**: Initial project guide that will shape our teams approach and schedule for developing the project documentation.
- **Stakeholder Analysis**: Results from the QFD and/or Pareto Analysis.
- **CONOPS (Excerpt)**: Describes the concept of operations for our project; also, the beginning of how we plan to fit our solution into the existing systems within the fleet.
- **Functional Area Analysis**: Identification of operational tasks, conditions, and standards needed to accomplish the system objectives.
- **Functional Architecture (Department of Defense Architecture Framework [DoDAF] products)**: High-level functional diagrams depicting the overall system alignment and functions from a system view. Also, details interactions within the system and identifies the key functions that are performed.
- **Initial Capabilities Document (ICD) (Excerpt)**: As defined in the Chairman of the Joint Chiefs of Staff Instruction (CJCSI) 3170.01F, *Joint Capabilities Integration and Development System (JCIDS)*. This will be the main deliverable for the system engineering effort of our project. The ICD will be used to identify the KPPs and Key System Attributes (KSAs) which define the most critical elements of performance for our system. This document will be closely tied to the CONOPS; this is done to ensure that the KPPs identified meet the overall need of the system as originally defined during the analysis phase.
- **Analysis of Alternatives Results**: These will be used to evaluate each of the possible system combinations. This analysis will take into account the ability of the alternatives to meet KPPs and KSAs as well as affordability and schedule constraints.
- **Metrics, Models and Simulation Analysis**: Used to detail the models and associated metrics that will be used to validate the chosen systems performance to ensure it meets MOEs and KPPs.

- **Final Report**: Collection of the artifacts that were delivered earlier in the project. The final report will be the documentation of the final process and schedule that the team used to assess and present the recommended system architecture.

3.3 SCHEDULE

The overall schedule for the analysis and delivery of the key work products is outlined in Figure A-7.

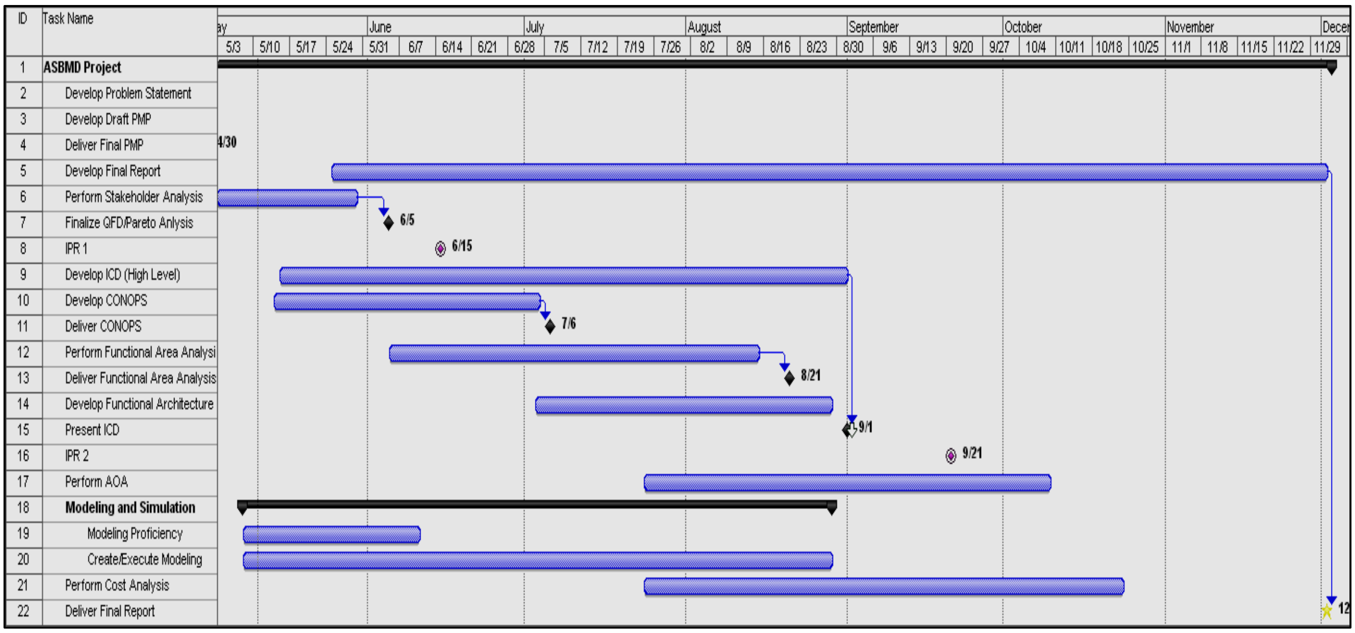

Figure A-7. ASBMD Current Project Schedule

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ANTI-SHIP BALLISTIC MISSILE DEFENSE (ASBMD)

APPENDIX B

CONCEPT OF OPERATIONS (CONOPS)

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Appendix B

ILLUSTRATIONS

TABLES

Appendix B

ABBREVIATIONS AND ACRONYMS

ASBM	Anti-Ship Ballistic Missile
ASBMD	Anti-Ship Ballistic Missile Defense
BMC4I	Battle Management Command, Control, Communications, Computers, and Intelligence
BMD	Ballistic Missile Defense
BMDS	Ballistic Missile Defense System
C2BMC	Command and Control, Battle Management and Communications
CONOPS	Concept of Operations
EO	Electro-Optic
GBI	Ground Based Interceptor
GCCSM	Global Command and Control System Maritime
ICD	Initial Capabilities Document
IR	Infrared
km	Kilometer(s)
MDA	Missile Defense Agency
MSSE	Master of Science in Systems Engineering
MTBF	Mean Time Between Failures
PAC	Patriot Advanced Capability
PMP	Project Management Plan
SBT	Sea-Based Terminal
SBX	Sea-Based X-Band Radar
SM	Standard Missile
SMT	SM-2 Block IVA
TADIL-J	Tactical Digital Information Link
THAAD	Terminal High Altitude Area Defense
UEWR	Ultra Early Warning Radar

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Appendix B

1 ANTI-SHIP BALLISTIC MISSILE DEFENSE CONOPS

1.1 Objective

The objective of the Anti-Ship Ballistic Missile Defense (ASBMD) system is to detect, track and eliminate Anti-Ship Ballistic Missile (ASBM) threats. The team will research and document a proposed architecture for a total system solution that could potentially be used to combat the evolving ASBM threats.

1.2 Assumptions

The following list of assumptions will apply to this document and all follow-on efforts for this project:

- ASBM threats will be launched from land.
- All current communication mechanisms are operational and deployed on all systems.
- While used for Ballistic Missile Defense (BMD), the system will not be required for additional functions.

1.3 Scope

This document outlines the ASBMD Concept of Operations (CONOPS) for support of the Team 1 Master of Science in Systems Engineering (MSSE) Capstone project. The system under investigation is limited to the specific scope that has been defined in the problem statement and detailed in the Project Management Plan (PMP) created earlier in the project. The scope of the project includes the research, creation and documentation of the total system architecture that may be used to combat the identified threats. The system is limited both by the assumptions outlined in Section 1.2 and by the constraint that it must communicate and integrate into the existing Ballistic Missile Defense System (BMDS).

Due to the maturity of existing capabilities to detect and track ballistic missiles during the boost phase, the ASBMD team will primarily focus the detailed analysis and architecture documentation on the post-boost phase – tracking and eliminating the threats during later phases of the ballistic flight-path. Figure B-1 depicts the basic stages of flight of a nominal ballistic missile.

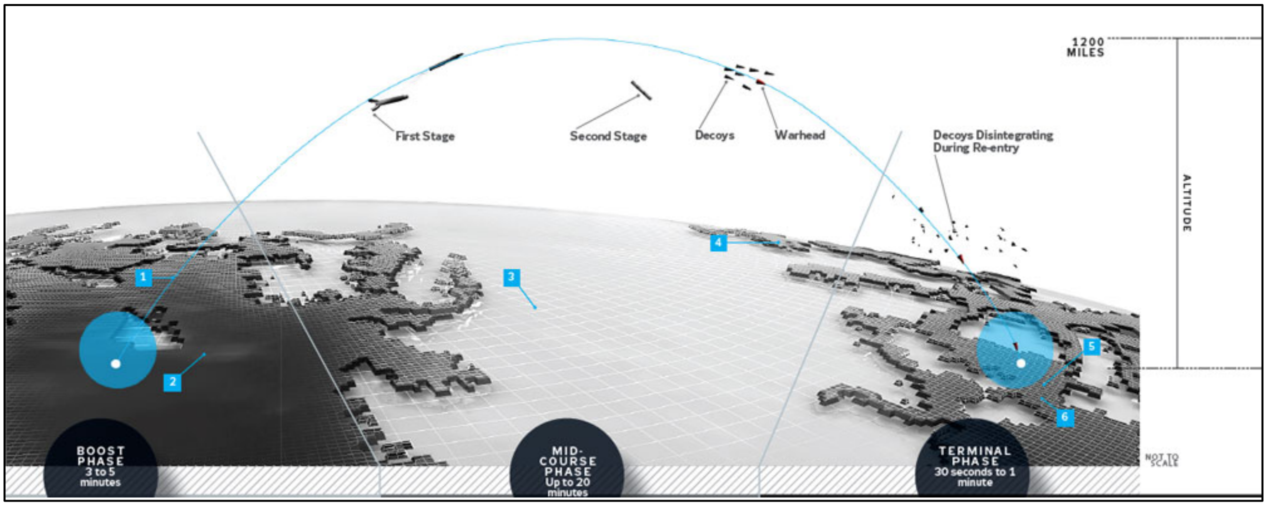

Figure B-1. Phases of Ballistic Missile Flight

2 SYSTEM NEED

2.1 Problem Statement

Recent intelligence reports have suggested, as described recently in *U.S. Naval Institute's Proceedings Magazine*, that multiple nations are developing ballistic missiles that can be used against moving targets, such as ships. These threats are being increasingly characterized as having the ability to maneuver for evasion and to track their targets during the terminal phase of the ballistic missile flight path, as depicted in Figure B-2. One such technology is said to be able to cover a range of 2,000 kilometers (km) and operate at a speed of Mach 10. This type of threat could greatly impact the current CONOPS of U.S. Navy ships. While there are currently BMD solutions that can intercept threats in the midcourse and terminal phases, no comprehensive system has been developed to counter a maneuvering reentry vehicle threat post-launch. Figure B-3 demonstrates the potential range for these threats if launched from mainland China.

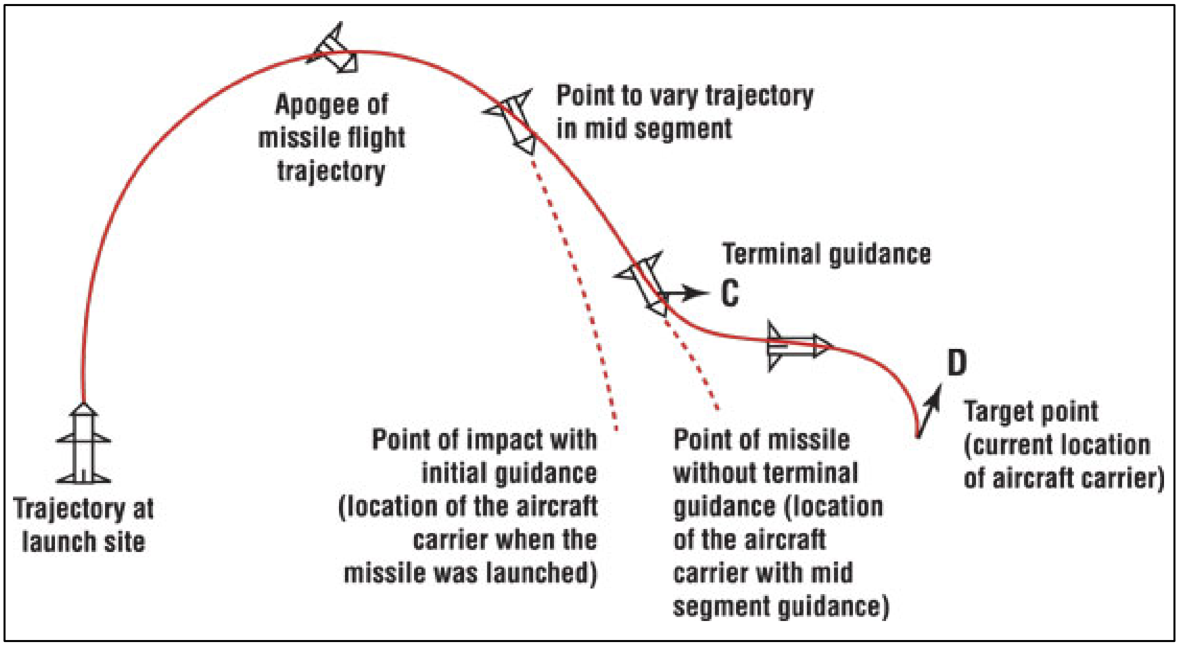

Figure B-2. Notional Operation of ASBM Threat with Maneuvering Reentry Vehicle

Figure B-3. Map of China and Overlay of Missile Ranges

2.2 The Ballistic Missile Flight

Intercepting a missile in its boost phase is the ideal solution for ballistic missile defense. If the missile is carrying a chemical, biological, or nuclear weapon, the debris will most likely fall on the country that launched the missile. At the least, it will certainly not have obtained enough velocity to reach its intended target. Because of this, it is not critical to completely destroy the missile’s warhead. Although attacking a missile while it is struggling against the earth’s gravity is ideal, it poses significant challenges to a defense system. First, the boost phase is relatively short. This means that sensors will have to detect a launch and relay accurate information about the missile very quickly. Second, an interceptor missile would have to be very close, or extremely fast to catch up to the accelerating missile, and properly configured to intercept a target in the boost phase. When possible, for the global coverage and protection against more lethal payloads it can provide, a capability to intercept a missile near its launch point is always preferable to attempting to intercept that same missile closer to its target.

The midcourse phase allows the largest opportunity to intercept an incoming missile. At this point, the missile has stopped thrusting, so it follows a more predictable path. Depending on the interceptor launch location, multiple interceptors could be launched, with a delay between them to see if the first ones were successful. Since the interceptor has a longer time to engage, fewer interceptor sites are needed to defend larger areas. Unfortunately, a longer period in space provides an attacking missile the opportunity to deploy countermeasures against a defensive system. However, the defensive system also has more time to observe and discriminate countermeasures from the warhead.

The terminal phase of a ballistic missile's flight is normally less than one minute long. At this point, defensive systems must be very close to the missile's target in order to defend against the attack. Countermeasures are less of a challenge in this phase. They usually fall slower than the warhead and are burned up as the warhead re-enters the atmosphere. Defensive systems designed for the terminal phase are most effective in protecting nearby troop concentrations, ports, airfields, and staging areas. Currently fielded terminal phase interceptors have not been proven to be effective against maneuvering re-entry vehicles.

2.3 Existing Capabilities

There are currently multiple systems deployed that are designed to combat Theater Ballistic Missiles. Each of the individual systems are designed to focus on specific phases of the ballistic missile flight as described in section 2.2. Some examples of these systems and their primary functions are described in Table B-1 below.

Appendix B

Table B-1. Existing Systems, Time Phase, and Function

	System Name	Phase	Function
Weapon Systems	Ground Based Interceptor (GBI)	Midcourse	Engagement
	Patriot Advanced Capability-3 (PAC-3)	Boost/Midcourse	Engagement
	Standard Missile (SM)-3 Block IA	Midcourse	Engagement
	SM-2 Block IVA (SMT)	Terminal	Engagement
	Terminal High Altitude Area Defense (THAAD)	Terminal	Engagement
Sensors	Cobra Dane Radar	Boost	Detection/Tracking
	Ultra Early Warning Radar (UEWR)	Boost	Detection/Tracking
	AN/TPY-2 (Forward-Based Mode)	Boost	Detection/Tracking
	AN/TPY-2 (THAAD Mode)	Terminal	Detection/Tracking
	AN/SPY-1	Midcourse/Terminal	Detection/Tracking
	Space-Based Sensor Suite	Boost/Midcourse	Detection/Tracking
	Sea-based X-band Radar (SBX)	Boost/Midcourse	Detection/Tracking
BM C4I	Command and Control, Battle Management and Communications (C2BMC) Spiral 6.2	All	BMC4I

A specific example of such a system includes the successful Aegis BMD System. This specific system uses both remote and local detection and tracking via ground and satellite based sensor systems and shipboard sensors. Once the threat has been detected and transitioned to track, the remote systems can “hand over” the threat track to the shipboard AN/SPY-1D Radar System for organic tracking and engagement. The handover of the threat is accomplished by having the remote tracking system calculate a flight trajectory of the threat track and cue the organic radar to a point in space where the threat will be at a given time. This method requires direct high speed communication between all elements in the system. The Aegis BMD systems also rely heavily on the availability of the SM-3 or SM-2-Block IVA missile to engage and destroy ballistic targets in the midcourse and terminal phases, respectively. The systems currently have no alternate or complementary shipboard weapons that could be used to combat a ballistic threat.

