NAVAL POSTGRADUATE SCHOOL

MONTEREY, CALIFORNIA

THESIS

ANALYSIS AND DESIGN OF A COOPERATIVE WEAPON ASSIGNMENT MODULE FOR ADVANCED BATTLE MANAGER OF A BALLISTIC MISSILE DEFENSE SYSTEM

by

Willie D. Brown

March 2006

Advisor:	Man-Tak Shing
Co-Advisor:	J. Bret Michael

THIS PAGE INTENTIONALLY LEFT BLANK

REPORT DOCUMENTATION PAGE			*Form Approved OMB No. 0704-0188*
Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instruction, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188) Washington DC 20503.			
1. AGENCY USE ONLY *(Leave blank)*	**2. REPORT DATE** March 2006	**3. REPORT TYPE AND DATES COVERED** Master's Thesis	
4. TITLE AND SUBTITLE: Title (Mix case letters) Analysis and Design of a Cooperative Weapon Assignment Module for Advanced Battle Manager of a Ballistic Missile Defense System			**5. FUNDING NUMBERS**
6. AUTHOR(S) Willie D. Brown			
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Naval Postgraduate School Monterey, CA 93943-5000			**8. PERFORMING ORGANIZATION REPORT NUMBER**
9. SPONSORING /MONITORING AGENCY NAME(S) AND ADDRESS(ES) N/A			**10. SPONSORING/MONITORING AGENCY REPORT NUMBER**
11. SUPPLEMENTARY NOTES: The views expressed in this thesis are those of the author and do not reflect the official policy or position of the Department of Defense or the U.S. Government.			
12a. DISTRIBUTION / AVAILABILITY STATEMENT Approved for public release; distribution is unlimited			**12b. DISTRIBUTION CODE**

13. ABSTRACT (maximum 200 words)

The United States is in the midst of an ambitious effort to build and deploy a wide range of ballistic missile defense systems. These ballistic missile defense systems will be effective against a host of current and postulated threats from ballistic missiles. In this thesis study, we explore the process of enhancing the effectiveness of weapon assignment for a system of systems. First, analysis of information is drawn from current proposed system of the ABM and its construction from the ground up. This research analyzes two ballistic Missile Defense System (BMDS), Aegis and Patriot respectively, their attributes, and their current and future roles in a Global Ballistic Defense Missile System. In addition, this thesis presents a software architecture for the ABM weapon assignment component module with object oriented design feasibility with integration as the key ingredient. This research contributed to highlighting some shortfalls in efforts to integrate capabilities and desired capabilities as the missile threat evolves and presents recommendations for follow-on research to improve ABM's weapon assignment capabilities.

14. SUBJECT TERMS Design, analysis, weapon assignment, Aegis, Patriot, layered architecture			**15. NUMBER OF PAGES** 104
			16. PRICE CODE
17. SECURITY CLASSIFICATION OF REPORT Unclassified	**18. SECURITY CLASSIFICATION OF THIS PAGE** Unclassified	**19. SECURITY CLASSIFICATION OF ABSTRACT** Unclassified	**20. LIMITATION OF ABSTRACT** UL

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. 239-18

THIS PAGE INTENTIONALLY LEFT BLANK

ANALYSIS AND DESIGN OF A COOPERATIVE WEAPON ASSIGNMENT MODULE FOR ADVANCED BATTLE MANAGER OF A BALLISTIC MISSILE DEFENSE SYSTEM

Willie D. Brown
Lieutenant Commander, United States Navy
B.S., Florida A&M University, 1996

Submitted in partial fulfillment of the
requirements for the degree of

MASTER OF SCIENCE IN COMPUTER SCIENCE

from the

NAVAL POSTGRADUATE SCHOOL
March 2006

Author: Willie D. Brown

Approved by: Man-Tak Shing
Advisor

J. Bret Michael
Co-Advisor

Peter Denning
Chairman
Department of Computer Science

THIS PAGE INTENTIONALLY LEFT BLANK

ABSTRACT

The United States is in the midst of an ambitious effort to build and deploy a wide range of ballistic missile defense systems. These ballistic missile defense systems will be effective against a host of current and postulated threats from ballistic missiles. In this thesis study, we explore the process of enhancing the effectiveness of weapon assignment for a system of systems. First, analysis of information is drawn from current proposed system of the ABM and its construction from the ground up. This research analyzes two ballistic Missile Defense System (BMDS), Aegis and Patriot respectively, their attributes, and their current and future roles in a Global Ballistic Defense Missile System. In addition, this thesis presents a software architecture for the ABM weapon assignment component module with object oriented design feasibility with integration as the key ingredient. This research contributed to highlighting some shortfalls in efforts to integrate capabilities and desired capabilities as the missile threat evolves and presents recommendations for follow-on research to improve ABM's weapon assignment capabilities.

THIS PAGE INTENTIONALLY LEFT BLANK

TABLE OF CONTENTS

LIST OF FIGURES

THIS PAGE INTENTIONALLY LEFT BLANK

LIST OF TABLES

THIS PAGE INTENTIONALLY LEFT BLANK

LIST OF ACRONYMS

AAW	Air Warfare
ABL	Airborne Laser
ABM	Advanced Battle Manager
ABT	Air Breathing Threats
AEGIS BMD	Aegis Ballistic Missile Defense
AMDTF	Air and Missile Defense Task Force
AOA	Amphibious Objective Areas
AOR	Area of Responsibility
ASCMs	Anti Ship Cruise Missiles
AWACS	Airborne Warning and Control System
BMC3I	Battle Management, Command and Control, Communications, and Intelligence
BMD	Ballistic Missile Defense
BMDO	Ballistic Missile Defense Organization
BOS	Battlefield Operating Systems
C2BMC	Command and Control, Battle Management and Communications
CARM	Counter Anti-radiation Missile
CDI	Classification, Discrimination, and Identification
CE	Communications Enhancement
CEC	Cooperative Engagement Capability
CM	Collection Manager
CRG	Communication Relay Group

CUG	Control Unit Group
DBK	Dominant Battlespace Knowledge
DOD	Department of Defense
DOF	Degrees of Freedom
EADSIM	Extended Air Defense Simulation
ECM	Electronic Countermeasures
ECS	Engagement Control Station
EDR	Embedded Data Recorder
EWCC	Expanded Weapons Control Computer
FB	Forward Battle
FTM	Flight Test Maritime
GEM	Guidance Enhanced Missile
ICBM	Intercontinental Ballistic Missiles
IOC	Initial Operational Capability
KW	Kinetic Warhead
LRC	Learning Resource Center
LRS&T	Long Range Surveillance and Tracking
LS	Launching Station
MDA	MDA Missile Defense Agency
MEADS	Medium Extended Air Defense System
NATO	North Atlanta Treaty Organization
NMD	National Missile Defense
NP	Non-deterministic Polynomial Time
NTW	Navy Theater-Wide

ODS	Optical Disk System
OTM	On the Move
PAC-3	Patriot Advanced Capability-3
PDAL	Prioritized Defended Asset List
PDB	Programmed Data Base
PDP	Programmed Data Processor
PK	Probability of Kill
PLGR	Precision Lightweight Global Positioning System Receiver
PTOD	Precise Time of Day
RAM	Reliability, Availability, and Maintainability
RCS	Radar Cross Section
REP	Radar Enhancement Phase
RISTA	Reconnaissance, Intelligence, Surveillance, and Target Acquisition
RLCEU	Remote Launch Communications Enhancement Upgrade
RS	Radar Set
SALT	Strategic Arms Limitation Treaty
SAM	Surface to Air Missile
SBIRS-High	Space-Based Infrared System-High
SM-2	Standard Missile-2
SM-3	Standard Missile-3
SPG IOC	Signal Processor Group Input/Output Control
TBMD	Theater Ballistic Missile Defense
TCT	Time Critical Target

THAAD	Theater High-Altitude Area Defense
TLE	Target Location Error
TM	Theater Missile
TMD	Theater Missile Defense
TPT	Time Processing Target
UOES	User Operational Evaluation System
WAC	Weapon Assignment Computation
WMD	Weapons of Mass Destruction
WTA	Weapon Target Assignment

ACKNOWLEDGMENTS

I would sincerely like to thank Dr. Shing, Dr. Michael, and Dr. Caffall for their assistance in this research area and their prestigious insight toward improvement with students for further studies.

THIS PAGE INTENTIONALLY LEFT BLANK

I. INTRODUCTION

A. AREA OF RESEARCH

The area of research and purpose of this thesis is to develop an object-oriented design for a cooperative weapons assignment weapon module for a system-of-systems within the Advanced Battle Manager (ABM) framework focusing on the strategies for weapon targeting and weapon pairing for ballistic missile defense. The research will involve studies of missiles and weapon profiles to develop weapon assignment constraints. Through classification and thorough examination of the threat missile attributes, the target threats can be discriminated as benign or suspect and distributed for further processing within the weapon assignment network. Dynamic command and control and battle management functions require fast and effective decision aids to provide optimal allocation of resources (object/sensor pairing, weapon/target assignment) for effective engagement and real-time battle damage assessment. The basic Weapon Target Assignment (WTA) problem considers the assignment of a set of platforms/weapons to a set of targets such that the overall expected effect is maximized.

In this thesis study, we explore the process of enhancing the effectiveness of weapon assignment for a system of systems. First, analysis of information is drawn from current proposed system of the ABM and its construction from the ground up. This research analyzes two ballistic Missile Defense System (BMDS), Aegis and Patriot respectively, their attributes, and their current and future roles in a Global Ballistic Defense Missile System.

In addition, this thesis presents a software architecture for the ABM weapon assignment component module with object oriented design feasibility with integration as the key ingredient. This enhances capability to destroy weapon classified as a threat to U.S. forces and their allies stationed overseas. Strategic placement of assets in the correct arena of operation to accomplish missile defense objectives is critical. Acquiring and distributing the appropriate data in a timely efficient manner reduces technological, organizational, and strategic shortcomings.

1. Weapon Target Assignment

A key component in planning and controlling the weapon target pairing is the assignment function of resources (e.g., kinetic kill vehicles, rail guns, and lasers) to targets. The Weapon Target Assignment (WTA) problem is to find a proper assignment of weapons to targets with the objective of maximizing the overall effect associated with targets. Various methods for solving this NP-complete WTA problem have been reported in past literature. This research directs focus at one or more types of weapons carried by a set of platforms against a set of targets, and extend the basic WTA problem by allowing for multiple target assignments per platform as required. In addition, investigation may be directed toward how the formulation can be applied to collaborative planning where multiple sources may be required per target.