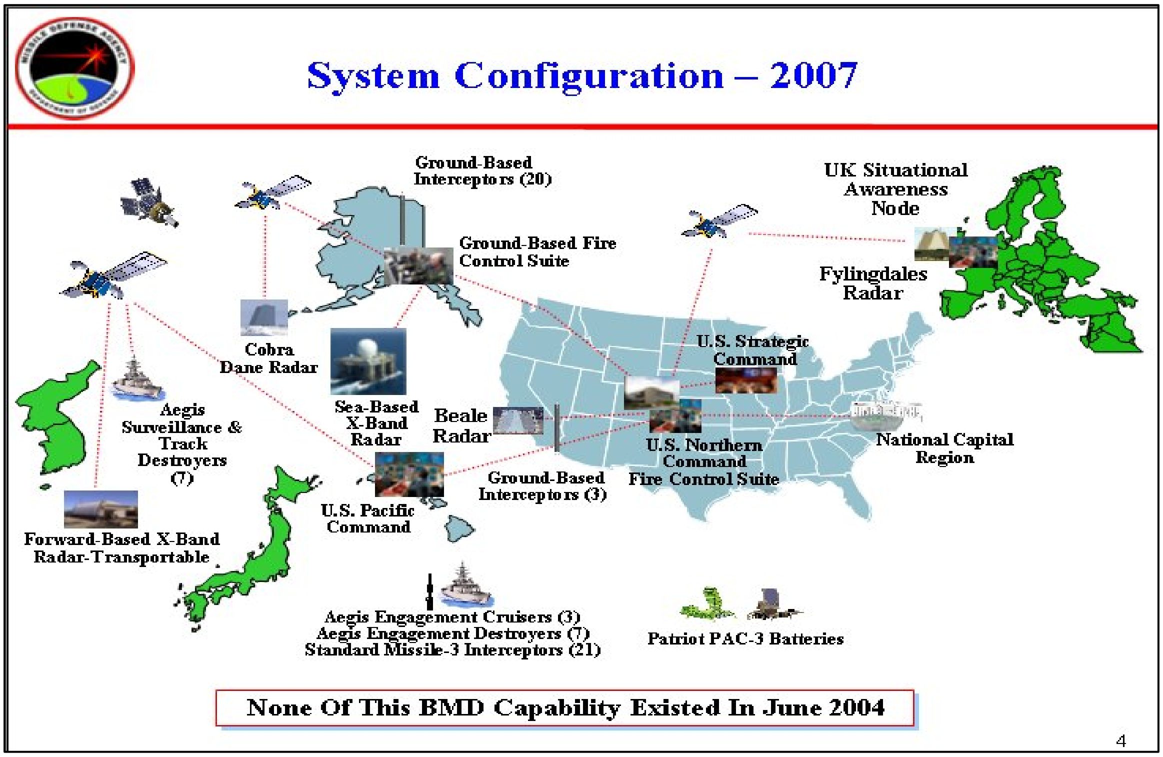

Figure B-4. Missile Defense Agency (MDA) Ballistic Missile Defense System, as of 2007

As discussed earlier in this document, there are multiple systems currently deployed or in development that have the ability to detect and track ballistic missiles during boost, midcourse, and terminal phases. Coupled with the existing system that provides the capability to engage these threats during the same phases, the U.S. has a robust system design that has a successful track record during test intercepts of ballistic targets.

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3 SYSTEM JUSTIFICATION

3.1 Current System Shortcomings

3.1.1 Sensors

As previously described, the current BMDS rely heavily on the ability of remote, internal, and onboard sensors to predict and relay the flight path trajectory of the ballistic threat. The anti-ship threats that are being introduced have uncovered a major shortfall in the current deployed systems. Using the example threat given in the problem statement, upon re-entry the threat can be traveling in excess of Mach 10 and can maneuver during the terminal portion of flight, altering its aim-point and ultimately forcing a defense system to estimate a false trajectory. Given the current capabilities, the ability of the system to predict the flight path of these threats becomes impossible.

3.1.2 Weapon System

Another shortcoming of the current system is that, for sea-based intercepts, it relies exclusively on the availability of ships configured with the Aegis BMD Weapon System and loaded with SM-3 or SM-T missiles. Only 5 cruisers and 16 destroyers are configured to conduct Aegis BMD missions, so these assets must be strategically located to provide adequate coverage. While the SM-3 Block IA is a full rate production missile, it is only capable of conducting midcourse intercepts. The Sea-Based Terminal (SBT) terminal-phase intercept capability is provided by use of the modified SM-T. Since this missile is no longer in production, the SBT capability is limited to the remaining inventory of this missile. Given the minimal system availability, there exists a very large operational risk for most carrier battle groups. Based on the capabilities deployed to-date, if the threats that we have identified are put into production, there would need to be a very large shift in the current operational CONOPS for the U.S. Navy. Without a robust and reliable system to counter these threats, U.S. Navy Carrier Ships would be required to drastically reduce their ability to operate within close vicinity of countries that have the threat production capabilities.

3.2 New System Benefits

The system architecture that the ASBMD team will be producing will document a system that will eliminate the ASBMD threat by using remote data for tracking and engagements. The specific benefits of the ASBMD System will be its ability to track and eliminate or avoid maneuvering threats during the midcourse or terminal phases of flight. The Navy will benefit from a robust architecture that can provide engagement-quality data to a system that can be used to eliminate the threat during the terminal phase of flight.

3.3 Priority of New Features

The ASBMD team has prioritized the key system features taking into consideration existing systems that can perform portions of the mission. As stated earlier, there are multiple systems that have the ability to detect and engage ballistic missiles during the boost phase of ballistic missile flight, therefore the priority of our proposed system and analysis will be the tracking and engagement of anti-ship ballistic missiles during the midcourse and terminal phase of flight.

Within the terminal phase of flight there are two key features, tracking and engagement, and we have prioritized these functions as well. The ASBMD team prioritized tracking of the re-entry vehicles as the highest priority and then the engagement of the threats as the second highest. This prioritization is based on the fact that the ASBMD System is predicated on the ability of the system to provide engagement quality data that may be used to engage and eliminate the threats; therefore, tracking of the threats is of the utmost importance.

4 FUNCTIONAL REQUIREMENTS

Discussions with stakeholders resulted in high level operational requirements that will be used as a starting point for further analysis and decomposition. The list is subject to change as feedback is generated in subsequent systems engineering steps. A complete final list will be documented in the ASBMD Initial Capabilities Document (ICD).

1) ASBMD System shall be capable of sending, receiving, and processing intelligence reporting messages to be used for situational awareness related to Ballistic Missile flight path. (Includes but not limited to the ability to receive and process Global Command and Control System Maritime (GCCSM), Link-16 Tactical Digital Information Link (TADIL-J), N-Series Messages, and J-Series Messages).

2) ASBMD System shall process received intelligence messages and create radar search sectors to be used by both on-board and off-board sensors.

3) ASBMD System shall detect and track Ballistic Missiles including up to 10 vehicles during terminal phase of missile flight path. Tracking shall include the production and dissemination of engagement quality data.

4) ASBMD System shall be capable of near simultaneous engagement of no-less-than 10 ballistic vehicles.

5) ASBMD System shall be capable of performing “Launch on Remote” using fire control quality data from the BMDS network.

6) ASBMD System shall have the ability to perform both self-defense and BMD missions.

7) ASBMD System shall have a Mean Time Between Failures (MTBF) that is greater than or equal to the MTBF of the existing BMDS System.

8) ASBMD System shall have the ability to perform high fidelity object discrimination.

9) ASBMD System shall have the ability to perform localization.

10) ASBMD System shall have the capability to perform threat identification.

4.1 Mission Features Capabilities and Functions

4.1.1 System Components and Functions

The ASBMD capability will be achieved by a system of systems that, to meet its mission requirements, is comprised of a minimum set of components. Components that will be considered and analyzed may include: radar, electro-optic (EO)/infrared (IR) sensors, passive electronic warfare sensors, communications/link architecture, command and control, decoys, electronic countermeasures, and weapon system.

A preliminary functional analysis has resulted in a list of the primary system functions, as follows:

- **Search**: The system will be capable of conducting search functions in self-defense and BMD modes.
- **Detect**: The system will be capable of detecting an incoming threat organically (using own-ship sensors). The system will also be capable of initiating engagement sequences based on remote sensor detection and hand-off of track.
- **Acquire Track**: The system will be capable of conducting organic track acquisition and communicating that track to the BMDS. The system will also be capable of a launch on remote track data, with eventual acquisition of the track organically, or full engagement on remote track data (with no organic track acquisition).
- **Planning**: The system will be capable of communicating with BMDS resources for determination of the best use of local radar and weapon resources.
- **Identification**: The system will be capable of identifying the threat type and not engage on countermeasures, within margin, via onboard sensor discrimination.
- **Engagement**: The system will be capable of executing an engagement against the incoming threat.

- **Kill Assessment**: The system will provide kill assessment data to the operator and the BMDS so that a determination of kill and potential for re-engagement can be assessed.

4.1.2 Operational Environment

The system must be capable of surviving and operating in the tactical environment and will meet all requirements for system certification and fielding. Ships with this capability can be deployed in any operational area necessary to provide coverage in the ASBMD mission area.

4.1.3 System Interfaces

The system, as designed, must interface with the larger BMDS for the purposes of battle management, data sharing, and command and control. It will interface with its battlegroup or ships in company for local and remote fire control, radar resource and weapon management.

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5 CONCLUSIONS

Currently there is no single solution to address the threat described in the problem statement. In designing a system of systems solution, a key objective of this project will be to consider technologies that would complement a layered approach that takes advantage of remote and forward-based capabilities as well as organic/own-ship capabilities. Any leveraging of existing technology will require that the systems are made more robust to meet requirements for sensor function, detection, and BMDS interfaces. The final product of the system design will be to propose a reliable, compatible, and interoperable ASBMD functionality to support defense of critical assets and mission areas to the U.S. Navy.

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Appendix B

6 REFERENCES

Erickson, A. & Yang, D. (2009). On the Verge of a Game-Changer. *U.S. Naval Institute Proceedings Magazine*, 153(5), 1,275.

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Naval Postgraduate School (NPS)
Capstone Project
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ANTI-SHIP BALLISTIC MISSILE DEFENSE (ASBMD)

APPENDIX C

INITIAL CAPABILITIES DOCUMENT (ICD) EXCERPT

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CONTENTS

Appendix C

ILLUSTRATIONS

Appendix C

ABBREVIATIONS AND ACRONYMS

ASBM	Anti-Ship Ballistic Missile
ASBMD	Anti-Ship Ballistic Missile Defense
BMDS	Ballistic Missile Defense System
C2	Command and Control
CONOPS	Concept of Operations
GCCSM	Global Command and Control System Maritime
ICD	Initial Capabilities Document
ID	Identification
KA	Kill Assessment
LOR	Launch on Remote
MOE	Measures of Effectiveness
MOP	Measures of Performance
MTBF	Mean Time Between Failures
SATCOM	Satellite Communication
TADIL-J	Tactical Digital Information Link

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Appendix C

1 SCOPE

The proposed Anti-Ship Ballistic Missile Defense (ASBMD) System is scoped to be a system of systems that provides a set of value-added functions that will be operated within the existing Ballistic Missile Defense System (BMDS). The system's objective is to provide increased capabilities to defend against and eliminate Anti-Ship Ballistic Missile (ASBM) threats. The proposed system will be fully integrated, interrelated, and interoperable with the existing BMDS. As a result, the ASBMD System will be an information environment within an existing combat system comprised of interoperable computing and communication components. As originally defined in the ASBMD Concept of Operations (CONOPS), the ability of an ASBM threat to maneuver during its terminal phase of flight is what differentiates it from the average ballistic missile. Due to the distinct operational attributes of the ASBM threat, the unique functionality of the ASBMD System will be limited to the tracking and elimination of these threats during the post-boost phase of flight. Although the threats will be tracked throughout their flight by remote and onboard sensors, the engagement of the threats will not occur until post-boost phase.

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2 NOTIONAL ARCHITECTURE

Figure C-1 depicts the high level notional architecture of the ASBMD System that will be used to eliminate the defined threats. Each of the key functions identified will be discussed in detail in later sections of this document.

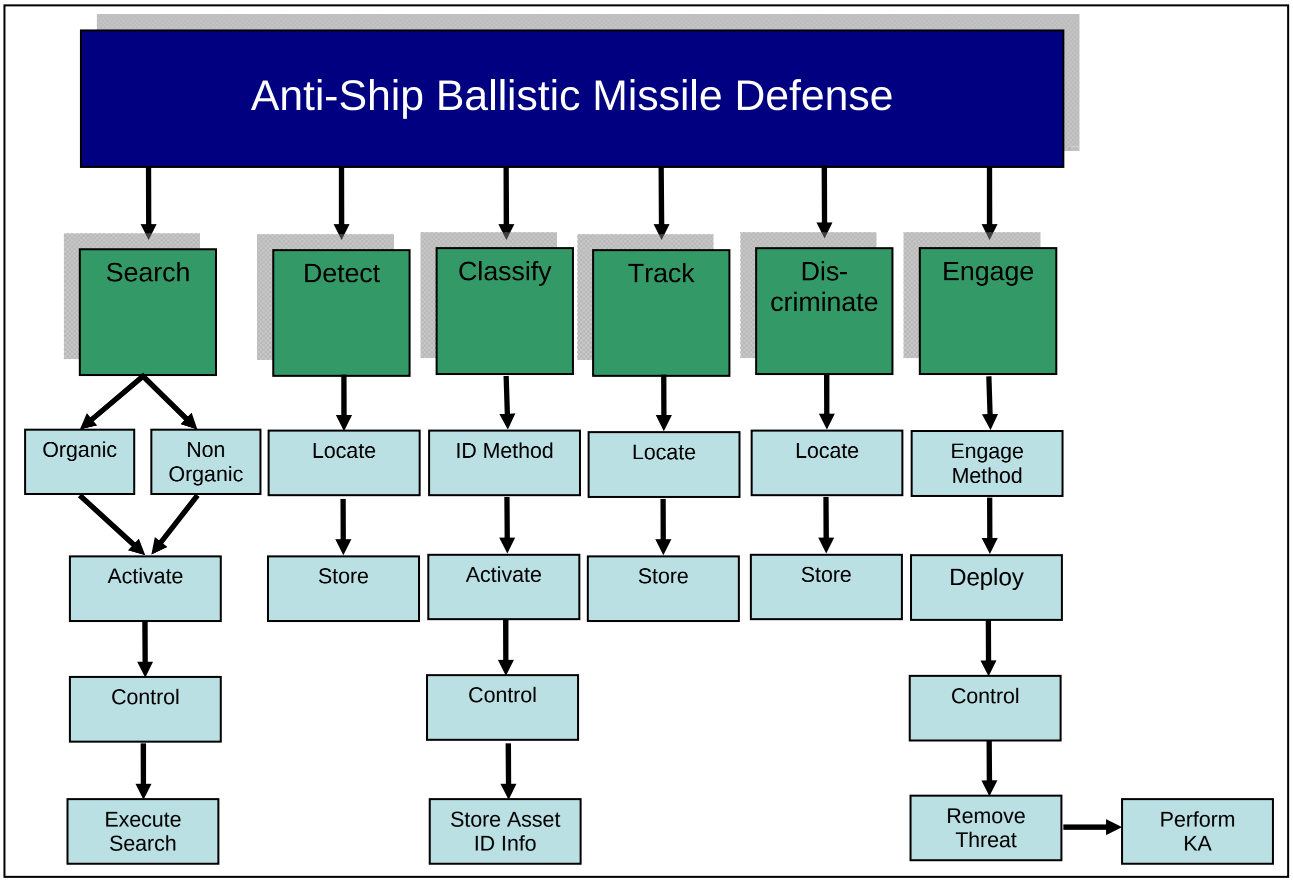

Figure C-1. Notional Functional Diagram

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3 GENERATION OF SYSTEM REQUIREMENTS

Figure C-2 depicts the general flow that was used to create the high-level functional requirements, Measures of Effectiveness (MOEs), and Measures of Performance (MOPs) for the ASBMD System. As depicted, the process began with definition of the initial needs statement; the team then created a general set of system requirements to address the capabilities that a system would need to fulfill in order to address the needs statement. The next step was to create a CONOPS to help bound the high-level system requirements in an operational context, which leads directly into development of MOEs and MOPs for the system. Each of these products is identified below.