The general dynamical WTA problem is that of a defensive battle manager that must allocate defensive weapons to offensive threats to maximize the surviving value of targeted assets. An *asset* is defined as any entity (or collection of entities) of military importance, ranging from fixed installations like factories, bridges, and buildings, to moving objects like battleships, convoys, etc. Each asset has a value assigned to it by the defense. A *threat* can be anything potentially causing damage to defensive assets. Different threats may be moving at different speeds at different distances. Also, a threat may suddenly change its course. A *weapon* may be any means that can be used to eliminate a threat. A weapon system is assumed to have a certain number of weapons in its inventory. Different weapons may require different amounts of time to engage the same threat. The number of weapons, the number of threats, and the number of assets may vary as function of time. Any weapon can kill any threat in range with kill probability dependent on the threat, the weapon, and the firing time. It is assumed that the defense knows how many offensive threats there are at each moment during an attack and against which asset each threat is directed.

During a hostile engagement, the battle manager must initiate a set of consecutive actions. The initial defensive response is threat detection and identification. The threats are then prioritized according to their danger to the asset. Rule-based methods are used to generate a schedule of events to counter the attack and prevent the threats from hitting the asset. A schedule is a finite, discrete-time indexed list of decision instants with associated events. The problem is to maximize the expected surviving defensive values by determining the best firing schedule over time given the number of weapons to defend the number of assets against the number of threats. The number of weapon and the number of threats can possibly result in a large problem.

B. HISTORY AND BACKGROUND

The earliest recorded use of powered missiles in warfare was in 1232 at the military siege of Kaifeng, former capital of the Chinese province of Henan, in which rockets were used to set fire to tents and wicker-work fortifications. European technology developed these rockets into larger and longer-range weapons. In 1807, for example, Copenhagen and a large French fleet in its harbor were almost totally destroyed by a British naval attack using thousands of iron rockets. The national anthem of the United States reflects the common use of these weapons in naval battles in the 17th and 18th centuries, when Francis Scott Key saw the American flag "by the rocket's red glare."

The first true ballistic missile — one that has a brief period of powered flight, continues on a ballistic trajectory outside the atmosphere, then curves back to an impact point on earth — was developed at the end of World War II. Serious efforts to find a defense against ballistic missiles began shortly after the first German V-2 slammed into London, without success. Overall, the United States has spent more than $100 billion (in current dollars) in the pursuit of missile defense since the mid-1950s (plus $17 billion on the Patriot system, developed separately by the Army as an anti-aircraft system.) The United States remains the only nation devoting a significant portion of its national defense budget to missile defense.

President Eisenhower began the search for a defense to these missiles when he authorized the operational development of a nuclear-tipped interceptor missile, Nike-Zeus, and commissioned Project Defender to develop components for a nationwide ballistic missile defense system. In the late 1960s, President Richard Nixon approved the deployment of the Safeguard Anti-Ballistic Missile (ABM) system, in response to the Soviet development of an ABM system around Moscow. Although many in Congress were concerned that the system would be ineffective, vulnerable to attack, and easily overwhelmed, it was approved in order not to undermine America’s negotiating position in the Strategic Arms Limitation Talks.

In 1972, the Soviet Union and the United States announced the first Strategic Arms Limitation Treaty (SALT 1) as well as an agreement limiting defensive systems--the ABM Treaty. Both nations agreed "that effective measures to limit anti-ballistic missile systems would lead to a decrease in the risk of outbreak of war involving nuclear weapons." In attaining both of these agreements at the same time, the negotiators intended to ensure strategic stability by stopping large scale deployment of strategic defensive systems while attempting to limit offensive forces.

The broad purpose of the ABM Treaty is to prevent either party from fielding a nationwide ballistic missile defense of its territory. The Treaty prohibits the development, testing or deployment of sea-based, air-based, space-based, or mobile land-based ABM systems, as well as components based on advanced physical principles. The U.S. Arms Control and Disarmament Agency notes the ABM Treaty is designed to "decrease the pressures of technological change and its unsettling impact on the strategic balance."

The proven logic behind the prohibition against a nationwide defense is that an arms race in strategic defense systems fosters the proliferation of offensive missiles and the development of countermeasures to defeat the defense.

The ABM Treaty permitted a limited deployment of defenses. Russia for years maintained a site of 100 nuclear-tipped interceptors around Moscow. Administration officials have always been confident that United States missiles could penetrate and overwhelm this defense. If the Soviets had deployed more advanced or proliferated defenses, the United States would surely have deployed more advanced devices to ensure the continued capability to penetrate. Russian officials recently indicated that they have recently taken all nuclear warheads off the Moscow ABM interceptors.

In the Administration of President Gerald Ford, officials and military advisors determined that defenses permitted to the United States under the Treaty were not worth maintaining since they could easily be penetrated by Soviet ballistic missiles. As a panel of the George C. Marshall Institute (proponents of deploying a space-based defensive system) noted during the Star Wars debates of the late-1980s, the problems with the 1970s defensive systems were that "a 'ground-based' defense is readily overwhelmed and that the fixed, ground-based radars on which the system depends are 'easily targeted by the Soviets and vulnerable to destruction in a surprise attack." Ultimately, although the Safeguard system was deployed, it was operational for only a few months in the mid-1970s, and then shut down as obsolete. Under President Jimmy Carter, the United States continued an active research program into strategic defenses, averaging just under $1 billion per year. At the beginning of the Reagan Administration, the consensus in the defense community was that ballistic missile defenses could not be militarily effective. Some, however, disagreed and promoted two systems — High Frontier and space-based lasers — each considered by the Reagan Administration and rejected before the President's surprise "Star Wars" speech of March 23, 1983. **(CIR)**

The 1991 Gulf War was the first test of a ballistic missile defense in actual combat and the first successful, if inadvertent, use of countermeasures. Those engagements between missiles contain lessons for engineers on both the attacking and defending sides. Scuds launched from Iraq spiraled during reentry! Outmaneuvering the slower, less agile Patriot interceptors, and disintegrated at random, their debris creating false targets that disrupted the Patriot homing process. For the most part, the Patriot's combat environment was shaped by the unexpected behavior of the attacking Scuds-this striking fact alone showing that the U.S. weapon's performance depended on the characteristics of both the defense and the attacking missiles. As it happens, the countermeasures that defeated the Patriot were probably unintended and their effects accidental. But this first experience with missile defense is a warning that the existence of countermeasures cannot be ignored. Evidently, it would be wise to examine some of the countermeasures that could confront future missile defenses.

1. Purpose of Study

The Department of Defense has been successfully exploiting rapidly developing advances in information technology for military gain. On tomorrow's multidimensional battlefield or "battlespace" the increased density, acuity, and connectivity of sensors and many other information devices may allow U.S. Armed Forces to see almost everything worth seeing in real or near-real time. Such enhanced vision of the battlespace is no doubt a significant military advantage, but a question remains: “How do we achieve dominant battlefield knowledge, namely, the ability to understand what we see and act on it decisively”? The implementation of the Advanced Battle Manager (ABM not to be confused with the Anti-ballistic missile) shall be able to address the most critical aspects of that problem.

> If the United States develops the means to acquire dominant battlespace knowledge (DBK), how might that affect the way it goes to war, the circumstances under which force can and will be used, the purposes for its employment, and the resulting alterations of the global geomilitary environment? Of particular interest is how the authors view the influence of DBK in light of the shift from global to regional stability issues that marks the post-Cold War world. While no definitive answer has yet emerged, it is clear that the implications of so profound a change in military technology are critical to the structure and function of the U.S. Armed Forces. **(LIBICKI)**

The basis of the analysis for the ABM design for the weapon assignment weapon module will be derived from a comprehensive analysis of existing missile defense systems for compatibility, expansion, growth, and proven capability through testing and performance through the years for ballistic missile defense. “Prioritizing our efforts against the most important threats, maintaining focus on those threats, accomplishing the research, conducting data base maintenance, and long term analytic projects required to maintain our analytic depth and generally being proactive instead of reactive will all become more difficult to achieve in a high tempo security environment”.**(SARTER)**

THIS PAGE INTENTIONALLY LEFT BLANK

II. WEAPON ASSIGNMENT

A. INTRODUCTION

The goal of the ABM Weapon Assignment component is to accurately utilize the functionality associated with the different weapon systems. This chapter of the thesis will address and discuss the execution of how the ABM tactical operations battle management, command and control, communications, and intelligence behave with regards to developing a set of requirements for the framework of the ABM. We will explore both the Patriot PAC-3 and Aegis missile system in the following two chapters. In a ballistic missile defense automated system engagement sequence, a performance of search and detection, tracking, identification, threat evaluation, engagement decision, weapon assignment, engagement planning and execution, and kill assessment are all time critical and take place under high stress. In accordance with Caffalls' framework, information drawn from the track processing will undergoes discrimination computation. By thoroughly examining the weapon assignment component of the ABM, future research and further tailoring for the system can be discovered.

1. ABM Weapon Assignment Overview

Since the track data will represent three track types, threat, benign, or suspect respectfully, the system processing and discrimination of the weapon assignment component only needs to direct primary focus toward threat tracks. Since there will be an interface addressing pre-conditions, post-conditions, and other invariants that are vital to correlation within the constraints of the specified timeframe through a thorough process of elimination, all threat tracks will be correlated and displayed within the Kill Data Store. The goal of the weapon assignment processing initiates and commences dispensation of assigning a weapon system to engage each track in Kill Data Store.

The polling of the weapon assignment processor will occur at a specified time of every two seconds. The polling takes a threat track from the top of the stack and sends the track to the iPrioritize interface which will address pre-condition, post conditions and invariants. **(CAFFALL)** A copy of the diagram is shown below.