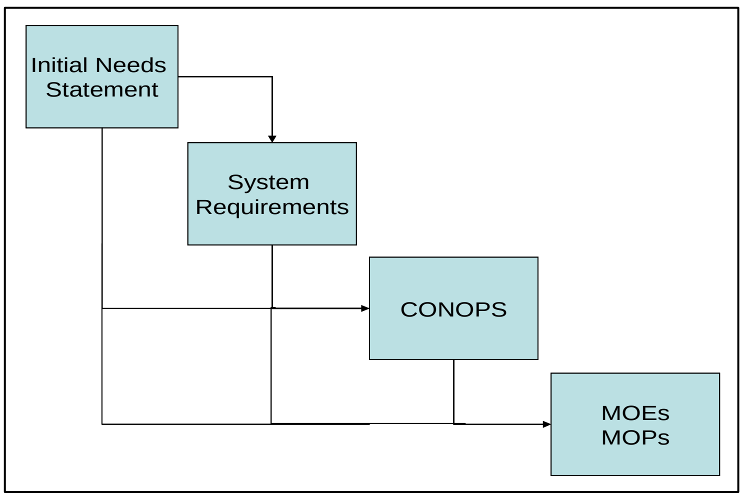

Figure C-2. Requirements Generation Process Flow

3.1 Functional Requirements

The following is a list of high-level functional requirements that was used to perform the follow-on system analysis and decomposition into the functional architecture shown in Figure C-1. This is an excerpted list of requirements provided as part of the CONOPS, and should not be viewed as a complete list of requirements that the system must meet.

1) ASBMD System shall be capable of sending, receiving, and processing intelligence reporting messages to be used for situational awareness related to Ballistic Missile flight path. (Includes, but is not limited to, the ability to receive and process Global

Command and Control System Maritime [GCCSM], Link-16 Tactical Digital Information Link [TADIL-J], N-Series messages, and J-Series messages)

2) ASBMD System shall process received intelligence messages and create radar search sectors to be used by both on-board and off-board sensors.
3) ASBMD System shall track ballistic missiles including no less than 10 vehicles during midcourse and/or terminal phase of missile flight path. Tracking shall include the production and dissemination of engagement quality data.
4) ASBMD System shall be capable of near simultaneous engagement of no-less-than 2 ballistic vehicles.
5) ASBMD System shall be capable of performing launch on remote using fire control quality data from the BMDS network.
6) ASBMD System shall have the ability to perform both self-defense and Ballistic Missile Defense (BMD) missions.
7) ASBMD System shall have a Mean Time Between Failures (MTBF) that is greater than or equal to the MTBF of the existing BMDS architecture into which the ASBMD System has been integrated.
8) ASBMD System shall have the ability to perform high fidelity object discrimination.
9) ASBMD System shall have the ability to perform localization.
10) ASBMD System shall have the capability to perform threat identification.

3.2 MOEs and MOPs

The key ASBMD System MOEs and MOPs are identified below. As with the System Requirements before, these lists should not be considered complete, since they are meant to be excerpts that were used to help bound the system.

3.2.1 MOEs

1) Probability of detection
2) Probability of false alarm
3) Probability of kill
4) Probability of correct identification
5) Probability of correct discrimination

6) Maximum number of targets engaged
7) Probability of information exchange
8) Maximum number of targets simultaneously tracked

3.2.2 MOPs

1) Track formulation time
2) Organic detection time
3) Mean time to discriminate
4) Engagement time
5) Re-engagement time
6) Time to conduct kill assessment
7) Number of simultaneous engagements
8) Number of non-detections

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4 CAPABILITIES AND FUNCTIONAL DECOMPOSITION

As originally depicted in Figure C-1, the notional functional decomposition contains key functions that are needed to ensure that the ASBMD System can meet its key mission requirements. This section of the Initial Capabilities Document (ICD) will decompose each of the high level functions to a lower level which will allow easier and more detailed mapping of each function to the defined functional requirements. A basic definition of each high-level function is provided below. The definition will help frame the expectations and flow of each of the decomposition diagrams.

4.1 System Components and Functions

The key system components and functions are defined below.

4.1.1 Search

The basic flow of the Search function is depicted in Figure C-3, and is started upon the receipt of a queuing signal from either an off-board source (BMDS) or the human operator. The queuing parameters are then converted to radar parameters that are used to build the sector of space that will be searched. After calculation of the radar parameters and required resources, the system will then evaluate the ability to perform the requested search function with organic resources. At this point in the functional flow the system will take one of two actions, either it will determine organic resources are available and it will carry out the search function, or if it is determined that organic resources are not available, the system will then wait for remote search data from the BMDS that will be passed to the tracking function. From this point on in both this document and future documents this type of track data transfer will be called Launch on Remote (LoR).

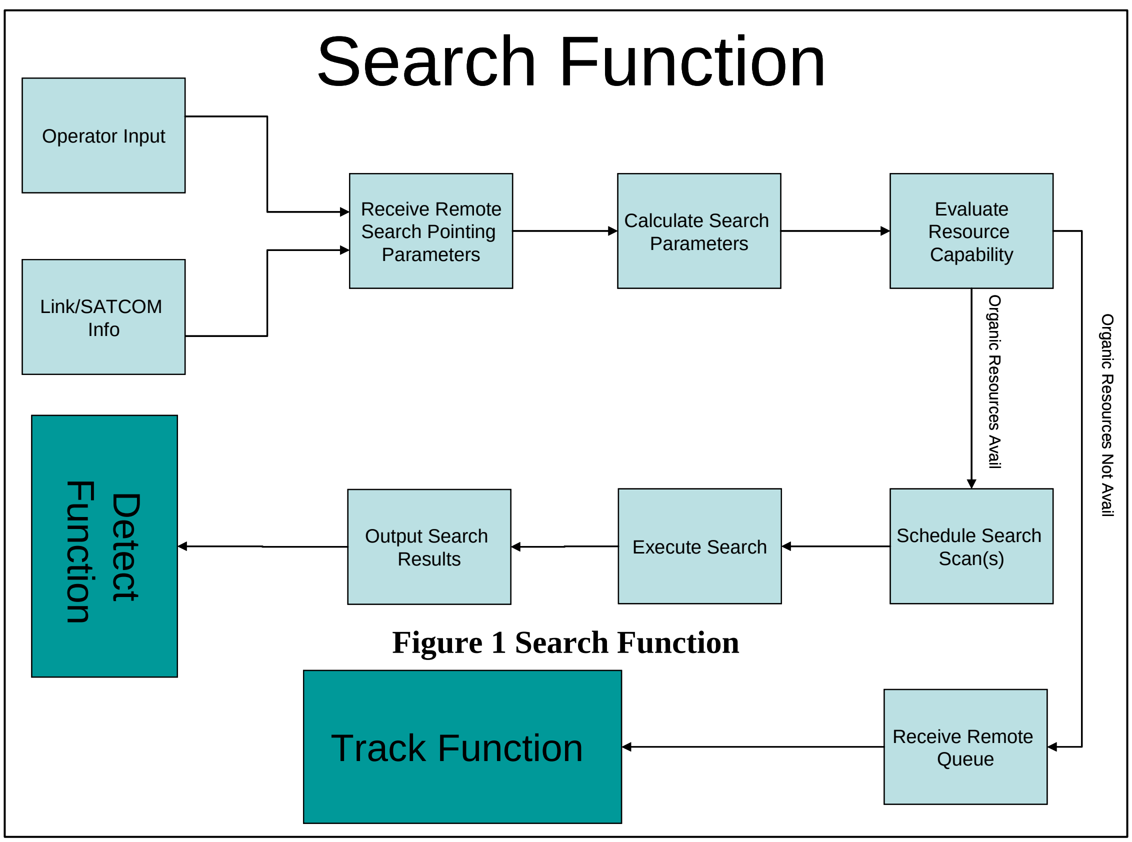

Figure C-3. Search Function

4.1.2 Detect

The Detect function is shown in Figure C-4. The Detect function is started when search results are received from either organic or remote sensors. The results from the search function are compared against the current file of existing objects and the system determines if the any of the attributes are either new or have changed. If changes or new objects are noted, the location information is sent to the Classify function.

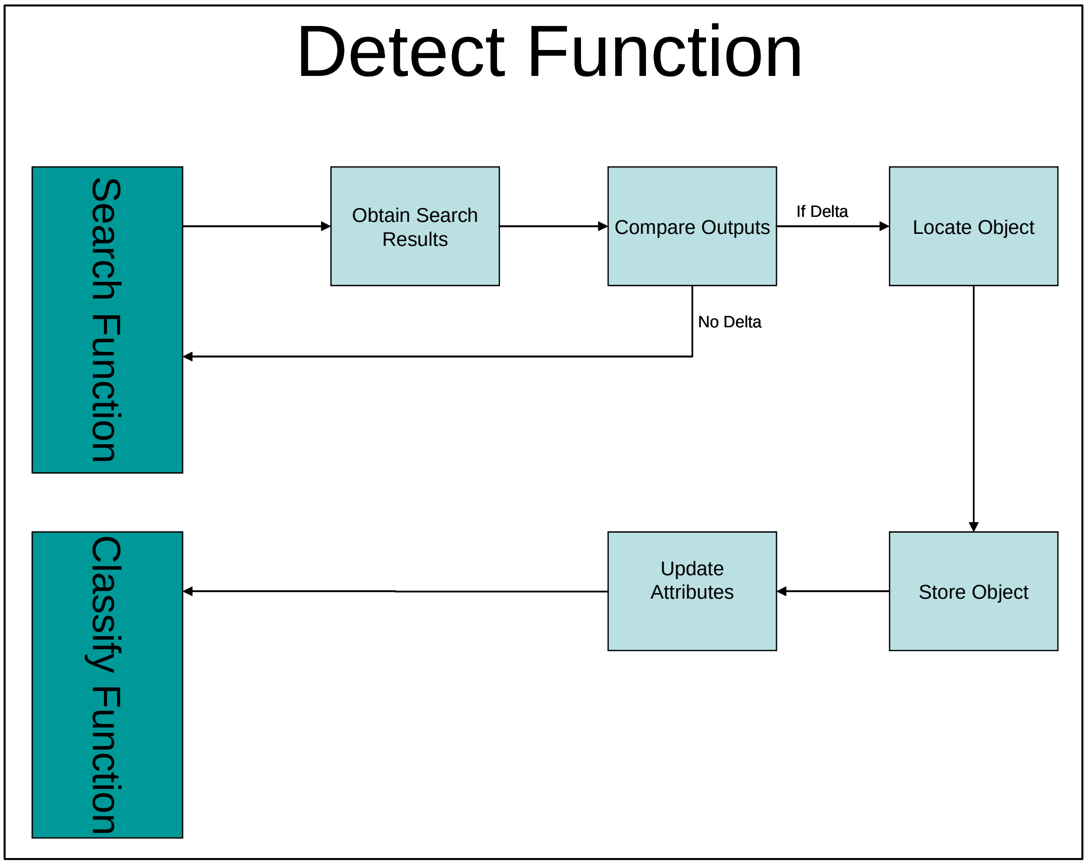

Figure C-4. Detect Function

4.1.3 Classify

The Classify function is shown in Figure C-5. The Classify function receives object attributes from the Detect function and compares them against algorithms to determine if they represent ballistic or non-ballistic objects. Upon determination of the classification of the objects, the Classify function updates the object attributes including the identification and passes the information to the Track function.

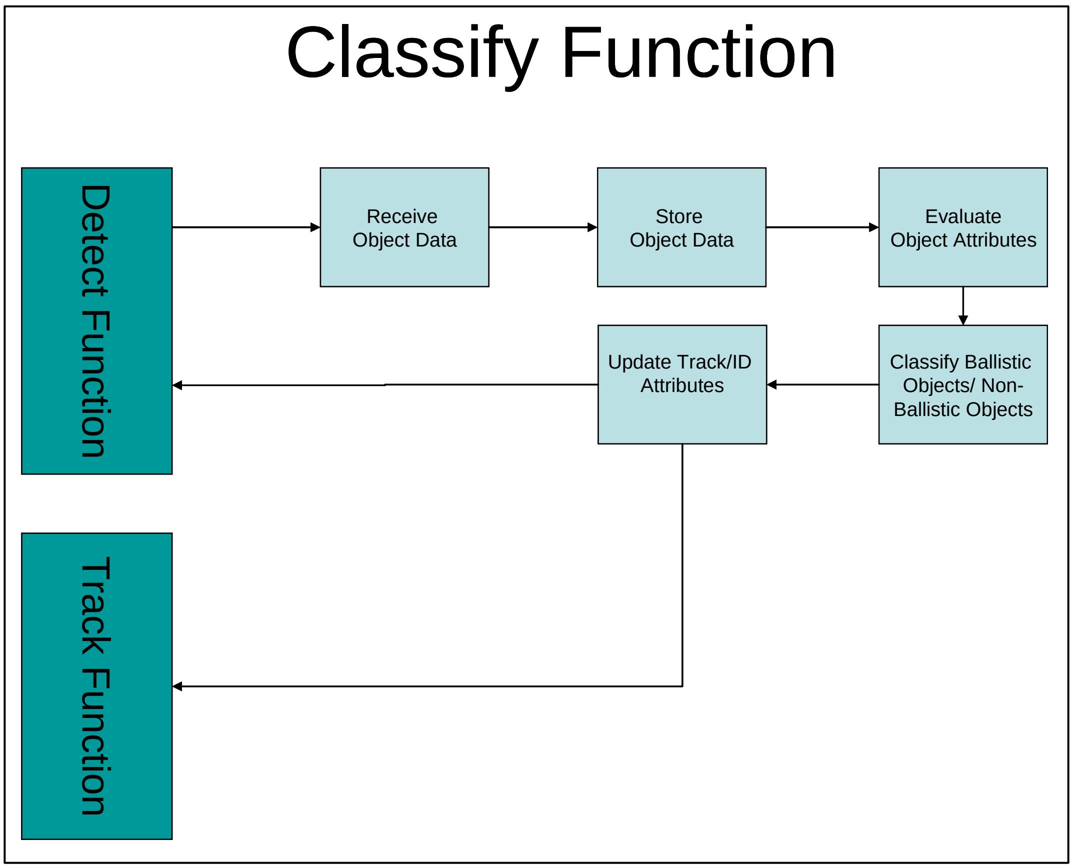

Figure C-5. Classify Function

4.1.4 Track

The Track function is shown in Figure C-6. The Track function receives objects from the Classify function and computes the object trajectory. After determining and updating the track attributes, the track file is updated and stored. The updated tracking data is sent to the Discrimination function.

The Track function is key to the ability of the ASBMD System and is independent of all other functions of the system. The Track function can be executed using remote or organic track data within the ASBMD System. Compilation of the object trajectory will be used to help determine the ability of the system to engage the object.

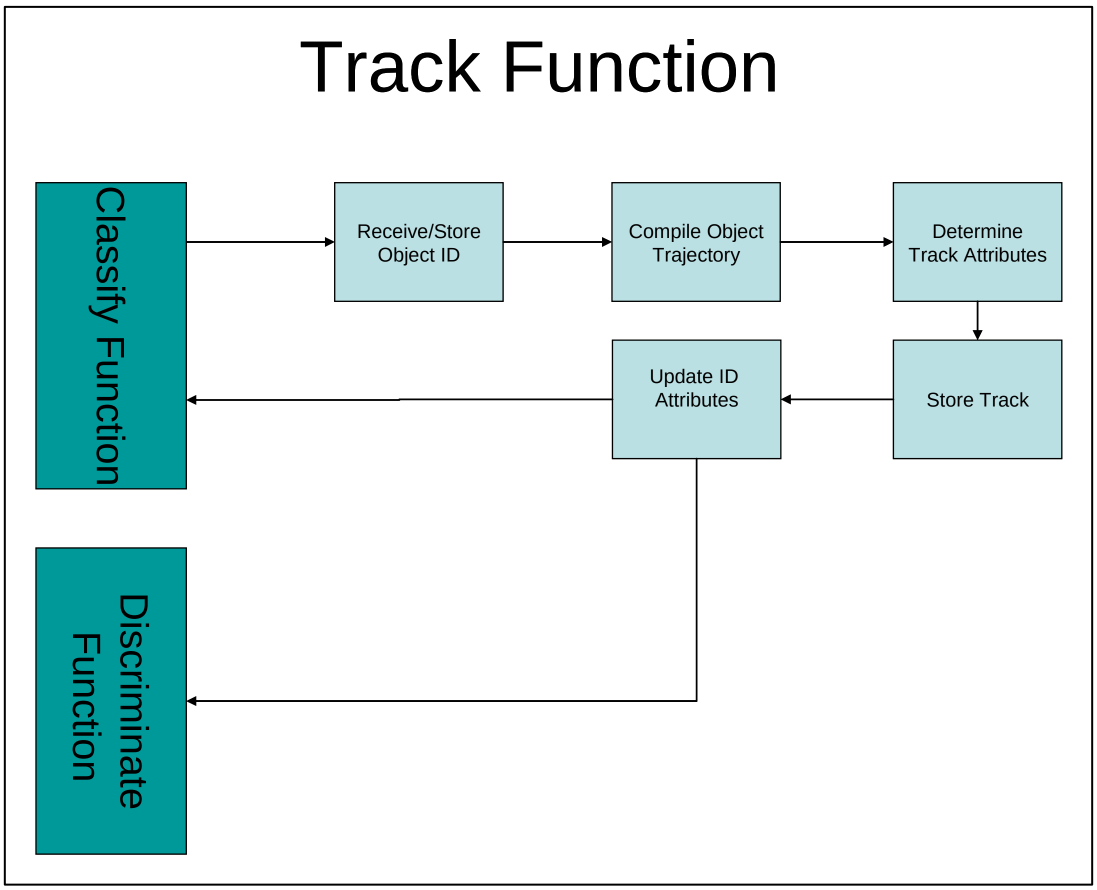

Figure C-6. Track Function

4.1.5 Discriminate

The Discriminate function is shown in Figure C-7. The Discriminate function receives track data from the Track function and evaluates them against predetermined discrimination algorithms. The output of the evaluations will be the identification of the number of lethal objects in the current track gate. If the output of the evaluation determines that there are more lethal objects than previously known, the Discrimination function will notify the Track function of new objects to be tracked. If the output of the evaluation determines no new objects, the Discrimination function will update the attributes of the existing tracks and report back to both the Track and Engage functions.