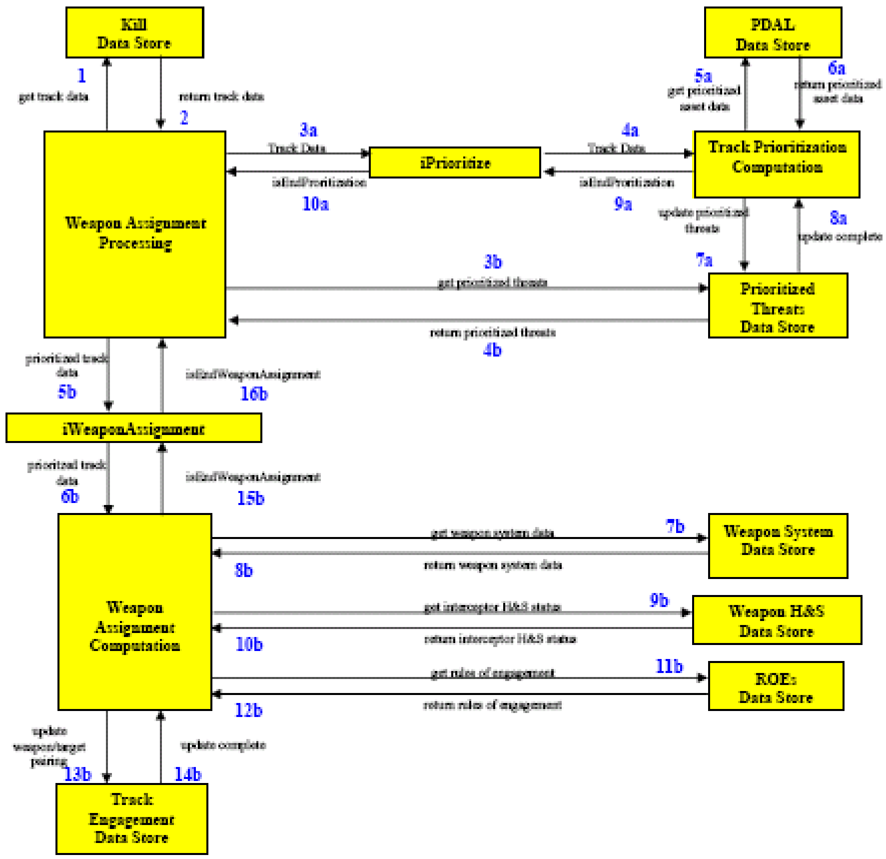

Figure 1: Weapon Assignment Processing Component (From [CAFFALL], pp 144,145)

Incorporated inside the weapon assignment processing component is the track prioritization computation to determine the priority of the tracks based upon a Prioritized Defended Asset List (PDAL) which will be further outlined in Chapter V and drawn from Caffalls' framework (p 145**). (CAFFALL)** Significant events take place inside the PDAL which details an algorithmic approach toward prioritization in the direction of any assets within specified parameters.

The next feature of the weapon assignment processing component is the iWeaponAssignment interface that links between weapon assignment processing and weapon assignment computation. In addition, iWeaponAssignment interface will address pre-condition, post conditions and invariants which will be further outlined in Chapter V and drawn from Caffalls' framework (p 146). **(CAFFALL)**

The next major component of the weapon assignment processing component is the Weapon Assignment Computation (WAC). The WAC will act as a passive component and perform send and receive actions from three different data stores. A weapon is assigned to each threat inside this component based upon three important characteristics which are available weapon system, health and status of available weapon system, and rules of engagement. The Weapon System Data Store contains information of all weapon systems in the BMDS including their range, accuracy, altitude and range to intercept maximum number of available launchers, reload times, and maximum number of current engagements of the weapon system. The Weapon Health and Status Data Store contains information that is continually updated of each weapon health and status associated within the ABM to include the readiness of the weapon, readiness of the number of interceptors, current engagement assignments to the weapon system as well as current engagements of the weapon system. The Rules of Engagement Data Store contains information as set forth in the BMD planning phase to include shot doctrine and firing trigger listing the available shots, probability of kill, and the desired interceptor reserve. In addition, the WAP sends and receives information from the Track Engagement Data Store which keeps track of the current engagement status of every prioritized track.

Further extension of some of the key concepts to capture a broader range of the scope of the ABM will be elaborated upon.

- Elements per Target: Some targets contain more than one element. This is used when considering weapons allocation and when determining the resolution required for detection of the target. Elements per target can be represented as a table of constants indexed by target class.
- Target Value: Some targets are more important than others are. When calculating the platform plan or the weapon-target-pairing algorithm, the value of a target can be used to select important targets for attack. The target value can be modeled as a constant for each target class. It can be represented as a table of constants indexed by target class.
- Correlation: This concept will play a vital role during the processing. Several sensors in the mix may see and collect information on the same target. This phenomenon is accounted for by correlation, a percentage of sensed targets that are not duplicates. A correlation of 90 percent, for instance, would mean that ten percent of sensed targets are duplicates, and 90 percent of sensed targets are separate targets. Correlation can be represented as a constant.
- Engagement Time Requirements: The minimum time from the tasking of a weapon platform until the weapon engages the target, represented as a table

of time requirements indexed by platform type and range band.

- Weapon Target Location Error (TLE): The accuracy with which the target location must be known in order to use a weapon effectively. TLE for a target is compared to the weapon TLE requirement when allocating weapons. Weapon TLE requirements can be represented by a table of TLEs indexed by weapon.
- Health and Status Inventory: The numbers of weapons incorporated among all weapons launch platforms in all of the AORs represented as a table indexed by type of weapon.

Defensive weapons being allocated from any AOR weapon platform must share some common characteristics such as small reaction time, extremely high probability of success and multiple simultaneous engagements capability. Having those common characteristics will result in autonomous operation of the weapon suites from detection to engagement. A bidding process will aid in weapon assignment precluding the expenditure of multiple weapons from different weapons platforms on one target. Each weapon system will evaluate the threat and determine its evaluation of probability of kill and then place a bid for destruction of the target to the ABM weapon assignment processing components.

Because of the complexity and size of the planning space and the number of possible combinations of options and constraints that must be considered, manual planning methods and most current automated methods may appear to be inadequate. They may emerge as narrowly focused, inflexible, time consuming, and not scalable. As options or constraints are added, the ABM plan complexity increases several folds which add to the time necessary to develop the plan. Weapon performance from the US and its Allies will depend on the characteristics of both the defenses and the attacking missiles.

2. Analysis of the ABM Weapon Assignment

A threat will generate a set of weapons pairs. Each threat or weapon pair will consist of the threat and the effective weapon resource that is capable of defeating the threat. A generic algorithm will select a unique weapon pair from among the weapon platform options based upon doctrines and resources. The interceptor must be able to engage a target coming from any number of directions, at different speeds and ranges, and at many different points along the axis and engaging multiple targets at once which will be further outlined in Chapter V.

The ABM will attempt to capture the increase speed of classification and discrimination for a ballistic object while ensuring consistency across a distributed architecture. In addition, the ABM will increase the understanding of target identification, threat classification and discrimination, weapon selection, weapon target assignment, and hit to kill assessment.

Within the stated concepts of the ABM, the models capture a valuation of targets and assets. A target’s value consists of two components: intrinsic value and dynamic value. Intrinsic value reflects the campaign-wide impact of the survival of the target, while dynamic value represents the immediate capacity of the target to inflict damage on friendly assets. The value of an available weapon asset also consists of intrinsic and dynamic components. The intrinsic component includes the value of all strike and support weapon platforms in their cognate AORs and the dynamic component captures the opportunity cost of diverting the weapon asset from the originally planned AOR mission to a TCT prosecution.

The framework will also support the evaluation of all possible weapon-target pairs. The value of a weapon-target pair if taken as an assignment is the net of an adjusted target value minus an adjusted weapon asset value. The adjusted target value is the target value (defined above) multiplied by the probability of target kill by the weapon asset. The probability of target kill is in turn a function of the probability of weapon asset's safe ingress to the target area, the probability of target acquisition by the asset's on-board sensors, and the probability of target destruction with the weapon load on the asset. For the adjusted weapon asset value, the weapon asset's intrinsic value (defined above) is multiplied by the probability of the weapon asset being killed in the assignment while its dynamic value or the opportunity cost (defined above) will be included in full regardless of the weapon asset being killed or not. The probability of a weapon asset being killed is calculated from the probability of its safe ingress and the probability of its safe egress, both of which depend on the threats present on the asset's flight route.

The ABM will provide guidance in the determination of an optimal pairing plan. With all possible weapon-target pairs evaluated and each assigned with a value, the pairing optimization will be invoked to determine the best assignment of available weapon assets to Time Critical Targets (TCT) so that the overall value is maximized. A generic algorithm will have to be constructed for optimization through variation similar to the problem known in operations research as the assignment problem. During the process of time critical engagement coordination, numerous decisions have to be considered as well as a multiplicity of questions as follows:

-How to allocate resources effectively

-What specific area of concentration

-Payload of the target and where it is headed

-Number of shots and when to take the shot

-Target selection choices and who should shoot at what

-When can the interceptor divert to intercept another target if required?

-Can the interceptor be redirected to intercept other targets within the threat area?

-Was the engagement successful or is there a need to reengage the threat corridor **(MITRE)**

The process can be described in the following functional area of a Threat Priority Evaluation and Weapon Assignment module. The Threat Priority Evaluation and Weapons Assignment will allocate assets to targets, estimate asset damages, and generate a selected number of engagements. ABM force operations will provide each AOR commander a set of areas of responsibility and rules of engagement for operational response to encounterable threats. The ABM will provide commanders an attribute of engagement control which will monitor remote and local engagements. The Threat Priority Evaluation and Weapons Assignment component module utilizes discrimination computation with correlation to determine the best refined technique for neutralizing the threat. This module will consist of the three additional major parts in addition to addressing the threat and engagement.

- Threat Evaluation: associates targets to assets and estimates asset damage using a greedy optimization strategy that is based upon a likelihood function.

- Generate Engagements: a set of candidate engagements is produced using an interpolation method that will take place inside the seven data stores encompass inside the weapon assignment processing component. This will primarily poll each of the kill data stores individually to meet all timing and geometry constraints.

- Select Engagements: selects the set of coordinated engagements which satisfies the rules of engagement within the collective timing and resource constraints.

Once a threat has been evaluated and an acceptable engagement has been determined, the Weapon assignment processing component will transmit the necessary messages to the selected launcher and supporting radar for intercept and engagement. At the same time, there has to be critical communication and precise coordination for the engagement status for follow through. This will play a pivotal role in determining the success of the module. Furthermore, there are other specifications and considerations that should involve determination of actions to be taken which are as follows: weapon type used (conventional or nuclear), Arena in which the actions occurs (strategic or theater), type of action (preempt, defend, deny, destroy, retaliate, etc), and percent of damage expected before constraints. In conjunction, consideration for another tool suggest an assessment tool to further examine attributes of targets in the database such as error radius, hardness, mobility, population density, priority, target class, and environmental conditions.