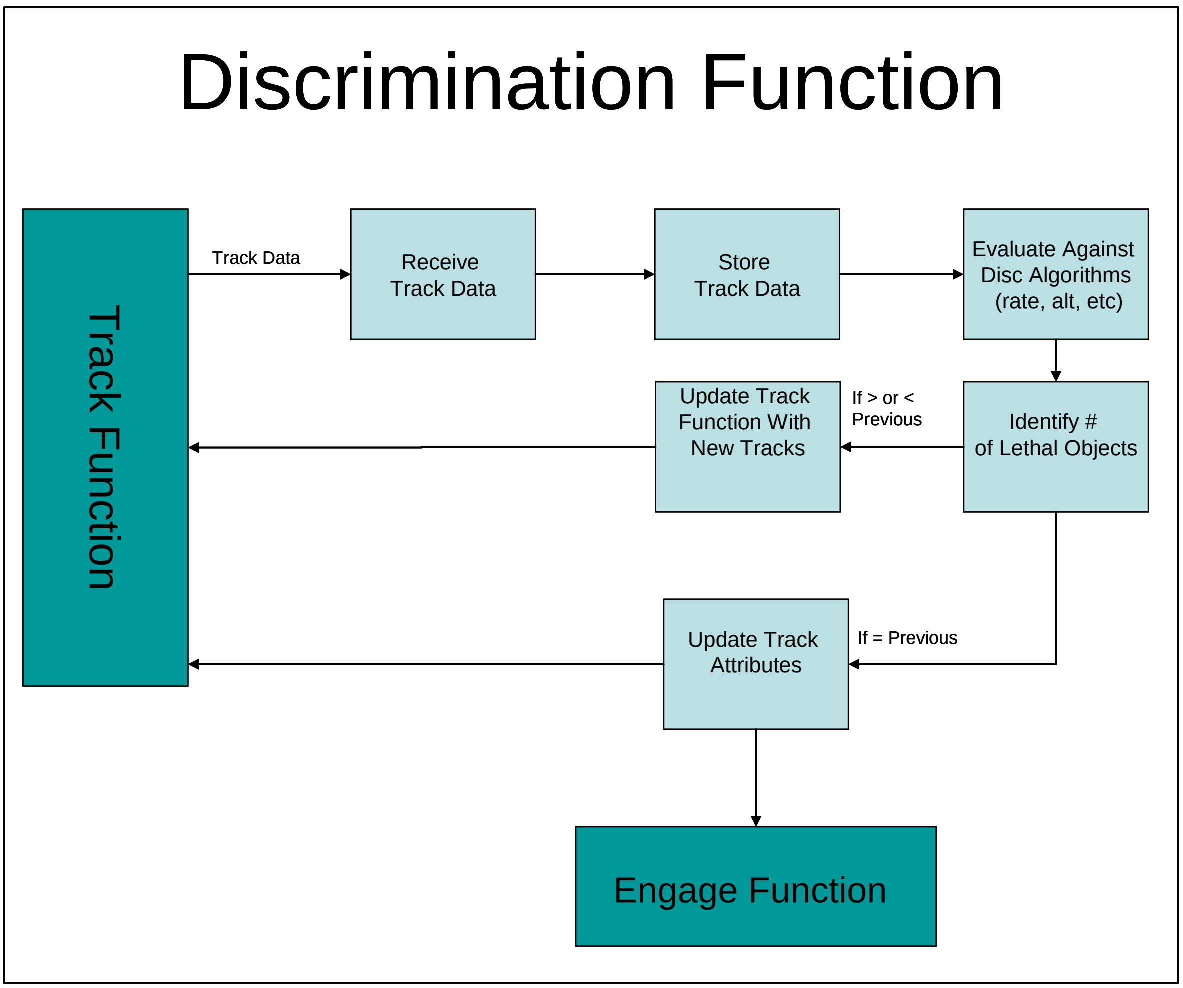

Figure C-7. Discriminate Function

4.1.6 Engage

The Engage function is shown in Figure C-8. The Engage function receives track information from the Discrimination function and, upon operator initiation, will compute and disseminate the fire control solution for the selected target. After operator approval, the weapon will be deployed and the Engage function will compute and carry out the guidance and kill assessment portion of the engagement. The Engage function is also responsible for creating and communicating the current status of the engagement to the larger BMDS.

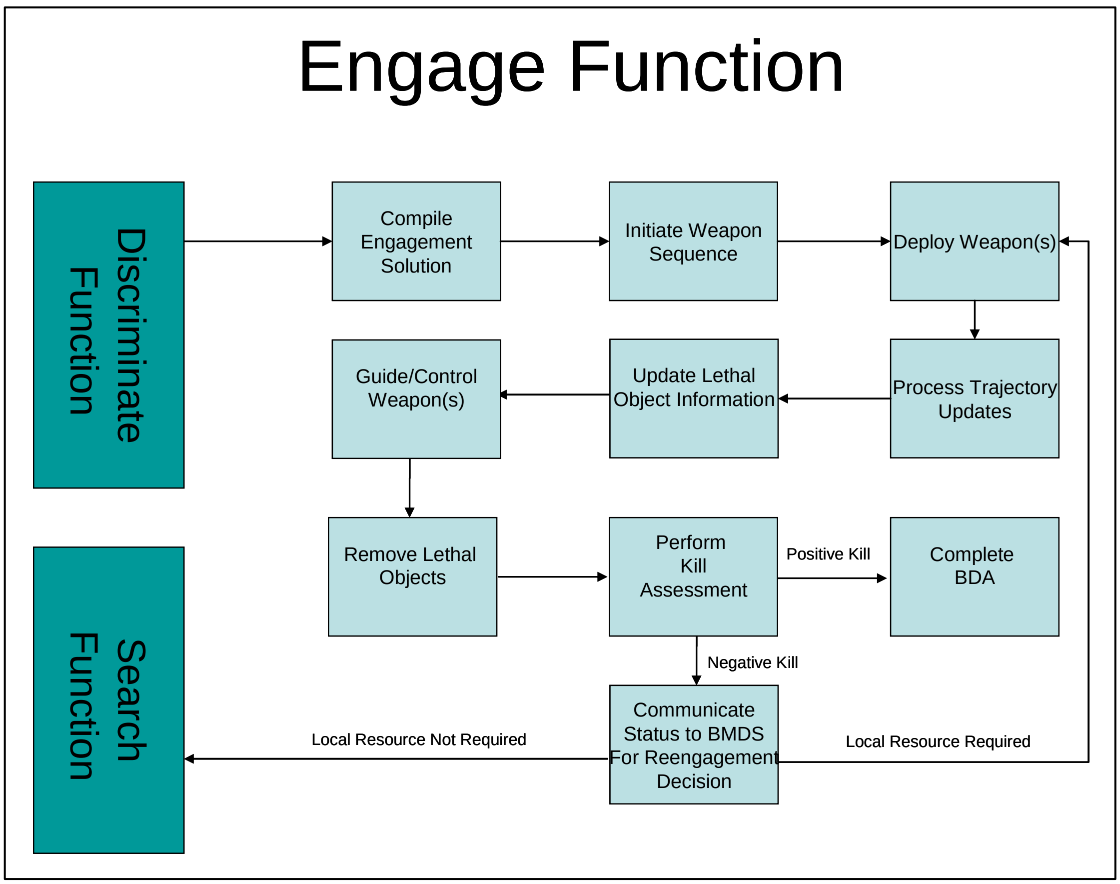

Figure C-8. Engage Function

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5 CONCLUSION

The updated System Functional flow diagram is shown in Figure C-9. It is simplified, but shows the key flow of information that the ASBMD System must have to complete the intended mission.

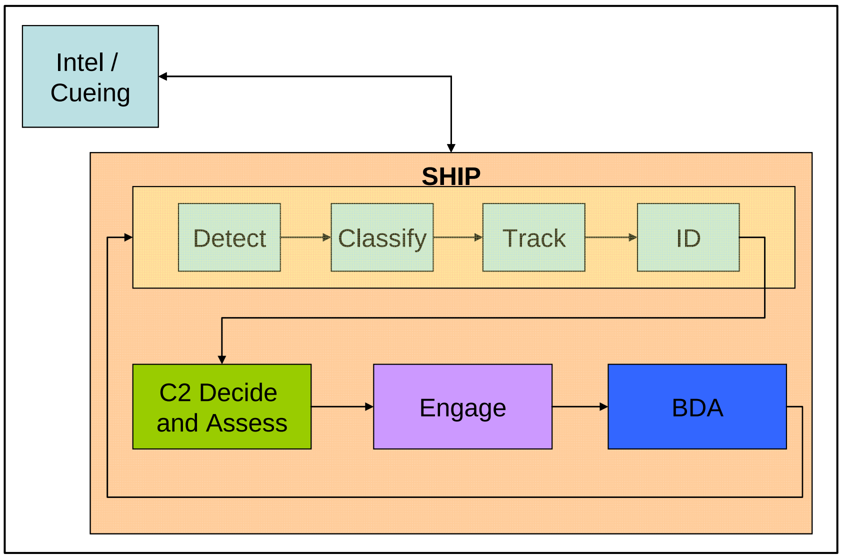

Figure C-9. System Flow

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APPENDIX D

SYSTEM DATA ANALYSIS

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Appendix D

ILLUSTRATIONS

TABLES

Appendix D

ABBREVIATIONS AND ACRONYMS

ASBM	Anti-Ship Ballistic Missile
ASBMD	Anti-Ship Ballistic Missile Defense
dB	Decibel(s)
EO	Electro-Optical
ft	Foot/Feet
GBR-P	Ground Based Radar Prototype
IR	Infrared
KM	Kilometer(s)
m	Meter(s)
RCS	Radar Cross Section
s	Second(s)
W	Watt(s)

Probability of Detection analysis was performed for of each of the four systems/elements that were evaluated to fulfill the search and detection functions.

Table D-1. Values for Calculation of Minimal Detection Range and Probability of False Alarm

				SPY-1	SPY-3	Cobra Judy	GRB-P
	P_{peak}	Power Transmitted by radar	kw	4000	4500	7000	8000
	G	Antenna Power Gain	Unitless	316.227	330	370	375
	A_e	Antenna effective area	m^2	20	22.64	25	20
	σ	Radar Cross Section (RCS)	m^2	1	1	1	1
6000	**R**	Distance from radar site to target	km	6000	6000	6000	6000
0.00	**S_{min}**	Minimal Signal Detection or Threshold		0.003	0.004	0.004	0.004
0.002	**N**	Noise Signal		0.002	0.002	0.002	0.002
1	**Pf**	Probability of False alarm		0.188776089	0.166952249	0.121390393	0.1263174

Table D-2. Values for Probability of False Alarm vs. Range

SPY-1			SPY-3			Cobra Judy			GBR-P		
Pf	**Range**	**S_{min}**	**Pf**	**Range**	**S_{min}**	**Pf**	**Range**	**S_{min}**	**Pf**	**Range**	**S_{min}**
4.53E-05	1000	0.020006	2.16548E-05	1000	0.021480569	3.2E-06	1000	0.025305	4.06E-06	1000	0.024827
0.006727	2000	0.010003	0.004653469	2000	0.010740285	0.0017888	2000	0.012652	0.002016	2000	0.012414
0.035636	3000	0.006669	0.027873054	3000	0.00716019	0.0147356	3000	0.008435	0.015956	3000	0.008276
0.08202	4000	0.005002	0.068216339	4000	0.005370142	0.0422938	4000	0.006326	0.044895	4000	0.006207
0.13525	5000	0.004001	0.116710715	5000	0.004296114	0.0796198	5000	0.005061	0.083513	5000	0.004965
0.188776	6000	0.003334	0.166952249	6000	0.003580095	0.1213904	6000	0.004217	0.126317	6000	0.004138

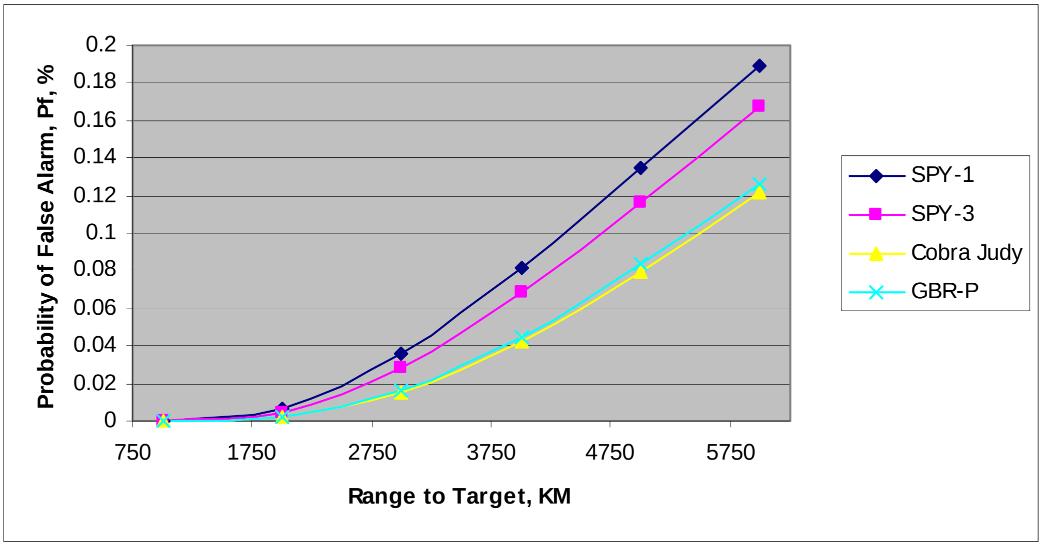

Figure D-1. Analysis of Probability of False Alarm vs. Range

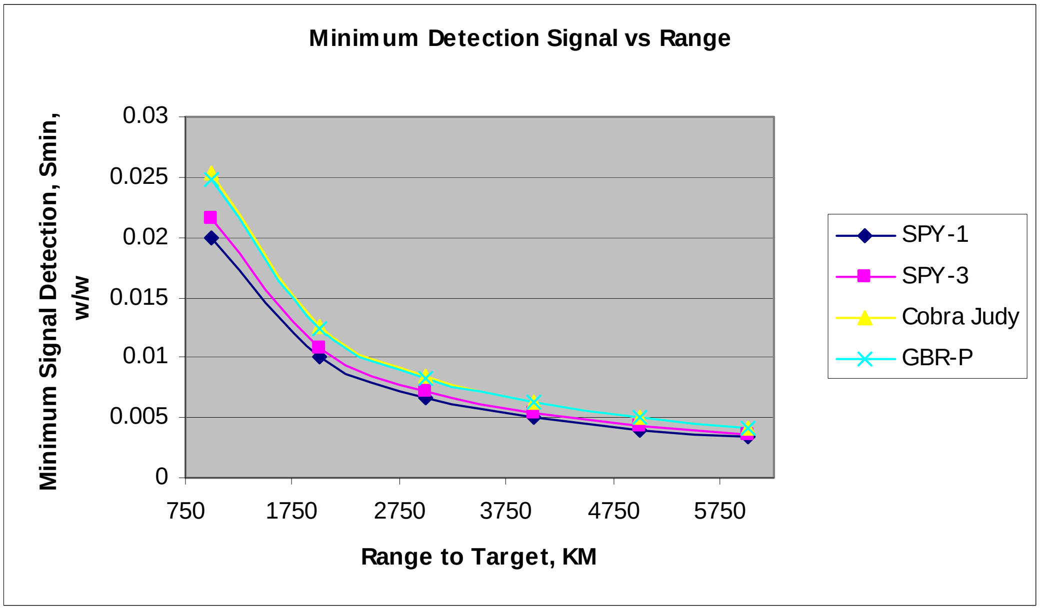

Figure D-2. Analysis of Probability of Detection vs. Range

Equation (D-1) provides the calculation of affective aperture size:

$$A_e = \frac{G_R \lambda^2}{4\pi} \quad 51020(0.3)^2$$

(D-1)

Equation (D-2) provides the calculation of maximum detection range:

$$R_{\max} = \left[\frac{P_{peak} G \sigma A_e}{(4\pi)^2 S_{\min}} \right]^{1/4}$$

(D-2)

Table D-3. Calculation of Maximum Detection Range vs. Radar Cross Section (RCS)

SPY 1			SPY 3			Cobra Judy			GBR-P		
Peak Power	4000000	Watts	Peak Power	4500000	Watts	Peak Power	7000000	Watts	Peak Power	8000000	Watts
Gain	316227	w/w	Gain	330000	w/w	Gain	370000	w/w	Gain	375000	w/w
A_e	20	m^2	A_e	22.64	m^2	A_e	25	m^2	A_e	20	m^2
S_{min}	0.03	w/w	S_{min}	0.005	w/w	S_{min}	0.004	w/w	S_{min}	0.005	w/w
Wavelength	0.03	m	Wavelength	0.03	m	Wavelength	0.03	m	Wavelength	0.03	m
RSC dB	RSC W	Range KM	RSC dB	RSC W	Range KM	RSC dB	RSC W	Range KM	RSC dB	RSC W	Range KM
1	1.26	1611	1	1.26	2706	1	1.26	3371	1	1.26	3128
2	1.58	1704	2	1.58	2864	2	1.58	3567	2	1.58	3310
4	2.51	1913	4	2.51	3215	4	2.51	4005	4	2.51	3716
6	3.98	2147	6	3.98	3608	6	3.98	4494	6	3.98	4170
8	6.31	2409	8	6.31	4049	8	6.31	5043	8	6.31	4679
10	10	2703	10	10	4543	10	10	5658	10	10	5250

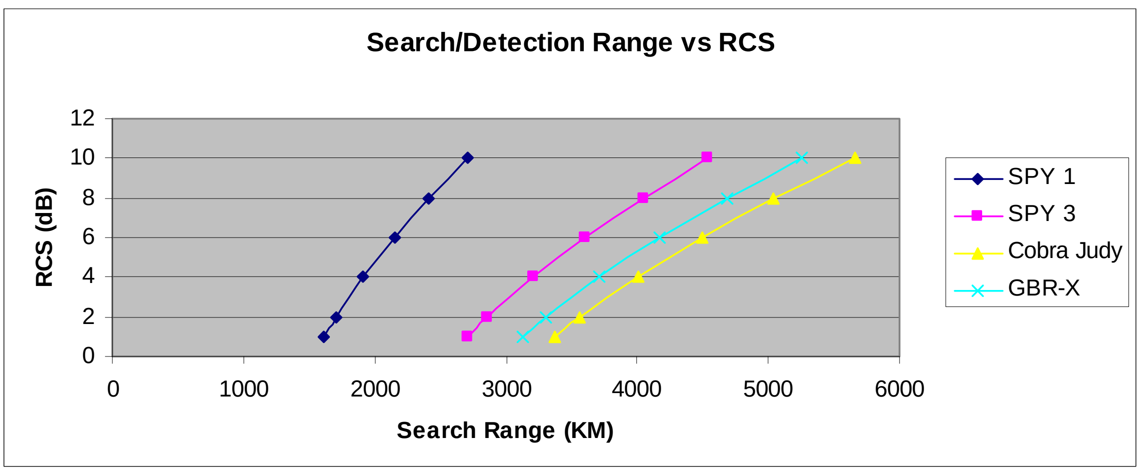

Figure D-3. Maximum Detection Range vs. RCS

Table D-4. Values for Power-In vs. Range

A_e =	1m^2
P =	2000 w
Range	Pin
0	0
200	0.003979
400	0.000995
600	0.000442
800	0.000249
1000	0.000159
2000	3.98E-05
3000	1.77E-05
4000	9.95E-06
5000	6.37E-06
6000	4.42E-06
7000	3.25E-06
8000	2.49E-06
9000	1.96E-06

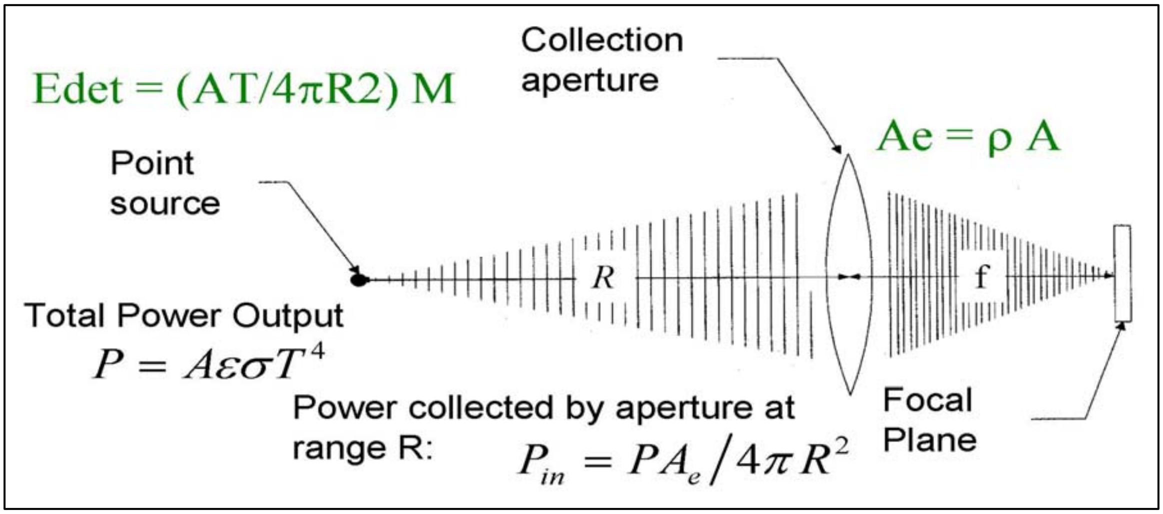

Figure D-4. Formula for Power-In vs. Range

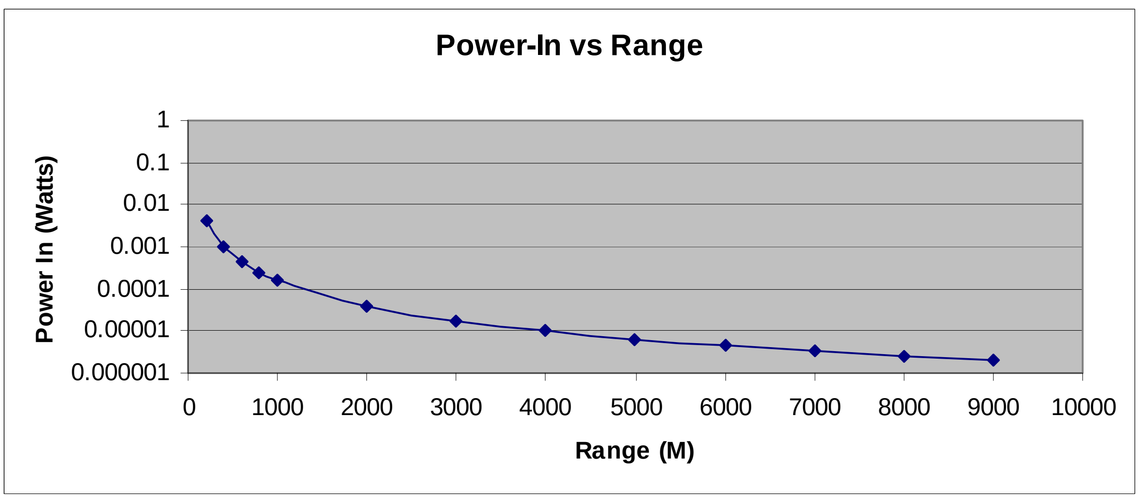

Figure D-5. Power-In vs. Range for EO/IR Sensor

Table D-5. Power-In vs. Range for EO/IR Sensor

Target Surface Area =		**3**	**m^2**	**Target Surface Area**	**Range**	**Pin**
Emissivity =		0.95		0.5	7035.407	3.22E-06
Temperature =		500	K	1	9949.568	1.61E-06
Effective Aperture =		1	m^2	1.5	12185.68	1.07E-06
Frequency Band =		2 – 6 um		2	14070.81	8.04E-07
S_{min} =		0.0000006	w	2.5	15731.65	6.43E-07
P =		2000	w	3	17233.16	5.36E-07
				3.5	18613.94	4.59E-07
				4	19899.14	4.02E-07
				4.5	21106.22	3.57E-07
				5	22247.91	3.22E-07
				5.5	23333.8	2.92E-07

Equation (D-3) provides the calculation of maximum range for the EO/IR sensor:

$$R_{max} = \sqrt{\frac{\varepsilon\sigma\left(T^4 - T_e^4\right) A_{tgt} A_e F}{4\pi S_{min}}} \quad \textbf{(D-3)}$$

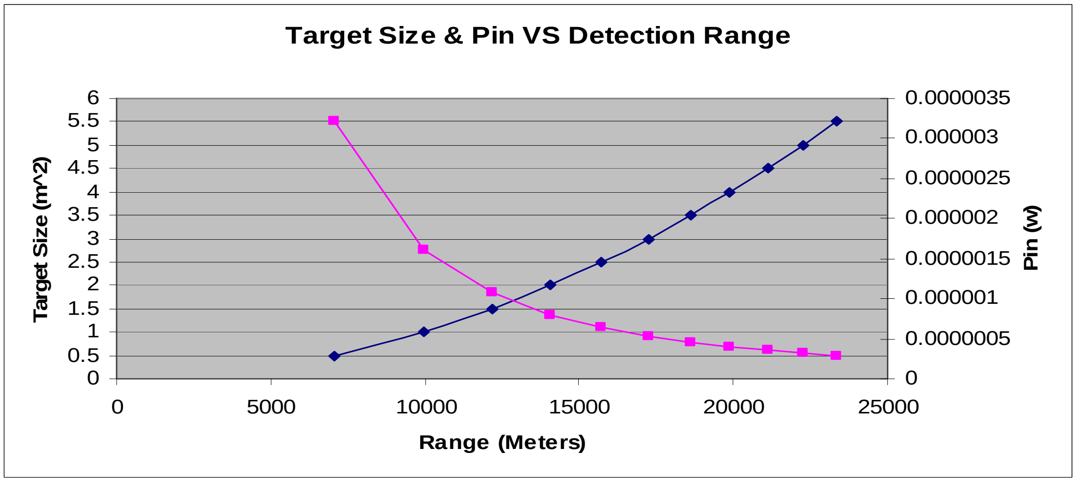

Figure D-6. Power Target Size and Power-In vs. Detection Range

The team performed operational analysis consisting of the operational range capabilities of the platform. This is the range that the host platform can maneuver away from the defended asset and still be able to defend it if fired upon. The analysis is highly dependent on the capabilities of the interceptor that is used against the threat.

Table D-6. Calculation of Maximum Interceptor Launch Range vs. Interceptor Speed

Max Interceptor Launch Range (km)	Interceptor Speed (km/s)	Z range	X/Y Range
480	1.2	50.00	430.00
640	1.6	50.00	590.00
640	1.6	50.00	590.00
800	2	50.00	750.00
960	2.4	50.00	910.00
1120	2.8	50.00	1070.00
1200	3	50.00	1150.00
1360	3.4	50.00	1310.00
1520	3.8	50.00	1470.00
1600	4	50.00	1550.00
Conversion Units:			
ft	**meters**	**miles**	**km**
5280	1655.172414	1	1.655172414
160000	50156.73981	30.3030303	50.15673981
Assumptions:		Exoatmosphere = > 160K ft or 50 km	
Total Target Flight Time = 420 sec		Target flight time to re-entry = 403 sec	
Organically Tracked 3 sec after liftoff		Reaction time + interceptor flyout 400 sec	
Target Speed = 3 km/s		Constant interceptor speeds	

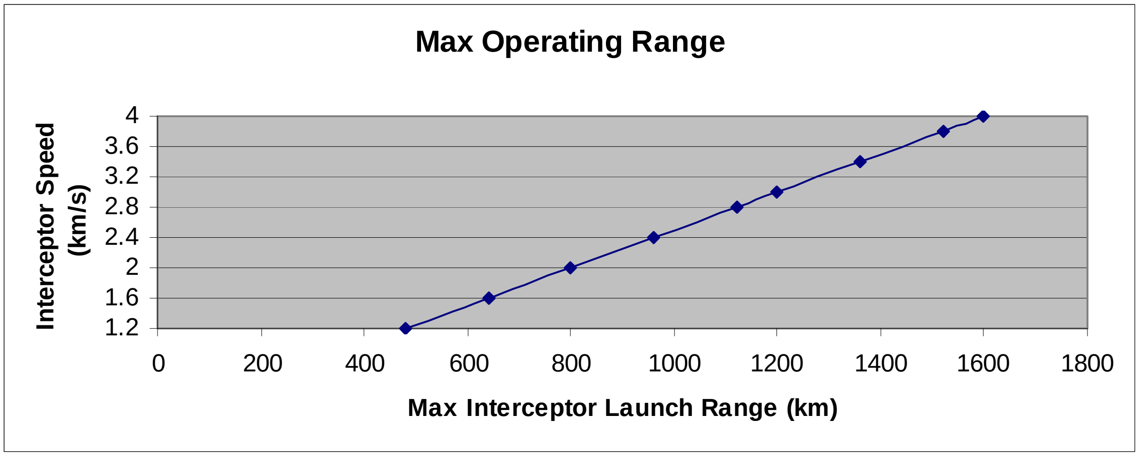

Figure D-7. Power Maximum Operating Range vs. Interceptor Speed

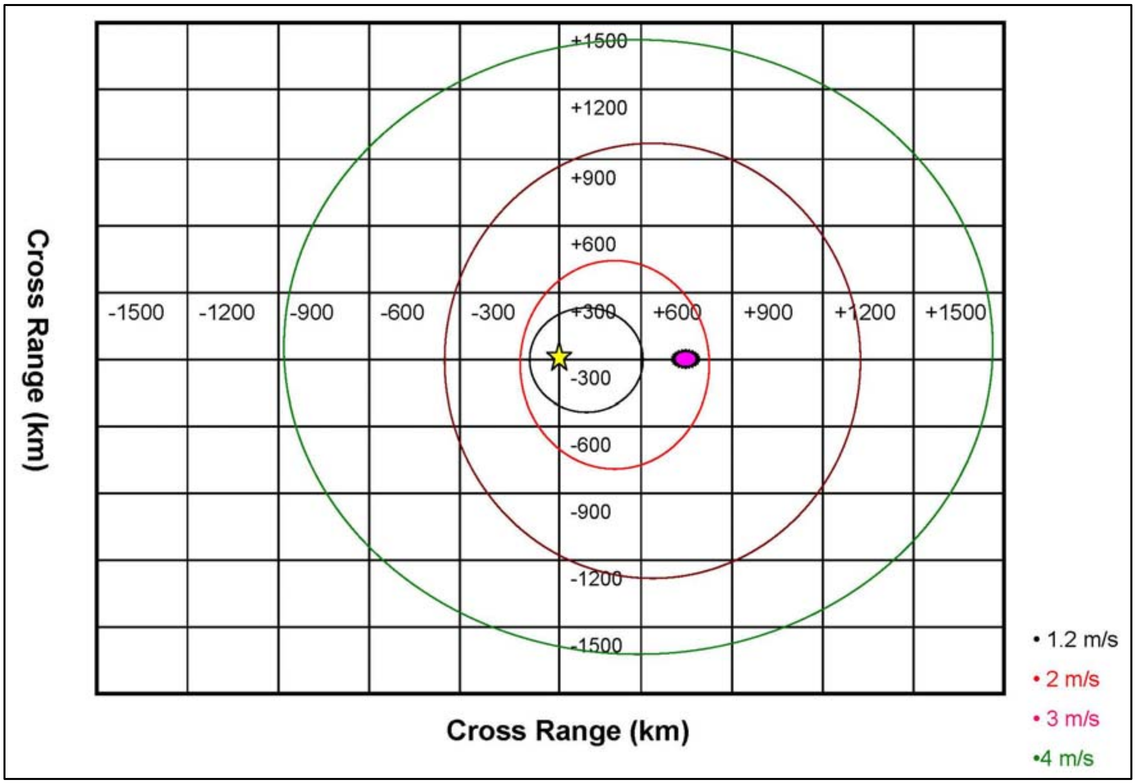

Figure D-8. Maximum Operational Range for Host Platform

The team performed a Data Covariance Analysis to determine the effects of integrating systems that output filtered data. This analysis also shows the effects of filtered data on a system that is designed to use unfiltered raw data. The analysis confirms that trying to combine multiple sources of filtered data can produce an outcome that is less useful than if the system uses a single source of data.