An additional fielding of a critical characteristic can be broken down inside the target class as follows: mobility (mobile or fixed), type of base (missile, air, or submarine), type of facility (nuclear, chemical, or biological), type of center (command or population), and whether it is a time-critical target or any other fielded element. Under the importance of the target value, ranking can be listed as follows: highest, high, medium and low. **(ELLIS)**

3. Theater Missile Defense (TMD) Systems

The resulting, and current modeling of missile defense programs consists of four systems, three of which (Navy Area excepted) use hit-to-kill interceptors (see Table 1):

a. Patriot Advanced Capability-3 (PAC-3) is designed to intercept missiles at altitudes below 25 km (low-endoatmospheric), acquiring its targets using a radio-frequency seeker.

b. The Navy Area Theater Ballistic Missile Defense (TBMD) utilizes an enhanced Standard Missile for low-endoatmospheric intercept, homing on targets with an infrared seeker. Navy Area TBMD exploits the considerable investment already made in AEGIS cruisers and destroyers equipped with SPY radars.

c. The Theater High-Altitude Area Defense (THAAD) system targets missiles at altitudes above 40 km, both inside (high endoatmospheric) and outside the atmosphere (exoatmospheric). THAAD is a ground-based system using infrared terminal guidance.

d. The Navy Theater-Wide (NTW) TBMD system intercepts missiles exoatmospherically (at altitudes in excess of 100 km), also using infrared homing and AEGIS sea-basing. The combination of the NTW and THAAD programs together will determine the future system that excels overall in program performance becoming the lead upper-tier system.

TMD System	TMD Capability	First Unit Equipped (est.)
PAC-3	Low-endo intercept	2001
Navy Area TBMD	Low-endo intercept	2003
THAAD	High-endo/exo intercept	2007
NTW TBMD	Exo intercept	2007
Airborne Laser	Endo/exo intercept (boost-phase)	TBD

Table 1. Active Missile Defense Systems and Capabilities

The core program consists of only land and sea components. Beyond these, the lead air component is the Airborne Laser (ABL), a Boeing 747 with a high-powered chemical laser capable of intercepting ballistic missiles during boost. Endoatmospheric intercept of the burning rocket booster is planned; exo-atmospheric intercept of the booster should also be possible, provided it continues burning above the atmosphere.

The effectiveness of the weapon assignment module will contribute significantly toward threat defense. A solution with continuous coverage of enemy missiles, from ascent through late midcourse, would require fewer interceptors than a single-layer or discontinuous system to achieve the same results. If each successive layer can, on cue, concentrate on targets that leak through previous layers, the number of interceptors per target can be reduced without reducing confidence. In addition, the mobility of the solution's boost-phase and early midcourse components would permit the surging of the system to concentrate on suspected threats. Based upon the fielding needs, a system of systems would offer more distinct technological options to improve kill probability in one or another layer, thus reducing the need to respond to more threats with proportionally more interceptors.

With stability within the ABM framework, subsequent efforts can be focused toward the threat. Research shows that a boost-phase intercept, when feasible, is the surest way to defeat most countermeasures because of both the opportunity to intercept before most countermeasures can be employed (especially sub munitions) and the bright booster rocket plume that facilitates target acquisition. The early midcourse component also helps by providing advantageous intercept ranges, angles, and relative velocities (i.e., slower than head-on).

A "system of systems" can be based on three synergistic layers:

1) Fixed U.S.-based defense, to ensure protection of the highest-value target--the homeland--even without strategic warning.

2) At the other end, deployable (with strategic warning) boost-phase intercept, to kill threatening ballistic missiles, of most any range, when they are first detected and before most countermeasures can be employed.

3) Bridging the two ends, a flexible, deployable element capable, with modest warning, of contributing at either end and of intercepting ballistic missiles in early midcourse.

The elements of this system of systems, and actual missile defense operations, can be integrated by a common, mainly space-based sensor and BMC3 system.

While the ABM structure will divide the world into well defined regional areas of responsibility, long range missiles do not necessarily remain inside those boundaries, nor do the sensors, interceptors, and communications infrastructures of a multilayered defense system. Since the ABM will focus as a global system of layered defenses, defense assets are not confined to a single region of the world. The ABM shall direct focus toward rules of engagement development from regional combatant commands and all the military services to develop and refine tactics, techniques, and procedures to counter a ballistic missile attack. Defense engagement execution will remain largely decentralized. The ABM will demonstrate a layered missile defense system that is intended to engage threat missiles of various ranges in various phases of flight. Those phases of flight will be able to employ the different types of interceptors that operate across many time zones and geographic region which may require additional operational integration. A reasonable decision of allowing the selected weapon platform to defend against a missile through its entire flight with multiple shot opportunities at different points in the flight of the missile might present another concept of advantage but has not been visited due to push for coordination of jointness.

Another interesting aspect of the ABM framework is the linking of missile elements on weapon platforms that act in conjunction with one another to provide enhanced precision solution computation and gives an efficient application of missiles assets toward the engagement of single and multiple targets. The ABM must monitor battle space within and outside every AOR and AOR commanders must be able to conduct battle operations while still maintaining situational awareness and effectively assess resources and support dynamic planning. The ABM must provide for execution of defensive, offensive and passive defense operations in support of missile defense mission. In the case of defensive operations, the AOR commanders should recognize and be able to select the best available means to engage the incoming threat throughout its flight profile, including re-engagements. Additionally, AOR commanders should be trained to perform threat evaluation and weapons assignment in accordance with ABM framework to accomplish execution of operations. AOR commanders will choose either the centralized or decentralized method of operations, recognizing such factors as the level of command interest, threat, current situation and involvement of multiple services or agencies. They will become proficient in knowledge of the ABM and its automated battle management aids during engagement sequences.

The AOR commanders must also identify attributes of whether there is an attack operations solution to respond to the air and missile threat. Through practice, the AOR commanders determine if the point of origin or other threat-related target such as infrastructures are engageable through attack operations options. If so, they will propose the selection of the best available attack operation option, including preplanned or dynamic targeting, and then monitors the attack engagement. After the attack, they will perform a re-attack assessment and select the best available re-attack option, if necessary. To fulfill this responsibility, AOR commanders will have to be well versed in offensive counter air operations.

ABM system knowledge must cover positioning or repositioning of resources, force protection, sensor coverage, weapons coverage, asset protection, post-engagement debris fall-out, communications ranges and logistics support in order to provide sound recommendations for execution of the missile threat or mission. If the ABM prioritize the threat and concludes that an enemy missile is going to hit a high value target, the system will choose to engage it with one of the many systems from the multiple weapon launch platforms. If there is a target that is a threat but no longer worth defending (destroyed earlier) it will not defend against it. The ABM must decide how many missiles it is willing to assign against an incoming missile threat.

The individual potential weapon launch platforms are critical and necessary to the support countering the threat and upholding operations. The weapon assignment portion of the ABM will present a dynamic defense in depth which will be fought across time and distance, engaging the enemy in every phase of their operations throughout the battlespace. Combined joint forces will engage the enemy as a functioning system, overcoming defensive tendencies to react to the enemy as a collection of independent threats. The dynamic defense in depth will again key on the windows of opportunity to disrupt or destroy the enemy's processes. The in-depth defense will aid in the synchronization of countering the threat of operational elements in decisive, high-tempo tactical operations. AOR commanders and their forces integrate their tactical actions, implementing the guidance and requirements from centralized planning.

B. CONCLUSION

Since the ABM will cross many layers of defense, weapon launch platforms must conduct prompt in-depth, decisive action against theater missiles in flight. Layering is particularly important to effective active defense, and increasingly extends to long distances inland and to exoatmospheric space. Ideally, forward-stationed Aegis ships and combat aircraft will promptly engage theater missiles in enemy airspace, primarily through network supported coordination utilizing air-to-air or surface-to-air missiles. In addition, weapon platforms that are designated as the first line in multiple engagement opportunities encompass the capability to use stand-off, long-range weapons effectively enabling prompt and early engagement. Ascent phase interception by Navy Theater-Wide interceptors is the most effective active defense against long-range TBMs. Fighters may be positioned anywhere between the source of the threat and the protected forces and assets. Armed with long-range, mid-range, and short-range air-to-air missiles, majority of the launch platforms will form an exceptionally flexible, strong defense when supported by long-range air surveillance and electronic warfare assets. Surface-to-air missile systems from Navy surface combatants and Marine or Army ground forces also cover a significant portion of the airspace between enemy airbases and launch positions and defended forces and assets, combining dispersed, often overlapping capabilities for point defense and area defense against all threats. The weapon assignment processing component of the ABM will ensure prompt engagement of enemy missile threats and will extend attack operations into the launch and post-launch periods. Defense measures have to be taken by AOR commanders in the targeted area focusing on detecting attacks and providing timely warning.

Therefore, there is a tremendous need for timely and responsive command, control, and communications for target assignment, defense weapon release, damage assessment, and reassignment if necessary. The time available for a space based element to react during the boost phase may be so short that only the speed of an automated response will do.

III. AEGIS

A. SEA-BASED SYSTEMS

In the U.S. there are two different naval TMD programs: Navy Area Defense and Navy Theater Wide. Navy Area Defense is mainly designed to protect military forces, airfields, ports and other valuable assets. Its weapon systems are for lower-tier defense. Missiles for this program are already in service such as the Standard Missile-2 (SM-2) which has been modified for improved capabilities. Navy Theater Wide is under development and will be able to destroy enemy ballistic missiles at altitudes higher than 100 km. For this purpose the Standard Missile-3 (SM-3) and Airborne Laser (ABL) is being developed. The ABL will destroy TBMs during their boost phase. Interceptor missiles can be either the THAAD or SM-3 missile. The future role of the navy in TMD hinges on successful tests.