Table D-7. Calculation of Data Covariance for Filtered and Non-Filtered Sources

Time	Source 1	Track Points 1	Covariance	Source 2	Track Points 2	Covariance 2	Filtered	Filtered Track Points	Filtered Covariance
1	10	12	2	20	22	2	15	22	7
2	14	12	2	24	22	2	19	12	7
3	18	20	2	28	30	2	23	30	7
4	21	19	2	31	29	2	26	19	7
5	23.5	25	1.5	33.5	35	1.5	28.5	35	6.5
6	25	23	2	35	33	2	30	23	7
7	26	28	2	36	38	2	31	38	7
8	27	25	2	37	35	2	32	25	7
9	28	30	2	38	40	2	33	40	7
10	29	27	2	39	37	2	34	27	7

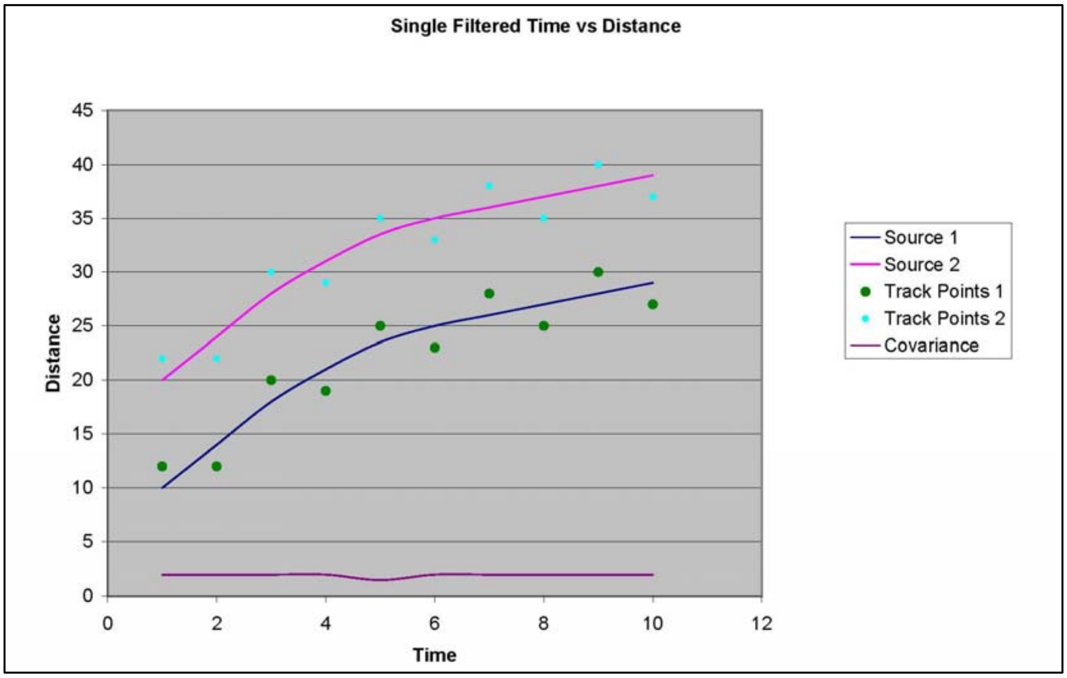

Figure D-9. Maximum Operational Range for Host Platform

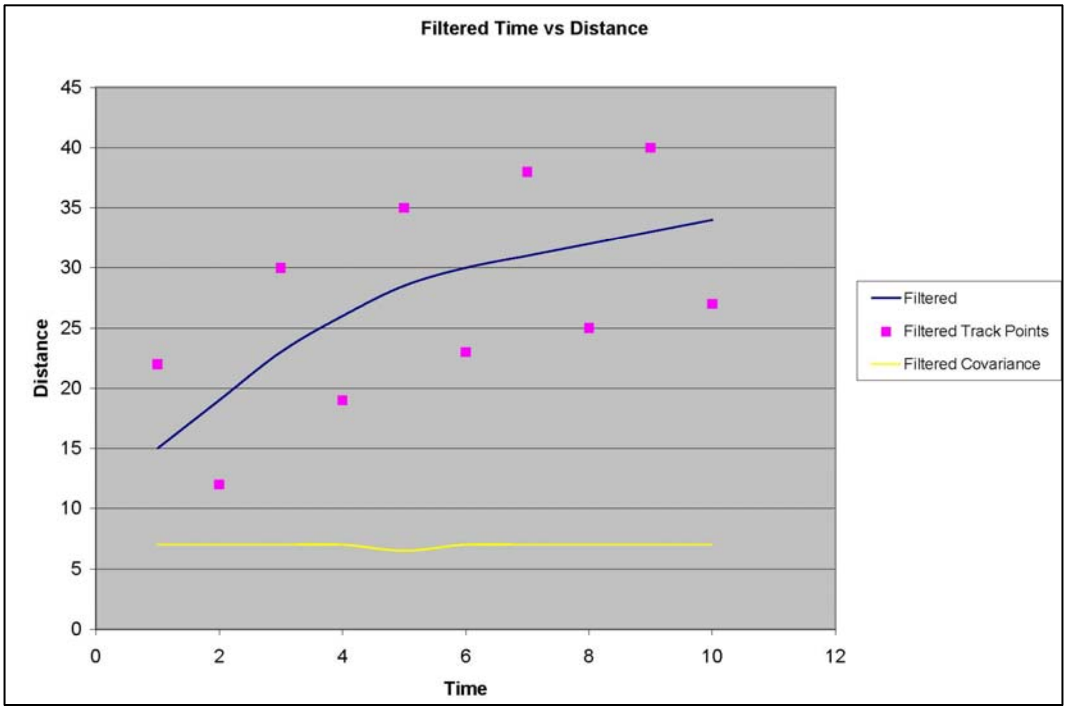

Figure D-10. Effects of Filtering Data on Accuracy

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APPENDIX E

ANALYSIS OF ALTERNATIVES

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ILLUSTRATIONS

TABLES

Appendix E

ABBREVIATIONS AND ACRONYMS

ASBM	Anti-Ship Ballistic Missile
ASBMD	Anti-Ship Ballistic Missile Defense
BMD	Ballistic Missile Defense
CONOPS	Concept of Operations
dB	Decibel(s)
DRM	Design Reference Mission
DRMP	Design Reference Mission Profile
EO	Electro-Optic
GBR-P	Ground-Based Radar-Prototype
ICD	Initial Capabilities Document
IR	Infrared
km	Kilometer(s)
km/h	Kilometer(s) per hour
m	Meter(s)
MW	Megawatt(s)
Pd	Probability of Detection
PRF	Pulse Repetition Frequency
RCS	Radar Calculation Sheets

Analysis of Alternatives Artifacts

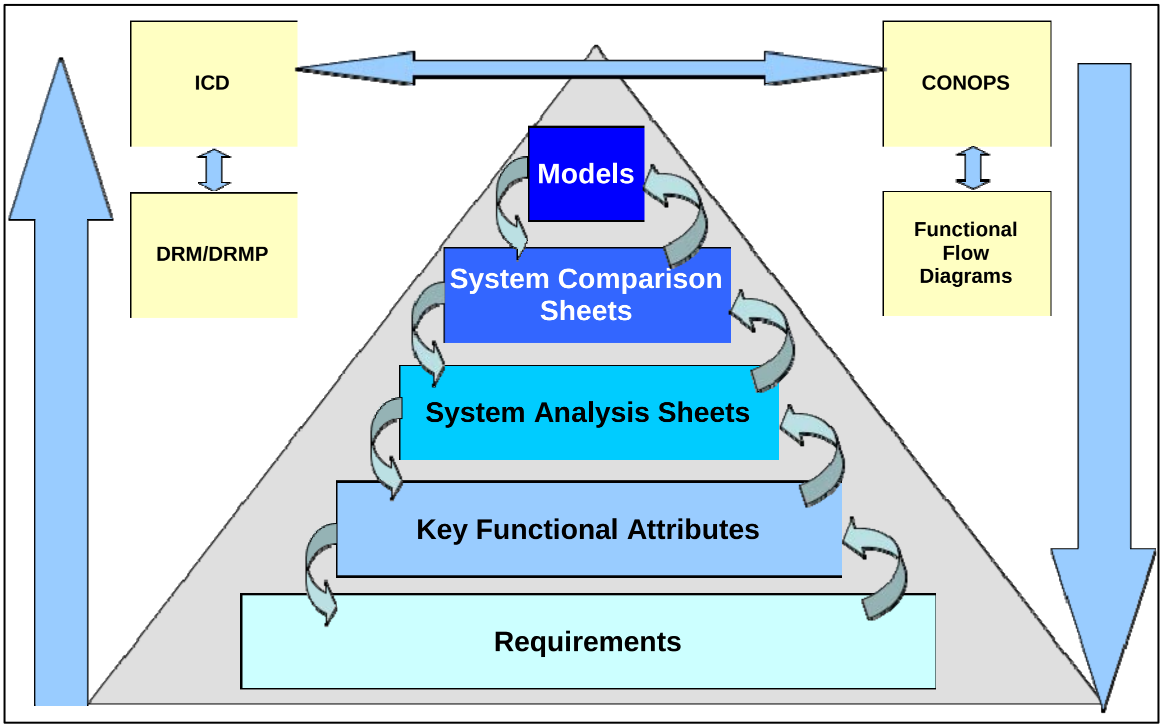

Figure E-1. ASBMD Analysis of Alternatives Process

Table E-1. Key Functional Attributes

Analysis Area	Recommended Attribute Analysis
Search	Search Rate (Scan Rate)
	Search Volume Capabilities
	Range
	Angular Resolution
Detection	Signal-to-Noise Ratio
	False Alarm Rate
	Probability of Detection (Adjusting Target and Environmental Attributes)
	Radar Range Calculation for Maximum Detection Range
Tracking	PRF and Tracking Errors
	Effective Aperture and Resolution Calculations
	Effects of Tracking Ranges Given Tracking and Turning Gate Changes
	Transition-to-Track Timeline Analysis
Intercept Variants	General Systems Capability Analysis
	Kill Timeline Analysis by Varying Range
	Maximum Effective Ranges

Table E-2. System Comparison (Search/Detection)

Function Name (Search/Detection)						
Options	Performance Parameters				Requirements	Pros / Cons
	Max Range/ Accuracy	Max Power	A_e (Effective Aperture Size)	S_{min}		
SPY-1 B(D)	* 1460 km	3 MW	20m^2	-13dB	ASBMD System shall be capable of searching a designated search sector of not less than 30 degrees at a distance of not less than 750 km in less than 2 seconds, when cued by either off board intelligence or the onboard operator.	**Pro:** Mature, proven system capability **Con:** Shorter maximum range limits the maneuverability options of the Fleet **Con:** Heavily reliant on intelligence data to allow for resource focusing
SPY- 3	** 2527 km	4.5 MW	23m^2	-23dB	ASBMD System shall be capable of searching a designated search sector of not less than 30 degrees at a distance of not less than 750 km in less than 2 seconds, when cued by either off board intelligence or the onboard operator.	**Pro:** Greater search range and accuracy capabilities than the SPY-1 **Pro:** Greater peak power and Ae size allows for search and detection of smaller RCS **Con:** Unproven system that is still under development **Con:** Power usage to excite radar elements exceeds that of current ship capabilities **Con:** Unable to uplink with current weapon inventory
Cobra Judy	** 2681 km	7 MW	26.4m^2	-20dB	ASBMD System shall be capable of searching a designated search sector of not less than 30 degrees at a distance of not less than 750 km in less than 2 seconds, when cued by either off board intelligence or the onboard operator.	**Pro:** Greatly Increases search and detection ranges **Pro:** Allows greater operational maneuverability **Con:** Large power consumption requirements **Con:** Unable to control current engagement weapons **Con:** Too large to fit onto current operational naval vessels
GBR-P	** 3297 km	8 MW	20.4m^2	-23dB	ASBMD System shall be capable of searching a designated search sector of not less than 30 degrees at a distance of not less than 750 km in less than 2 seconds, when cued by either off board intelligence or the onboard operator.	**Pro:** Increased search and detection ranges **Pro:** Increases operational capability of fleet **Con:** Power consumption is too large **Con:** Weight and size is restrictive **Con:** RCS signature much too large for naval vessel **Con:** No weapon control capability

All calculations assume 30 degree search sector.
* Derived from Aegis BMD briefing.
** See specific Radar Calculation Sheets.

Table E-3. Function Name (Track)

Function Name (Track)						
Options	**Performance Parameters**				**Requirements**	**Pros / Cons**
	Max Range/ Accuracy	**Max Power**	**A_e (Effective Aperture Size)**	**S_{min}**		
SPY-1 B(D)	* 1460 km	3 MW	20m^2	-13dB	ASBMD System shall be capable of tracking no less than 2 simultaneous ballistic missiles at a distance of not less than 750 km.	**Pro:** Mature, proven system capability **Con:** Shorter maximum range limits the maneuverability options of the Fleet **Con:** Heavily reliant on intelligence data to allow for resource focusing
SPY- 3	** 2527 km	4.5 MW	23m^2	-23dB	ASBMD System shall be capable of tracking no less than 2 simultaneous ballistic missiles at a distance of not less than 750 km.	**Pro:** Greater search range and accuracy capabilities than the SPY-1 **Pro:** Greater peak power and Ae size allows for search and detection of smaller RCS **Con:** Unproven system that is still under development **Con:** Power usage to excite radar elements exceeds that of current ship capabilities **Con:** Unable to uplink with current weapon inventory
Cobra Judy	** 2681 km	7 MW	26.4m^2	-20dB	ASBMD System shall be capable of tracking no less than 2 simultaneous ballistic missiles at a distance of not less than 750 km.	**Pro:** Greatly Increases search and detection ranges **Pro:** Allows greater operational maneuverability **Con:** Large power consumption requirements **Con:** Unable to control current engagement weapons **Con:** Too large to fit onto current operational naval vessels
GBR-P	** 3297 km	8 MW	20.4m^2	-23dB	ASBMD System shall be capable of tracking no less than 2 simultaneous ballistic missiles at a distance of not less than 750 km.	**Pro:** Increased search and detection ranges **Pro:** Increases operational capability of fleet **Con:** Power consumption is too large **Con:** Weight and size is restrictive **Con:** RCS signature much too large for naval vessel **Con:** No weapon control capability
EO/IR	9.9 km	N/A	1m^2	0.0000006 w	ASBMD System shall be capable of tracking no less than 2 simultaneous ballistic missiles at a distance of not less than 750 km.	**Pro:** Small complex system **Pro:** Very accurate (< 2 m error at maximum range) **Con:** Unable to only integrate with existing systems **Con:** Maximum usage is very restrictive for high altitude threat **Con:** Requires external preloading commands (no automated search capability)
All calculations assume 30 degree search sector. * Derived from Aegis BMD briefing. ** See specific Radar Calculation Sheets.						

Table E-4. Function Name (Engage)

Function Name (Engage)				
Options	Performance Parameters		Requirements	Pros / Cons
	Max Effective Range	Max Closure Speed		
SPY-T	167 km	3186 km/h	ASBMD System shall be capable of near simultaneous engagement of no-less than 2 ballistic vehicles.	**Pro:** Currently in production **Pro:** Flight test data available to prove time and PK **Con:** Max range limits intercept too close to or within atmosphere
SPY- 3	245 km	4248 km/h	ASBMD System shall be capable of near simultaneous engagement of no-less than 2 ballistic vehicles.	**Pro:** **Con:**
Rail Gun	400 km	7430 km/h	ASBMD System shall be capable of near simultaneous engagement of no-less than 2 ballistic vehicles.	**Pro:** Greater range than conventional weapons **Pro:** Greater closure speeds increasing accuracy due to less time for target to maneuver **Pro:** Ten shots per minute allow for multiple shots and multiple engagements in short time **Con:** Inability to modify flight path, very ineffective against fast moving maneuvering threats **Con:** Heat and power requirements may exceed capabilities of current fleet
Directed Energy System	375 km	N/A	ASBMD System shall be capable of near simultaneous engagement of no-less than 2 ballistic vehicles.	**Pro:** Virtually zero delay between firing and hitting target which eliminates the effects of moving targets. **Con:** Very fragile aiming and firing systems **Con:** Blooming effects cause the breakdown of the beam at distances greater than 300 km
* Closure speed calculated at > 40 K feet ** Rail Gun range based on theoretical values derived from data collected during 2008 Navy firings.				