B. BACKGROUND

Coalition experience in Operation DESERT STORM in combating the SCUD Theater Ballistic Missile (TBM) was ineffective and seriously jeopardized the cohesiveness of the coalition. In spite of a well-conducted air campaign using a thoroughly compiled target list in complete air superiority, an estimated 90 SCUDs were launched against coalition forces in Saudi Arabia and at Israel. To keep the Coalition together, thirty percent of the theater's allied tactical aircraft assets were shifted from battlefield air interdiction missions supporting the land campaign, to locating and attacking SCUD launch vehicles. Destruction of a TBM launch vehicle by a tactical aircraft was unseen and not accomplished. Additionally, post-war analysis of the active TBM defense by the PATRIOT missile system revealed interception rates far below what was first claimed. Because of their substandard construction and the modifications necessary to achieve an increased range, Iraqi SCUDs were unbalanced in their downward flight. Their erratic, corkscrewing descent caused many TBMs to break into fragments and self-destruct, inadvertently confusing the ground radars. Those that didn't break up were particularly difficult to intercept due to their unintentionally effective, maneuvering, final flight path.

1. Overview of Missile Defense from the Sea

Since most of the Earth's surface is covered by water, ships carrying interceptors can cruise to locations that are in reach of almost every potential trouble spot. The U.S. Navy's current fleet of Aegis cruisers already deployed around the world could be quickly ordered to various locations to establish a defensive shield between hostile states and the countries they threaten with missile attack. Using them would present relatively few political problems if the need arose to deploy such defenses during a regional crisis.

Stationed near the coasts of potentially threatening states, these ships could intercept and destroy enemy missiles in the ascent phase and in some cases in the boost phase of their trajectory. In the open seas, they could target enemy missiles in their mid-course phase. Deployed close to home or near the coastlines of America's allies, they could hit incoming missiles or warheads at the terminal phase of trajectory. Each phase presents different defense opportunities as well as different threats and risks.

Sea-based systems offer the most cost-effective protection from ballistic missiles and are the most readily available because the U.S. Navy already has cruisers deployed that are capable of fielding these systems. The earliest, least expensive way to achieve a global defense would be to build upon the nearly $50 billion that the United States has invested in the Aegis system to provide defense against enemy aircraft and cruise missiles.

The Aegis system will provide protection against missile attacks for a limited area with the Navy Area Wide Defense program. For maximum effectiveness, the Aegis system would need to exploit targeting information obtained from radar and other sensors that are not located with the interceptors, such as space-based sensors. This will aid with the interceptors launched from Aegis cruisers whether in the Sea of Japan, the Mediterranean Sea, the North Atlantic, or the North Pacific could successfully intercept intercontinental-range ballistic missiles launched from North Korea, North Africa, or the Middle East toward targets around the world, including the United States.

2. Aegis Concept of Operation

The MDA and the USN are jointly developing Aegis BMD as part of the Ballistic Missile Defense System (BMDS). To date, eight Aegis destroyers from a planned total of 15 have been upgraded with a Long Range Surveillance and Tracking (LRS&T) capability, while two Aegis cruisers have been outfitted with the LRS&T upgrade and given an emergency engagement capability against short- and medium-range ballistic-missile threats using the Aegis BMD Weapon

System and the SM-3 . A third Aegis cruiser will be given the same upgrade. **(JANES)**

3. Advantages of Sea-Based System

Sea-based TMD systems have several advantages over land-based systems. They are flexible and can be deployed outside territorial waters without the co-operation of a host nation and also without necessarily raising international tensions. At the same time they can cover a vast area of land. These systems consist of a combination of:

- missiles (for air warfare and for destroying launch stations),
- combat data systems (for processing incoming information from satellites, early warning aircraft and the ships' own radar systems),
- radar technology (for finding the TBM and guiding the missiles to their targets).

The ground-based system will be more expensive than a sea-based option because it would have to be built from the ground up. The sea-based option takes advantage of the significant investment America already has made in the U.S. Navy's fleet of Aegis cruisers. The long range ground-based system will be less effective because it must intercept warheads in space while they are traveling at their greatest velocity but after they could release their decoys. The military would have only one opportunity to shoot down the missile before the terminal stage. Sea-based defenses can be forward-deployed near potentially hostile sites to shoot missiles down during their ascent phase - when they are most visible, not yet up to optimum speed, and have not released their warheads or decoys. Moreover, should the first attempt fail, there is still time to launch a second or even third intercept attempt. Because of their mobility, ships can respond to changing world conditions.

4. Sea-Based Defense Attributes

According to international law, a U.S. warship is sovereign U.S. territory. This simple fact remains constant wherever the vessel operates. A warship operating in international waters is not hindered by many of the political constraints and over flight restrictions that may interfere with ground-based or air operations. Normally, ships stationed offshore are not obtrusive; as conflicts erupt, ground based forces, which are very visible may potentially escalate conflicts. Naval forces are truly expeditionary in nature. Although the other armed services flaunt this same capability, the fundamental difference is the Navy-Marine Corps performs this function through forward presence instead of continental U.S. based assets. As the U.S. continues to withdraw from overseas bases, naval forces will play a vital role in potential crisis situations. Navy surface combatants normally operate in potential threat areas, or can be rapidly repositioned to crisis areas. These forces are self-sufficient and can remain on station indefinitely.

More than seventy-five percent of the world’s land mass is bordered by water. Many of the areas are located where future conflicts are likely to materialize and are within the Navy’s capability to project power. The U.S. usually recognizes a 12 nautical mile (nm) territorial sea limit which means that Aegis surface combatants operating in a near land environment can be stationed closer to anticipated TBM launch points or predicted impact points.

C. PAST HISTORY AND WHY AEGIS IS A SOUND ASSET

The Navy TBMD program maximizes the use of existing technology and past investments in the Aegis, Standard Missile and command and control (C2) systems infrastructure. The nation has already invested billions of dollars in the production of 22 Aegis cruisers and more than 30 Aegis destroyers. The Standard Missile SM-2 Block IVA missile used for TBMD is a modified Standard Missile the Navy had already procured for TAD. The various blocks of Standard Missiles have been the Navy’s primary surface-to-air weapon for over 30 years and represent a 1 billion dollar investment. Aegis ships have state of the art C2 suites initially designed to support large scale, blue water air wars. The TBMD mission is an extension of the Aegis surface combatant’s primary role – air defense. Therefore, there will be no requirement for additional manning, training or logistics to support this mission.

1. Standard Missile

The Aegis Weapons System, with its Standard Missile, provides a robust area Anti-Air Warfare (AAW) capability against threat aircraft and Anti Ship Cruise Missiles (ASCMs) when conducting operations in the littoral areas. By providing this Area AAW shield, the Standard Missile is the enabler for operations close to land. For example, Aegis cruisers and destroyers can engage the F-1 Mirage aircraft and its electronic jamming techniques using the SM-2 Block IIIB missile at ranges up to 80 nm. If the Mirage launches ASCMs such as the Exocet, the SM-2 is relied upon to decrement the incoming raid by one half prior to engagement by self-defense weapons systems.

The SM-2 Block IV is an extended range variant of the Standard Missile that has reached initial operational capability (IOC) since FY99. The Block IV can engage threat aircraft and ASCMs at ranges up to 100 nm. It can engage stand off jamming aircraft beyond 100nm. It will also provide an increased capability against maneuvering ASCMs over earlier Standard Missile variants.

Both the SM-2 Block IIIB and the SM-2 Block IV missiles build on the foundation of excellence that has been proven reliable and in good standing with respect to the Standard Missile family. The SM-2 Block IIIB completed final operational testing and evaluation with a “grand slam of sorts” – 9 for 9 hits against incoming targets. The missiles weren’t special missiles; they were production missiles which are the types being fielded today. The Block IV missile has completed testing and initial operational capability (IOC).

2. Theater Ballistic Missile Defense

Positioning theater ballistic missile defense at sea can provide deterrence and war winning leverage. Capitalizing on the inherent flexibility of surface ships, TBMD at sea frees us from the need to provide land-based terminal defenses around every potential target we wish to protect. In the littoral, on-scene surface combatants can immediately influence events because they are combat ready and can sustain themselves independent of host nation support. In short, forces are position in a way to provide the most effective coverage against any encounter.

3. Navy Area TBMD

The mission of the Navy Area TBMD system is to provide US and allied forces, as well as areas of vital national interest, defense against TBMs. In support of forcible entry and sustained ground combat operations, such as those associated with an amphibious landing, Navy TBMD forces provide the earliest capability when the heaviest TBM attack intensity is likely and when other TBMD systems are still enroute or are only present in limited numbers. The Navy Area TBMD System will provide protection against short and medium-range TBMs for debarkation ports, coastal airfields, amphibious objective areas (AOAs) and expeditionary forces as they move from the sea towards their objective ashore. The Navy Area TBMD program consists of modifications to the AEGIS AN/SPY-1 radar to enable detection, tracking and engagement of TBMs using a modified SM-2 and minor changes to existing C2 systems. More than 50 AEGIS cruisers and destroyers are at-sea or under construction and the support, training and logistics infrastructure is already in place and operating. The plan includes:

- Software/firmware modifications to AEGIS Combat System including SPY-1 radar

- Development of changes to the SM-2 missile by incorporation of an infrared seeker, an improved fuze and modified warhead section to create the Block IV-A variant

The computer program and equipment installations have been completed as well as successful sea trials.

4. Navy Theater Wide TBMD

The Navy Theater Wide (NTW) Program builds upon the modifications to the AEGIS Combat System that provide Navy Area System capability, but provides fundamentally different and yields unique capabilities. Specifically, it is capable of exoatmospheric and ascent phase intercepts and has a vastly greater defended footprint. This Theater-Wide capability will enable AEGIS ships operating near launch areas to fully exploit their mobility, endurance, and forward presence to defend U.S. forces or allies in key world regions. The large defended operational areas afforded by NTW result in extensive flexibility for the joint commanders for their AOR's in accomplishing TBMD. A few ships can simultaneously protect many critical assets in the theater of operations as well as provide defense against longer ranged TBMs fired elsewhere. The NTW system provides a defensive overlay for Navy Area and land based TBMD systems. This overlay yields the opportunity to use layered defense for high value assets and target areas critical to achieving the C2BMC objectives. This will yield high cumulative kill probability where it is needed most and the flexibility to provide significant protection over much of the theater. This is especially important where mobile forces may move out from under the less mobile land based TBMD umbrella. Where geography or threat capabilities preclude forward placement of ships, external cueing from space assets or ground based radars enable employment of NTW over large operational areas. Engagements are possible with midcourse ship locations and terminal ship locations. For longer threat ranges, ships must be located closer to the defended areas to support engagement. However, even in these locations, NTW yields shoot-look-shoot opportunities when supported by Navy Area or ground based TBMD systems. **(SENATE)**

Aegis Ballistic Missile Defense (Aegis BMD) will provide an efficient and highly mobile sea-based defense against short- and medium-range ballistic missiles in their midcourse phase. At present, each Aegis cruiser and destroyer is outfitted with the Aegis Weapon System—the heart of which is the AN/SPY-1 radar system. AN/SPY-1 sends out beams of electromagnetic energy in all directions, thus allowing Aegis ships to track up to 100 targets simultaneously, while still retaining the ability to counter other air, surface, and submarine threats. AN/SPY-1 will be able to detect ballistic missiles as they rise above the horizon. Once a hostile missile has been detected, Aegis BMD will launch its Standard Missile-3 interceptor from its MK41 Vertical Launching System (currently deployed on Aegis cruisers and destroyers). Once close enough to the ballistic missile, the SM-3 will fire its kill vehicle, the Kinetic Warhead (KW), from its nosecone. The KW will immediately begin to search for its target. It will acquire the ballistic missile using a high-resolution seeker, and maintain an accurate trajectory using its internal navigational system. As it closes on its target, the KW will identify the missile's payload, and shift its aim point to ensure a lethal hit. When the KW finally slams into the enemy warhead, the kinetic energy of the high velocity impact will ensure complete destruction of the threat.

D. OPERATING RULES OF ENGAGEMENT

"ROE should not delineate specific tactics, should not cover restrictions on specific system operations, should not cover safety-related restrictions, and should not set forth service doctrine, tactics, or procedures. ROE should never be 'rudder orders' and certainly should never substitute for a strategy governing the use of deployed forces, in a peacetime crisis or in wartime." **(Roach)**

Naval Warfare Publication 1-14M, *The Commander's Handbook on the Law of Naval Operations*, states that "U.S. rules of engagement reaffirm the right and the responsibility of the operational commander generally to seek out, engage and destroy enemy forces consistent with national objectives, strategy and the law of armed conflict."**(Commander)** ROE are shaped by operational, political, legal, and diplomatic forces, and thus tend to evolve as these forces change over time. The unique operational and political characteristics of theater ballistic missiles will have a signal impact on the evolution of rules of engagement crafted to counter them. Rules of engagement for theater ballistic missile defense must be shaped by the unique nature of the threat. The high velocities attained by TBMs and the potential consequences of WMD warhead use argue the need for very rapid, if not automatic, engagement. Normally, the counterargument set in opposition to such a permissive and deadly defensive environment involves the challenge of deconfliction, how best to prevent the possible engagement of friendly assets.

However, the very kinematics that makes TBMs such challenging targets also aid deconfliction. Quite simply, unlike civilian and military aircraft, there is no such thing as a friendly incoming TBM.

1. Near Land Stationing Concerns

Placing a ship as close as possible to the area to be defended could be a promising tactic provided that the commander is certain that the country or city in that area is the only one targeted by the enemy's TBMs. Located within an inshore position, the AEGIS system does perform well, but the inherent mobility of a warship could possibly be lost.

The placement of a ship close to a single area is far from optimum, however, because at least one ship would be required for each area defended and the debris from successful engagements could fall on friendly, heavily-populated ground. Unfortunately, despite a successful intercept, Weapons of Mass Destruction (WMD) could still be effective against the target countries, cities and population if intercepted too close to the target.

2. Distant Stationing Concerns

Stationing a ship farther from the city defends a much greater area, has the potential for more kills, and allows for debris and the harmful effects of WMDs to fall into the sea, away from friendly territory. Distant from land, a ship may be able to support joint operations, other phases of the naval campaign and joint operations and would be free to maneuver to avoid and combat other attacks, especially by enemy submarines that prey on ships whose maneuvers are too predictable.

E. AEGIS ROLE IN GLOBAL BALLISITIC MISSILE DEFENSE

Over the years, MDA has conducted seven SM-3 flight tests. Out of those seven, six have been successful. The most recent test involved for the first time a “separating” target, meaning that the target warhead separated from its booster rocket. Previous tests were against unitary (non-separating) targets representative of “SCUD”-type ballistic missiles. The Aegis system is the maritime component of the Ballistic Missile Defense System and is designed to intercept and destroy short to intermediate-range ballistic missiles. The intercept used “hit to kill” technology, which means that the target warhead was destroyed when the missile collided directly with the target. President George W. Bush has called on MDA to deploy a preliminary defense shield—including sea-based assets. In September 2004, the Navy deployed an Aegis destroyer in the Sea of Japan capable of detecting and tracking missile launches from North Korea and China. In the event of a hostile launch, the destroyer will be able to transmit data to ten ground-based interceptors located in Fort Greely in Alaska and Vandenberg Air Force Base in California (which have been initially deployed since September 2004). During the year of 2005, the first fully operational Aegis BMD system has been deployed on an Aegis destroyer. MDA will conduct rigorous tests, using this initial deployment to integrate the AN/SPY-1 with SM-3 and improve the accuracy of the interceptor.

In 2006, the Navy will deploy nine Aegis ships outfitted with SM-3 missiles and configured to carry out ballistic missile defense operations from almost anywhere in the world. During this initial deployment phase, Aegis BMD will provide a cost effective means of countering emerging threats from rogue nations and terrorists. MDA’s long-term goal is to transform Aegis BMD into a comprehensive missile defense system capable of destroying intercontinental ballistic missiles (ICBMs), possibly in their boost phase. As MDA improves its layered missile defense system, Aegis BMD will be able to integrate its tracking system with other new BMD tracking systems such as Space-Based Infrared System-High (SBIRS-High) satellites, the Space Tracking and Surveillance System (STSS), or the Sea-Based X-Band Radar (SBX). MDA and the Navy are also considering the development of a larger and faster interceptor missile. **(MISSILE)**

IV. PATRIOT

A. INTRODUCTION AND BACKGROUND

In spite of the overwhelming victory during the Persian Gulf War, the United States and its coalition partners were essentially defenseless against Iraq's unguided, short-range theater ballistic missiles (TBMs). Although militarily insignificant, SCUD missiles proved to be a potent political tool. In one incident alone, 27 American soldiers were killed when a SCUD hit a barracks in Dhahran, Saudi Arabia. Some post-war studies suggested that the Patriot missile defense system, which was based on a recently modified anti-aircraft surface to air missile, was only marginally successful in defending against the majority of SCUD attacks. **(POSTOL)** Fragments of Iraqi SCUDS, intercepted by Patriot interceptor missiles, fell on U.S. and allied territory. If Iraqi SCUD missiles had been armed with nuclear, biological, or chemical (NBC) payloads, even successful intercepts would surely have changed the nature of the war.

The employment of ballistic missiles has new strategic implications because of the events of September 11, 2001. The global war on terrorism involves the newly defined “axis of evil,” composed of states capable of producing ballistic missiles. Missile technology transfers to third world countries threaten world stability, in view especially of the possible use of nuclear, chemical or biological warheads. If rogue states judge previous missile attacks to be successful, such “success” could motivate other leaders or terrorists to use their missiles as instruments of terror.

B. HISTORY OF PATRIOT

The Patriot surface-to-air missile system is currently operational with the U.S. Army and several allied nations. The Patriot program was initiated in 1965, but not fielded until the early 1980s. Designed to replace the HAWK and *Nike* systems, Patriot was initially intended to intercept only air-breathing threats. Each Patriot battery consisted of: one radar, eight launchers, 32 missiles and an environmental control station (Patriot's central nervous system). It is important to note that Patriot's phased-array radar did not provide 360-degree coverage. Patriot units tried to compensate for the limitation by overlapping radar coverage with other units, and predicting likely avenues of attack when positioning their radars. The Patriot system has undergone a series of upgrades called Patriot Advanced Capabilities (PAC). Shortly before *Desert Shield* a modernization program was initiated to improve the system's capabilities to intercept theater ballistic missiles. Patriot upgrades have continued since the Gulf War.

Air operations were not the only means used to counter the Iraqi missile threat. The difficulties in hunting Scuds from the air were only part of the problem. Ground based air defenses, in the form of Patriot surface-to-air missiles, were an integral part of the overlapping air and missile defense capability deployed in the theater during Desert Shield.

For the first time in history, the Allied coalition used a defensive missile to intercept and destroy an incoming ballistic missile. The Patriot, which was originally designed as an anti-aircraft weapon, was adapted to shoot down ballistic missiles targeted at key cities and military targets. Its success, more than any other measure, limited the intended effects of Hussein's terror missiles. Hussein launched seven SCUDS' at Tel Aviv on the second night of the Gulf War, which terrorized Israeli civilians. On the same night, four Patriots intercepted a SCUD launched at Dhahran, Saudi Arabia. Israel had refused Patriots from the United States prior to the war. The act assisted in demonstrating the effectiveness of the anti-ballistic missile system preventing Israel from retaliating against Iraq. As a condition for Israeli agreement not to retaliate against Iraq, the United States immediately shipped thirty-two Patriots and their crews to Israel.

Throughout the remainder of the war, those Patriot missiles successfully intercepted all threatening SCUD's fired at that country. The Patriot system allowed SCUD's to crash into the sea or desert if they posed no threat to civilians. The system had a valuable psychological impact on the people it protected. The Allied engagement doctrine for the Patriot missile was to fire at least two missiles at threatening SCUD's and to allow non-threatening ones to explode harmlessly into the Persian Gulf or the desert. Of the ninety missiles fired at Saudi Arabia and Israel, American crews determined that forty-seven were threatening and fired 158 Patriots to intercept them. Initial analysis showed that Patriots intercepted forty-five of those forty-seven SCUD's for an engagement success rate of 96 percent. The Patriots were designed to defend point targets such as airfields and ports, not entire cities. They suffered mixed results in fending off the Scud attacks; in many cases intercepting Patriots deflected the incoming Scuds, leaving the warheads and debris to rain down on Israeli and Saudi cities.

It is worth noting, however, that after the war a debate developed over the effectiveness of the intercepts in destroying the SCUD warheads and whether or not the SCUD and Patriot debris had caused as much damage as the SCUD warhead would have. The psychological effects of the Patriot elevated Allied and Israeli morale and neutralized Hussein’s attempt to terrorize them into a political settlement of the conflict.