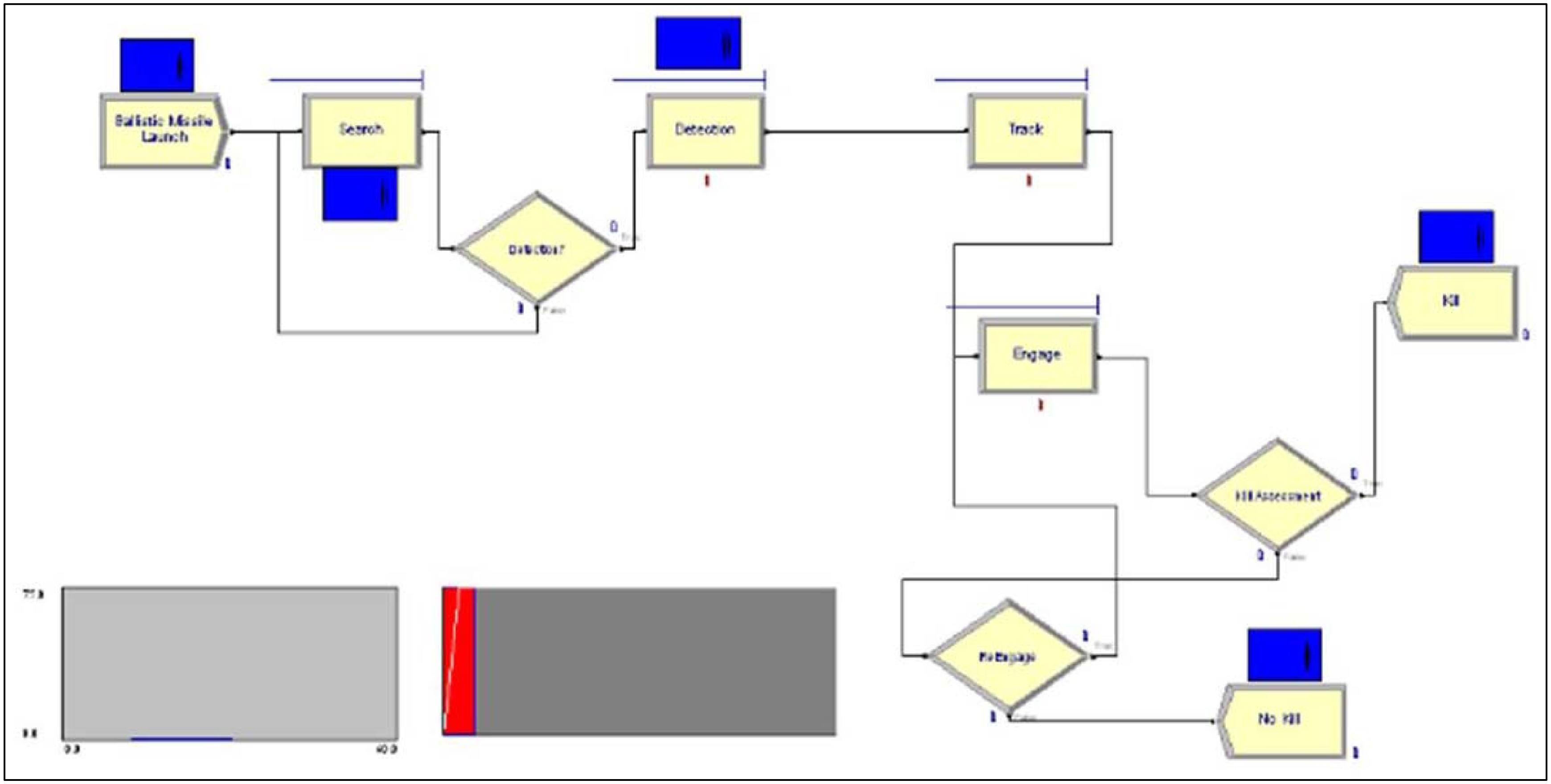

Figure E-2. Gross System Model

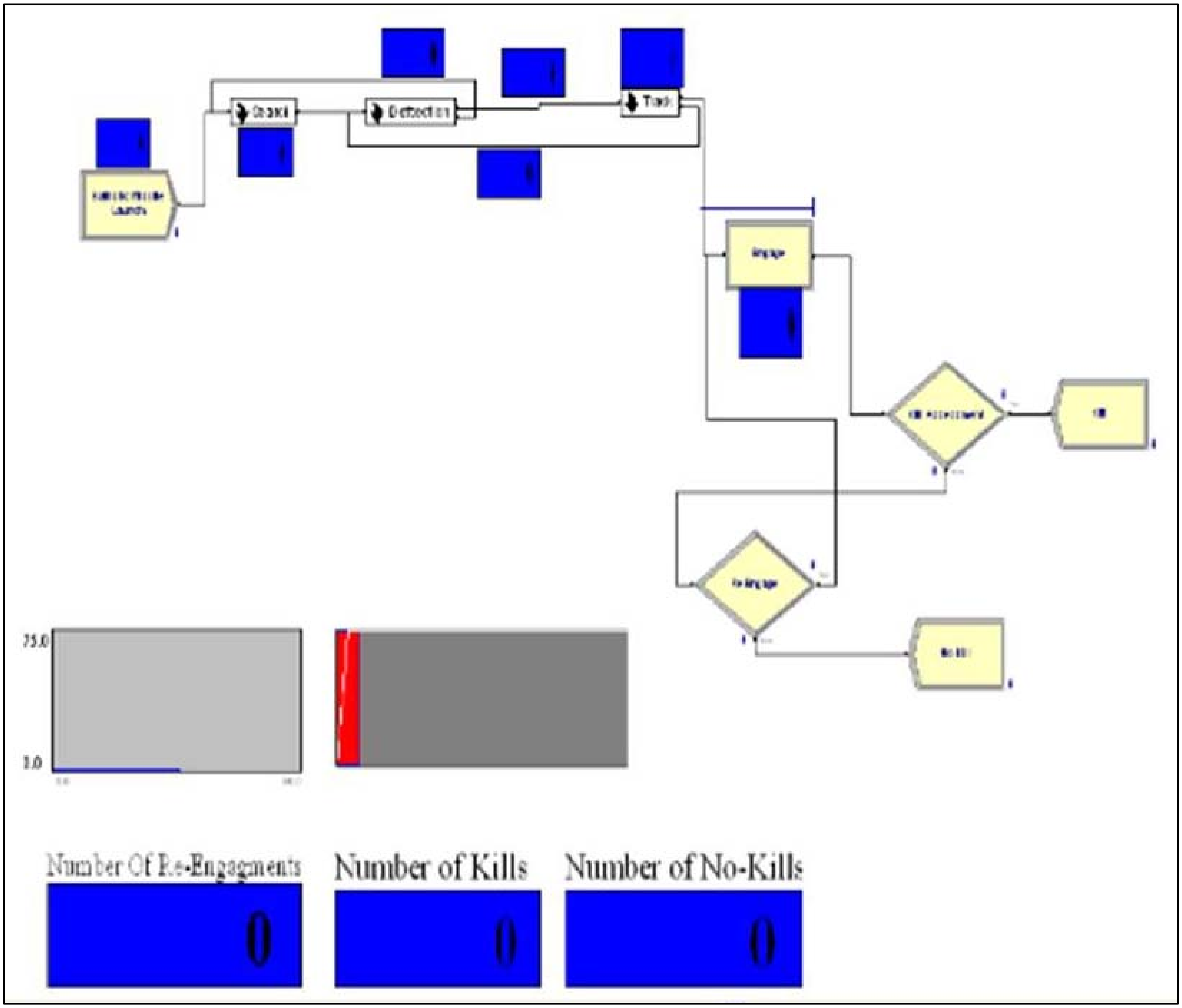

Figure E-3. Detailed System Model

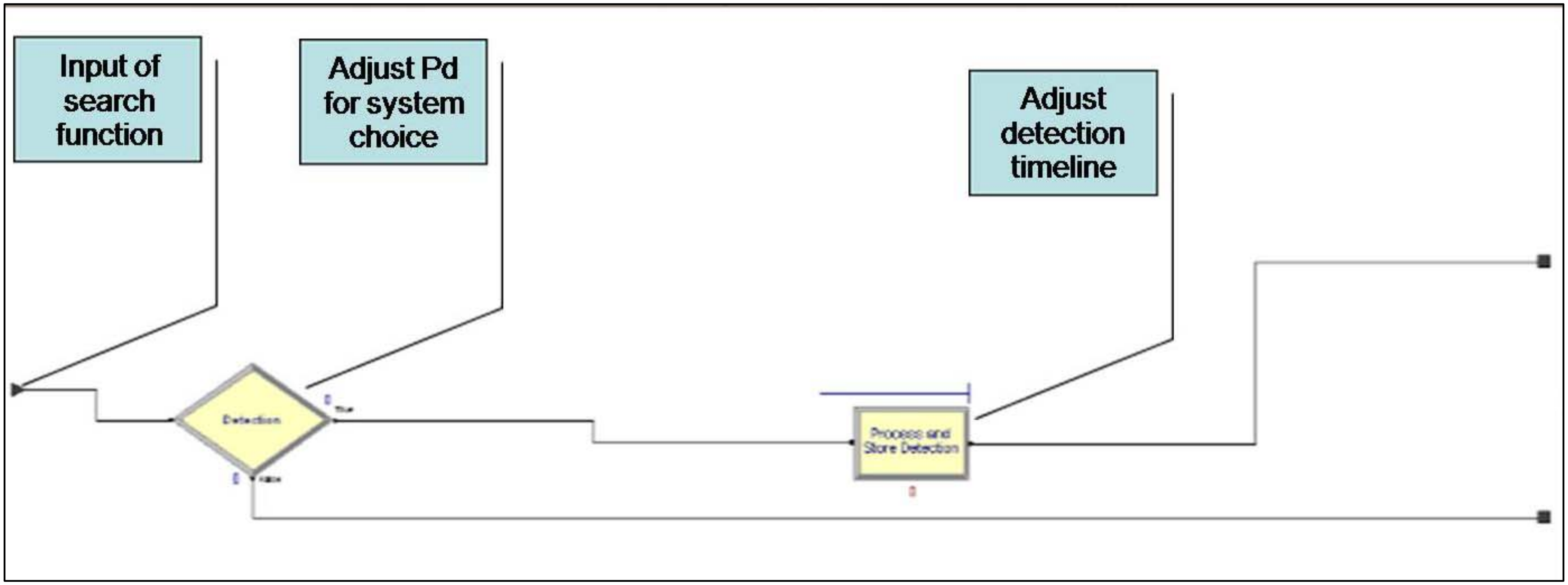

Figure E-4. Functional Sub-Model Breakout Example

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APPENDIX F

RISK MANAGEMENT

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Appendix F

ABBREVIATIONS AND ACRONYMS

AoA	Analysis of Alternatives
ASBMD	Anti-Ship Ballistic Missile Defense
CONOPS	Concept of Operations
DoD	Department of Defense
ICD	Initial Capabilities Document
IPR	In-Process Review
KPP	Key Performance Parameters
MOE	Measure of Effectiveness
MOP	Measure of Performance
RMG	Risk Management Guide
SSP	Strategic Systems Programs
T&E	Test and Evaluation

1 OVERVIEW

Risk is defined in the Risk Management Guide (RMG) for Department of Defense (DoD) Acquisition (DoD, 2006, August) as being "a measure of future uncertainties in achieving program performance, goals, and objectives within defined cost, schedule, and performance constraints." Unfortunately, both technical and programmatic risks are an inevitable fact of system development. Identifying and planning the strategies to mitigate these risks before they become issues is an important part of a successful systems engineering process. For this risk management process to be effective, it must be addressed throughout the entire system development process by the technical team and program management team.

The DoD RMG provides a risk management process model that can be used (or tailored, as necessary) to manage risk throughout the system acquisition process. This approach to managing risk was chosen by the Anti-Ship Ballistic Missile Defense (ASBMD team). Figure 1-1 shows the key activities for this risk management process.

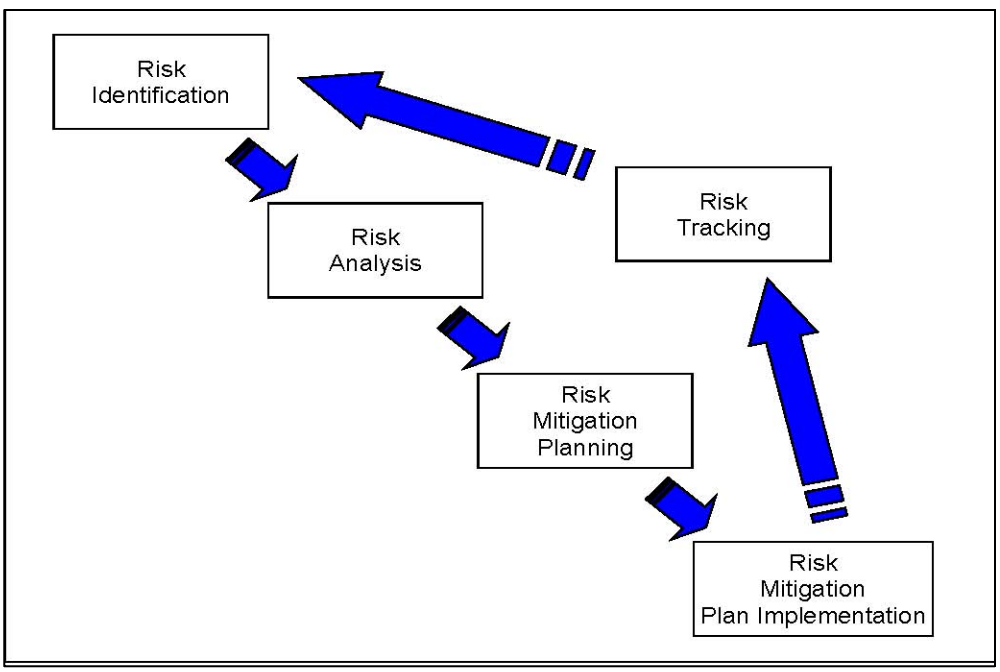

Figure F-1. DoD Risk Management

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2 RISK IDENTIFICATION AND ANALYSIS

The first step in the DoD risk management process is risk identification. The purpose of this activity is to identify what could go wrong that would prevent the system development from succeeding. The next activity is to analyze the risks that have been identified. Risks can be described as having three components:

- Root cause, which, if avoided, would prevent an issue from occurring
- Likelihood that this root cause will occur
- Consequence of this occurrence

Each root cause must be assessed as to the likelihood of it occurring and the consequence to the program development if it was to occur. The DoD RMG categorizes three types of risk that could adversely impact the success of a system acquisition: technical, schedule, and cost. The DoD RMG also provides a standard format for a matrix that may be used to evaluate and report the results of the risk analysis phase. This Risk Reporting Matrix is shown in Figure F-2. The level of risk for each root cause is represented as low (green cells), moderate (yellow cells), or high (red cells).

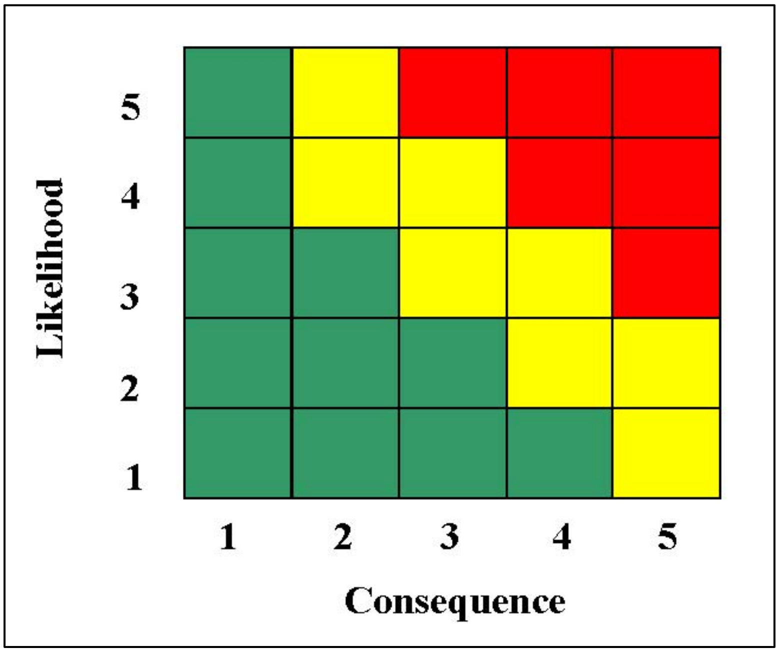

Figure F-2. Risk Reporting Matrix

Guidelines are provided in the DoD RMG for assigning the specific level, 1 through 5, for the likelihood and consequence of each root cause. The level definitions provided in the DoD RMG were evaluated and accepted for use by the ASBMD team when analyzing the risks for the system architecture development effort. Table F-1 lists the definitions provided in the DOD RMG that correspond to each level of the likelihood and probability of the occurrence of a risk's root cause.