C. PATRIOT PROGRAM OVERVIEW

Patriot Missile Defense System has been an important part of our air and missile defense. However, in recent years the Patriot system has become even more integral to our Theater Missile Defense (TMD) plan. Today it is considered to be a core TMD program, with one of the highest priorities in the development of Ballistic Missile Defense (BMD) systems. The Patriot Advanced Capability-3 (PAC-3) mission is part of the lower tier of the BMD architecture. This includes defending troops and fixed assets from short and medium range ballistic missiles, CMs, and other ABTs such as fixed or rotary wing aircraft. To accomplish this mission, the PAC-3 system added the capability to destroy enemy threats with hit-to-kill accuracy in the terminal phase of the threat missile’s flight. The PAC-3 system is planned to be interoperable with other Army and Joint systems, to provide a seamless missile defense in depth, and to be air transportable to support rapid deployments. PATRIOT is the only fielded, combat proven, Theater Missile Defense System.

Patriot missile does not have to hit the enemy warhead in order to destroy it. Each Patriot missile contains a fuze, which senses the presence of a target, and a warhead with metal fragment to disable or destroy the target and an explosive to propel the fragments to the target. When the Patriot missile flies close enough to the target to cause the Patriot’s fuze to issue a detonation order, the fragments are propelled at high velocity toward the target. The Patriot fragments that do not cause the target’s warhead to explode can damage the warhead to the extent that it will either not explode or will not explode with full force when it hits the ground or will go off course.

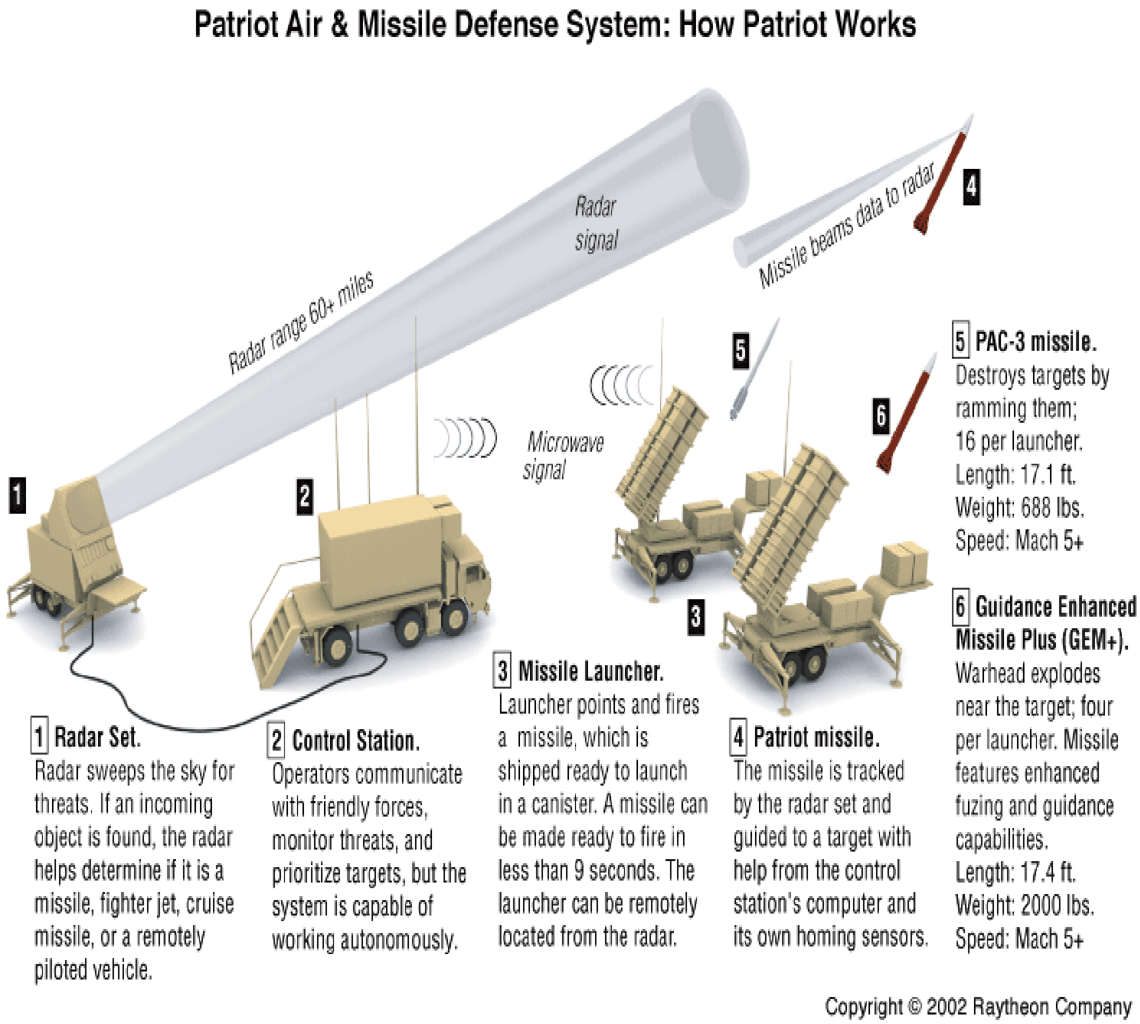

Figure 2: Patriot System

The Patriot Firing Battery (FB) consists of eight major items of Patriot equipment (see Figure 2). (1) The Engagement Control Station (ECS) is the operational and maintenance control center of the FB. (2) The Radar Set (RS) is the multifunction phased array radar that is remotely controlled by the ECS operators. (3) The Launching Station (LS) is used to transport, aim, and launch various types of Patriot Guided Missiles (GMs). (4) The Antenna Mast Group (AMG) is the mobile antenna mast system used to carry the amplifiers and antennas associated with the

Ultrahigh Frequency (UHF) communication systems in the ECS. (5) The Electric Power Plant (EPP) is the prime power source for the ECS, RS, and AMG. (6) The Battery Command Post (BCP) is the Command, Control, Communications, Computers, and Intelligence (C4I)/weapon system interface to other battlefield non-real-time digitized information systems and provide mission planning and monitoring capability to the FB. (7) The Patriot GM is mounted in a canister, which functions as a shipping and storage container and as a launch tube. (8) The Battery Maintenance Group (BMG) consists of the Battery Maintenance Center (BMC), Large Repair Parts Transporter (LRPT) and the Small Repair Parts Transporter (SRPT).

The single, multifunction phased array radar performs the following functions:

- High- and Low-Altitude Surveillance
- Target Detection
- Target Discrimination
- Target Identification
- Target Track
- Missile Track
- Missile Guidance (uplink/downlink)

The missile is command-guided by the radar to a point just prior to intercept. At that point, unique TVM guidance begins for the pre-PAC-3 missiles, or the active PAC-3 missile seeker begins to track the target. The RS sends out a special waveform that illuminates the target. The RS also sends an uplink message that commands the missile to open its receiver for detection of reflected TVM waveform energy from the target. The pre-PAC-3 missile encodes and sends bore-sight errors via downlink messages back to the RS. Guidance computations are then made in the ECS and sent back through the radar to the missile via uplink messages. This process continues until intercept. This automated operation provides firepower at saturation levels many times greater than older systems, in addition to a multiple simultaneous engagement capability. At the same time, Patriot permits a substantial reduction in manpower for any given defense level. Standardized circuit modules, Built-In Test Equipment (BITE), and automated diagnostics, along with fewer system-peculiar major items, provide a significant improvement in availability and maintainability for lower operating costs. Additionally, the system has a remote launch capability of 10km (Phase 1). Using a CRG as a Remote Launcher Group (RLG), the FB can provide expanded asset coverage to approximately 30km (Phase 3). During the first quarter of 2000, the Patriot system successfully performed an extended remote launch engagement.

D. PATRIOT ADVANCED CAPABILITY-3 EVOLUTION

PAC-3 was developed through a series of evolutionary phases which consisted of three increasingly sophisticated configurations. These phases were implemented by a series of preplanned, incremental, and complementary improvements fielded with supporting hardware and software. Collectively, these improvements were required to execute Air Defense Artillery (ADA) missions in support of operations against current and evolving third dimension threats. The integration of the PAC-3 missile into the Patriot system required modification to the Engagement Control Station (ECS), Radar Set (RS), Communication Relay Group (CRG), and Launching Station (LS). These changes increased battlespace, improved accuracy, and enhanced lethality against all types of TBMs. The improvements also enhanced the ABT missions by increasing the detection and engagement of LRCS ABTs and TBMs, aircraft flying in clutter, and intense ECM environments. Classification, Discrimination, and Identification (CDI) was also added, allowing the Patriot system to effectively fight in a joint (two or more U.S. Armed Forces) or combined (U.S. Armed Forces and one or more Allied Forces) air defense operations environment, positively identifying ABT's and classifying and categorizing TBMs, aerodynamic warheads, penetration aids, and debris.

1. PAC-3 Configuration 1

Configuration 1 was the first step toward achieving a true PAC-3 system. It consisted of a number of improvements, especially in Battle Management, Command and Control, Communications, and Intelligence (BMC3I). It also incorporated the Guidance Enhanced Missile (GEM) which increased lethality. Configuration 1 consisted predominantly of hardware modifications, primarily to support future system growth. These hardware changes provided improved system Reliability, Availability, and Maintainability (RAM). The changes include the GEM, Expanded Weapons Control Computer (EWCC), Optical Disk System (ODS), Embedded Data Recorder (EDR), Precision Lightweight Global Positioning System Receiver (PLGR), radar enhancements, automated logistics system, and operations and training software improvements.

2. PAC-3 Configuration 2

This configuration incorporates several major improvements to include Precise Time of Day (PTOD), Communications Enhancement (CE) Phase I, Counter Anti-radiation Missile (CARM), CDI, Post Deployment Build-4 (PDB-4), and PDP.

3. PAC-3 Configuration 2+

This is an interim configuration that incorporates change to the currently fielded Configuration 2 RS in order for the Configuration 2 FBs to run Configuration-3 PDB-5 software. The RS changes include upgrades to the memory in the Signal Processor Group Input/Output Control (SPG IOC) and to the memory in the Control Unit Group (CUG) digital data processor. BY CY02, all U.S. Patriot units had been upgraded to Configuration 2+. This allowed for standardized Patriot training and for system compatibility.