Table F-1. Likelihood Level Criteria

Level	Likelihood	Probability of Occurrence
1	Not Likely	~ 10%
2	Low Likelihood	~ 30%
3	Likely	~ 50%
4	Highly Likely	~ 70%
5	Near Certainty	~ 90%

Table F-2 lists the definitions which have been paraphrased from the DoD RMG for use by the ASBMD team for each level of consequence if a risk's root cause were to occur. Level definitions are provided for each level of the three risk categories.

Table F-2. Consequence Level Criteria

Level	Technical	Schedule	Cost
1	Minimal or no consequence to technical performance	Minimal or no impact	Minimal or no impact
2	Minor reduction in technical performance or supportability, can be tolerated with little or no impact on program	Able to meet key dates	Budget increase or unit production cost increase (< 1% of budget)
3	Moderate reduction in technical performance or supportability with limited impact on program objectives	Minor schedule slip; able to meet key milestones with no schedule float	Budget increase or unit production cost increase (< 5% of budget)
4	Significant degradation in technical performance or major shortfall in supportability; may jeopardize program success	Program critical path affected	Budget increase or unit production cost increase (< 10% of budget)
5	Severe degradation in technical performance; cannot meet KPP or key technical/supportability threshold; will jeopardize program success	Cannot meet key program milestones	Exceeds Acquisition Program Baseline threshold (> 10% of budget)

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3 RISK MITIGATION PLANNING AND TRACKING

The next steps in the risk management process involve mitigation planning. These activities identify and evaluate the options available to eliminate, or at least reduce, the risks that could jeopardize the success of the system architecture development effort. Successful mitigation plans are specific as to what needs to be done, when it needs to be done, and who is responsible for doing it. The method chosen by the ASBMD team for documenting risk mitigation plans is an adaptation of the template created by the Strategic Systems Programs (SSP), SP23 Fire Control Section, for use in managing the risks associated with the development of its weapon control systems. A blank copy of this template is shown in Figure F-3.

Risk:					
Description:					
Status:					
Context:					
Other Branches/Orgs Effected:					
Assigned to:					
Mitigation Plan	Step	Planned Completion	Actual Completion	Status	Risk State when done
Exit Criteria					

Figure F-3. ASBMD Risk Mitigation Plan Template

The last activity of the risk management process adopted by the ASBMD team is risk tracking. The ASBMD team completed regular reviews of the identified risks and their associated mitigation plans as part of a regular weekly team meeting.

The most important aspect of this, or any, risk management process is that it is continuous and needs to be revisited, iteratively, until the system development has been successfully completed. This aspect of risk management was also adopted by the ASBMD team and regular reviews of risk included the identification of any new/emerging risk root causes. As new risks were identified, mitigation plans were created and regularly reviewed.

4 ASBMD PROJECT AND SYSTEM RISKS

The ASBMD team had two primary areas of risk that were identified and tracked. One area was project management-related and encompassed the risks associated with successfully completing this Capstone Project. The risk reporting matrix for project management risks is shown in Figure F-4. Table F-3 summarizes these project management risks and includes an identifier used to track the risk, a description of the root cause, and the status of the risk at the time of the Capstone In-Process Review (IPR) #2.

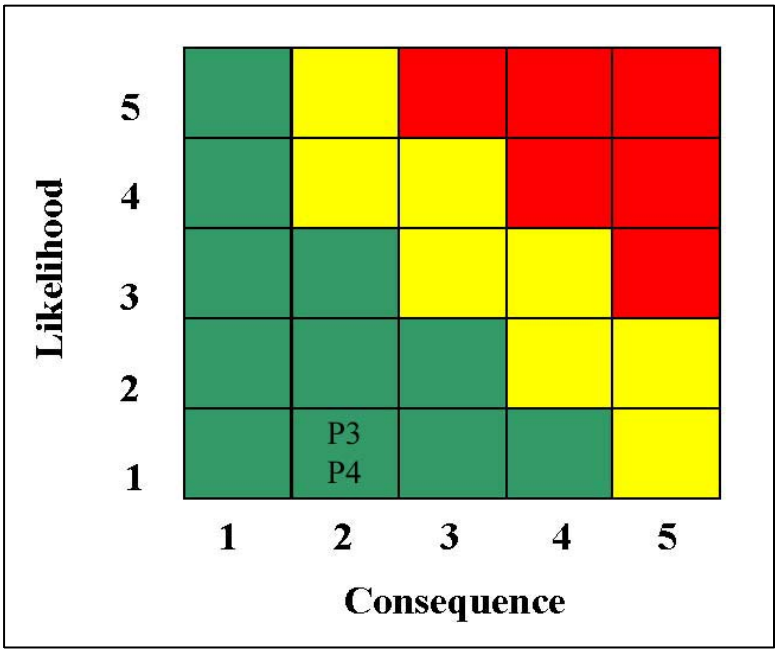

Figure F-4. ASBMD Project Management Risk Matrix (as of IPR #2)

Table F-3. ASBMD Project Management Risk Summary (as of IPR #2)

Risk ID	Description	Status
P1	Team will not be able to generate a list of viable alternatives in a timely manner.	Closed
P2	The team will not decide on a list of Key Performance Parameters (KPPs) in a timely manner.)	Closed
P3	Modeling and simulation tools will not be developed in time for use in the Analysis of Alternatives (AoA).	Improving
P4	Final project report will not be completed on time.	No change
P5	Team will not be able to identify viable candidate systems to support the AoA process.)	Closed

The second area of risk was related directly with the technical challenges of developing the ASBMD system itself. The risk reporting matrix for system engineering risks at the time of the IPR #2 is shown in Figure F-5. Table F-4 provides a summary of these systems engineering risks.

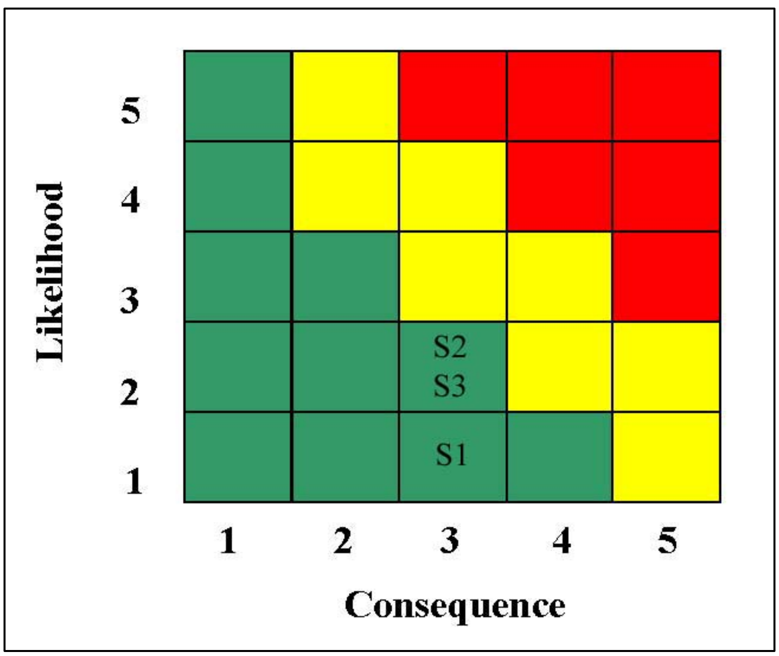

Figure F-5. ASBMD System Engineering Risk Matrix (as of IPR #2)

Table F-4. ASBMD System Engineering Risk Summary (as of IPR #2)

Risk ID	Description	Status
S1	The chosen solution is not able to be integrated with existing systems.	Improving
S2	The test agency will need to acquire a functionally representative threat target to test the proposed ASBMD system.	No change
S3	Necessary resources must be planned and allocated to backfit the system solution(s) into the Fleet.	No change

Risk mitigation plans were developed for each of these risk root causes and were tracked by the ASBMD team. Tables F-5 through F-12 show the mitigation plan for each of these risks at the time of the second IPR briefing. Since the second IPR, the ASBMD team has continued its work and its commitment to risk management. All risks have been mitigated to ensure the successful completion of our Capstone Project.

Table F-5. Risk Mitigation Plan for Risk P1

Risk:	**P1**: The team will not be able to generate a list of viable alternatives to counter the threat in a timely manner, so the analysis of alternatives will be delayed.				
Description:	Research still needs to be done by the team members to narrow the scope on what the threat is and what is needed to combat that threat. This will be a challenge with individual work schedules, travel schedules, and personal commitments.				
Status:	Closed				
Context:	Scope, schedule, and resource planning				
Other Branches/Orgs Effected:	Stakeholders				
Assigned to:	Team 1				
Mitigation Plan	**Steps**	**Planned Completion**	**Actual Completion**	**Status**	**Risk State when done**
	1) Discuss research progress at weekly team meetings.	1-May-09	15-Aug-09		Y
	2) Plan milestones and track progress on the team schedule for the definition of alternatives to consider.	1-May-09	15-Aug-09		Y
	3) Perform research to define the scope of the threat we are addressing.	15-May-09	30-Jun-09		Y
	4) Perform research to investigate any existing systems that may be used for the ASBMD architecture.	31-Jul-09	15-Aug-09		G
	5) Generate list of alternatives for further analysis.	31-Jul-09	15-Sep-09	Close Risk	
Exit Criteria	Team consensus on what the ASBMD system needs to do and a list of viable alternatives that could be used to implement it.				

Table F-6. Risk Mitigation Plan for Risk P2

Risk:	**P2**: The team will not decide on a list of KPPs in a timely manner, so analysis of alternatives will be delayed.				
Description:	There will be many choices for MOEs and MOPs. The team will need to select only a few for use as KPPs and come to an agreement on what these should be. Plus, there is always the challenge of individual work schedules, travel schedules, and personal commitments.				
Status:	Closed				
Context:	Scope, schedule and resource planning				
Other Branches/Orgs Effected:	Stakeholders				
Assigned to:	Team 1				
Mitigation Plan	**Steps**	**Planned Completion**	**Actual Completion**	**Status**	**Risk State when done**
	1) Designate a lead for the KPP selection. The lead will keep the effort on track and direct work on the task.	1-May-09	1-May-09	Lead is Mike Roberts	Y
	2) Plan milestones and track progress on the team schedule associated with MOE/MOP evaluation and KPP selection.	1-Aug-09	15-Aug-09		Y
	3) Decide what MOEs/MOPs are desired and investigate what data is available.	15-Aug-09	15-Aug-09		G
	4) Generate list of KPPs to use for the analysis of alternatives.	31-Aug-09	30-Aug-09	Close Risk	
Exit Criteria	Team consensus on the ASBMD system KPPs.				

Table F-7. Risk Mitigation Plan for Risk P3

Risk:	**P3**: Modeling and simulation tools will not be developed in time for their use in the analysis of alternatives.				
Description:	Because of competing individual work schedules, travel schedules, and personal commitments, the development of tools to analyze alternatives is delayed. This also might occur if other project risks are not properly or fully mitigated.				
Status:	Closed				
Context:	Schedule and resource planning				
Other Branches/Orgs Effected:	Stakeholders				
Assigned to:	Team 1				
Mitigation Plan	**Steps**	**Planned Completion**	**Actual Completion**	**Status**	**Risk State when done**
	1) Designate a lead for the model and simulation development. The lead will keep the effort on track and direct work on the task.	1-May-09	22-May-09		Y
	2) Plan milestones and track progress on the team schedule associated with tool development.	1-Jun-09	31-Aug-09		Y
	2(a) Perform modeling proficiency demonstration.	15-Jun-09	12-Jun-09		G
	3) Come to an agreement on what tools are needed.	15-Jul-09	1-Aug-09		G
	4) Generate needed tools.	15-Aug-09	31-Aug-09	Close Risk	
	Note: Modeling Overview was delivered to advisors on 31-Aug-09.				
Exit Criteria	Tools are available for use.				

Table F-8. Risk Mitigation Plan for Risk P4

Risk:	**P4**: Final project report will not be completed on time.				
Description:	Because of competing individual work schedules, travel schedules, and personal commitments, the writing of the project report and presentation is delayed. This also might occur if other project risks are not properly or fully mitigated. A lead for this task has already been chosen: Jeannie Hobgood.				
Status:	Improving				
Context:	Schedule and resource planning				
Other Branches/Orgs Effected:	None				
Assigned to:	Team 1				
Mitigation Plan	**Steps**	**Planned Completion**	**Actual Completion**	**Status**	**Risk State when done**
	1) Plan milestones and track progress on the team schedule for the project report and presentation.	1-May-09	on-going		G
	2) Start the project report with information for chapters I and II and the PMP appendix at the end of the first quarter (Spring 2009). Also start the final project presentation slides.	30-Jun-09	6-Jul-09	Released draft of Chap. 1 and have CONOPS and ICD documents to use for other chapters	G
	3) Update the project report and presentation with information available at the end of the second quarter (Summer 2009).	1-Oct-09	23-Oct-09	Chap 3 released for review and IPR #2	G
	4) Complete chapter 4 and remaining sections (appendices, abstract, executive summary, etc). Assemble and release for final team review.	20-Nov-09			G
	5) Complete final report and submit for department review.	30-Nov-09		Close Risk	
Exit Criteria	Correctly formatted report is submitted to Systems Engineering department.				

Table F-9. Risk Mitigation Plan for Risk P5

Risk:	**P5**: The team will not be able to find feasible solutions to meet the stated need.				
Description:	Although exhaustive research and analysis has been done, the team cannot recommend a solution that will resolve the problem statement.				
Status:	Closed				
Context:	Technical				
Other Branches/Orgs Effected:	Stakeholders, Advisors				
Assigned to:	Team 1				
Mitigation Plan	**Steps**	**Planned Completion**	**Actual Completion**	**Status**	**Risk State when done**
	1) Discuss research and analysis findings at team meetings.	15-Jul-09	15-Jul-09		G
	2) Discuss alternatives and brainstorm ideas.	1-Aug-09	1-Aug-09		G
	3) Generate table of alternative architectures for each functional area.	15-Sep-09	15-Sep-09	Close Risk	
Exit Criteria					

Table F-10. Risk Mitigation Plan for Risk S1

Risk:	**S1**: The chosen solution is not able to be integrated with existing systems.				
Description:	Although exhaustive research and analysis has been done, the team cannot recommend a solution that will work with existing systems.				
Status:	Improving				
Context:	Technical				
Other Branches/Orgs Effected:	Stakeholders, Advisors				
Assigned to:	Team 1				
Mitigation Plan	**Steps**	**Planned Completion**	**Actual Completion**	**Status**	**Risk State when done**
	1) Discuss research and analysis findings at team meetings.	15-Jul-09	15-Jul-09		Y
	2) Discuss alternatives and brainstorm ideas.	15-Aug-09	15-Aug-09		Y
	3) Primary selection criteria for alternatives include interoperability.	1-Sep-09	1-Sep-09		G
	4) Chosen architecture for system of systems supports interoperability.	15-Nov-09		Close Risk	
Exit Criteria					

Table F-11. Risk Mitigation Plan for Risk S2

Risk:	**S2**: Development of Test Threat Simulator				
Description:	The aim of this project is to eliminate a non-traditional threat that we currently have no technological equivalent of. The Test and Evaluation (T&E) Agency is going to have to develop an operationally representative threat to test the capability of any proposed system.				
Status:	Improving				
Context:	Technical				
Other Branches/Orgs Effected:	T&E Agency & Program Office				
Assigned to:	T&E Agency				
Mitigation Plan	**Step**	**Planned Completion**	**Actual Completion**	**Status**	**Risk State when done**
	1) Make T&E and Program Office group aware of risk.	15-Jul-09	20-Jul-09		G
	2) Monitor T&E plan development (include coverage in final report).	15-Nov-09		Close Risk	
Exit Criteria					

Table F-12. Risk Mitigation Plan for Risk S3

Risk:	**S3**: Outfitting the Current DoD assets with Solution				
Description:	The ability to "backfit" current hardware with a solution is historically a challenge. Identifying resources needed and implementing a plan are critical.				
Status:	Improving				
Context:	Financial, Programmatic				
Other Branches/Orgs Effected:	Program Office, Resource Sponsor				
Assigned to:	Program Office				
Mitigation Plan	**Step**	**Planned Completion**	**Actual Completion**	**Status**	**Risk State when done**
	1) Identify required resources for backfit.	1-Nov-09	4-Nov-09		Y
	2) Consider costs for those resources.	15-Nov-09	19-Nov-09		G
	3) Address results in final report.	20-Nov-09		Close Risk	
Exit Criteria					

5 REFERENCES

Department of Defense. (2006, August). *Risk Management Guide for DOD Acquisition* (Sixth Edition, Version 1.0). Washington, DC: Author.

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