4. PAC-3 Configuration 3

Configuration 3 is the final phase in a series of changes to the Patriot system to meet the PAC-3 program requirements. This configuration consists of several hardware modifications, a new missile, and the fielding of the PDB-5+ software. The PAC-3 program provides enhanced system performance against advanced air and missile threats, both TBMs and ABTs. These changes are designed to improve the search, detection, and tracking capabilities of the radar; improve communications within the battalion; improve interoperability with joint forces; enable TBM launch point determination; and, finally, increase lethality against TBMs. In addition, these modifications provide increased system RAM and improve operator interface functionality and situation awareness. The software build was developed to support the hardware modifications and user requirements for the PAC-3 program. This software is comprised of those changes necessary to support the Configuration-3 hardware modification, such as Radar Enhancement Phase (REP)-3, CDI Phase 3, Remote Launch

Communications Enhancement Upgrade (RLCEU), and the PAC-3 missile-integration.

E. SUMMARY OF PAC-3 ATTRIBUTES

The following list and Table 2 **(BARBERA)** shows the changes and attributes being made to Patriot by the PAC-3 upgrades.

- **Detection and engagement of lower radar cross-section (RCS) targets -** The threat includes lower RCS theater missiles (TMs) and aircraft flying in clutter and intense electronic countermeasures (ECM) environments.
- **Classification, discrimination, and identification (CDI) -** To effectively fight in a joint and combined air defense (AD) operations environment and discriminate targets requires Patriot to positively identify air-breathing threats (ABTs), and classify or categorize tactical ballistic missiles (TBMs) and aerodynamic missiles. Additionally, the Patriot radar discriminates between valid targets and penetration aids or debris.
- **Increased firepower and lethality -** To respond to a growing threat that is capable of conducting massed ABT, integrated ballistic and aerodynamic missile raids. Increasing multiple simultaneous engagement and track handling capabilities, buy back required designed battlespace and defense effectiveness against stressing and sophisticated threat Survivability. Patriot upgrades must counter growing lethality on the modern battlefield and advances in enemy reconnaissance,

intelligence, surveillance, and target acquisition (RISTA).

- **Force synchronization/integration -** Patriot must interoperate with other battlefield operating systems (BOS) and have compatibility with future Army, joint, and combined command, control, communications, computers, and intelligence (C4I) architectures.
- **Extended range -** Patriot must operate at extended ranges to disrupt enemy use of the airspace in the theater battle space.
- **Patriot-Terminal High Altitude Area Defense (THAAD) task force operations -** Patriot when coupled with THAAD, will form an air and missile defense task force (AMDTF). Patriot communicates with THAAD over the TADIL-J network. Patriot software improvements to the ICC allow processing a new set of TADIL-J TBM tracks and TBM engagement coordination messages between upper and lower tier. Integration of AMDTF defenses is an evolutionary step forward to protect the force against the expanding threat.
- **Training software -** Improvements to TPT, OTM, and LAT scenarios provide more realistic training for ICC and ECS operators. Enhanced ARM and TBM scenarios can be scripted and recorded using PAC-3 missile model.
- **Communication enhancements -** Includes upgrades to modifications to the ICCs, ECSs, and CRGs. Communications are enhanced by upgrading communication equipment to provide improved voice

> and data capabilities, improve the internal and external integration of defense alert warning and attack operations. Inherent to the communications upgrade is the ECS and CRG modifications to provide extended remote launch capabilities. This provides the commander greater flexibility to meet the TBM threat by accessing launchers remotely at extended ranges and expands the TBM defended area. **(BARBERA)**

The block 3A and 3B versions have the capability to be used with the Cooperative Engagement Capability (CEC) for over-the-horizon targeting by a remote sensor, or what is also called a forward pass intercept. A Cooperative Engagement Capability (CEC) has been developed to link ballistic missile tracking from Aegis, Patriot and HAWK radars together with a data fusion system to allow an integrated ship/land tactical ABM system to be used.

Specifications			
	PAC- 1	**PAC- 2**	**PAC- 3**
	MIM-104A	**MIM-104C**	**PAC- 3**
Type	Land-mobile, surface- to-air guided weapon system	Single-stage, low-to-high-altitude	Single- stage, short-range, low-to high-altitude
Launcher	four-round Mobile trainable semi-trailer		eight-round Mobile trainable semi-trailer
Manufacturer	Raytheon	Raytheon (Prime contractor), Lockheed, Siemens, Mitsubishi	Lockheed Martin Vought Systems
Status	Not in production	In production	In production
Length	5.3m	5.18m	5.2m
Diameter	41cm	41cm	25cm
Wingspan		92cm	50cm
Fins	Four delta shaped fins		
Launch Weight	914 kg	900kg	312kg
Propulsion	Single-stage solid propellant rocket motor	Single-stage solid propellant rocket motor	Single-stage solid propellant rocket motor with special attitude-control mechanism for in-flight maneuvering
Guidance	Command guidance and semi-active homing, track-via-missile (TVM)	Command guidance with TVM and semi-active homing	Inertial/Active millimeter-wave radar terminal homing
Warhead	HE single 90 kg	91kg HE blast/ fragmentation with proximity fuze	hit-to-kill + lethality enhancer 73 kg HE blast/fragmentation with proximity fuze
Max speed	Supersonic (in excess of Mach 3)	Mach 5	Mach 5
Time of flight		minimum nine seconds maximum three and a half minutes	
Min altitude		60 meters	
Max attitude	NA	24 km	10-15 km
Min range	NA	3 km	--
Max range - anti-air	70 km	160 km	15 km
Max range - anti-missile			15-45 km

Table 2. Patriot TMD

F. POST DEPLOYMENT BUILD

The Army is now testing the new Patriot PDB-6 software build. Below are some of the improvements that will be implemented with this software build:

- Improved classification of targets utilizing new technique of calculating ballistic indicator.
- Continuation of target classification processing after launch for targets classified as unmanned ABTs and TBM-As to allow further classification to ARM
- Use of adjustable range gate instead of mini-search range gate in order to minimize false alarms and detection from near-by targets.
- Improved cruise missile operator awareness.
- Provide operator with situational understanding of target flight profiles
- Provide estimated target length of ABT, ARM, AND TBM-A tracks by displaying in the FP TRK AMP DATA Tab next to the TYPE field.
- Add a debris indication in the ESTAT field on the TRK AMP DATA Tab and TBEQ at the ICC and FP when the target is discriminated as debris
- Add a long-term monitor to recognize the presence of interference, which cause false tracks.
- Modification of the TBM events hardcopy to provide additional data.
- New cruise missile search mode available to operator via Tab 1.” **(TPP)**

G. PATRIOTS ROLE IN GLOBAL BALLISTIC MISSILE DEFENSE

The PAC-3 upgrade has effectively quintupled the "footprint" that a Patriot unit can defend against ballistic missiles of all types, and has considerably increased the system's lethality and effectiveness against ballistic missiles. It has also increased the scope of ballistic missiles that Patriot can engage, which now includes several intermediate range and continental ballistic missiles such as the No-Dong and the CSS-2 and CSS-3. However, despite its increases in ballistic missile defense capabilities, the PAC-3 missile is a less capable interceptor of atmospheric aircraft and air to surface missiles. In addition, it is slower, has a shorter range, and has a smaller warhead compared to older Patriot missiles. The Patriot's PAC-3 interceptor will be the primary interceptor for the new Medium-altitude, Extended Area Defense System (MEADS), which is scheduled to enter service alongside Patriot in 2012.

Patriot upgrades continue, with the most recent being new software known as PDB-6 (PDB standing for "Post Deployment Build"). This software will allow configuration 3 units to discriminate targets of all types, to include anti radiation missile carriers, helicopters, unmanned aerial vehicles, and cruise missiles. The software also contains new search algorithms designed to counter the growing cruise missile threat. The PAC-3 missile is currently undergoing testing for a significant new upgrade, currently referred to as "MSE" or "Missile Section Upgrade". The upgrade is similar to the GEM+T/C upgrade, in that it consists of a body redesign and subsequent replacement of the PAC-3 interceptor. The upgrade includes a new fin design and a new, more powerful rocket motor. The modification is alleged to increase the operational capability of the current PAC-3 missile up to 50% and is scheduled to be added to all existing PAC-3 missile stores by 2008. Further upgrades to the dual-TWT radar set, the JTIDS uplink, and the system's processors and memory are scheduled to take place in the next few years.

THIS PAGE INTENTIONALLY LEFT BLANK

V. OBJECT-ORIENTED DESIGN FOR A WEAPON ASSIGNMENT WEAPON MODULE

A. SOFTWARE ARCHITECTURE AND OBJECT-ORIENTED DESIGN

Software architecture is receiving increasing attention as a critical design level for software systems. However, the current practice of architectural description is largely informal and ad hoc, with the consequence that architectural documents serve as a poor communication mechanism, are difficult to analyze, and may have very little relationship to the implemented system. Looking at the weapon assignment processing component diagram in Chapter II (see figure 1), further requirements for the system components have to be elaborated upon.

The object-oriented paradigm offers a new system-of-systems requirements and design methodology that provides for both minimizing accidental complexity and controlling essential complexity through the use of decentralized control flow, minimal messaging between classes, implicit case analysis, and information-hiding mechanisms. Although the ABM missile defense system will not be a pure object-oriented design, we can incorporate many of the principles of object-oriented design to decrease the complexity of the overall work of art produced during the development of the system of systems. Research suggests that software engineers of system-of-systems can use this object-oriented paradigm to produce a sound design for the system-of-systems rather than the established association of systems through a highly coupled communication medium.

The purpose of the ABM weapon assignment module is to take input from the threat track processing and provide a precise integration of the weapon assignment module for requirements. By developing a class diagram with abstract classes for the major components of the weapon assignment module of the ABM BMDS, one can reason about the design in our attempt to develop subclasses to which researchers can begin to allocate requirements and analyze system capabilities and limitations.

B. UML MODELS FOR A WEAPON ASSIGNMENT MODULE DESIGN

The development of a class diagram enhances understanding for the operators and users of the system. The overall concepts can be drawn from the diagrams and addresses the goals of the weapon assignment components within the ABM BMDS system. The design class model aids in producing a coherent description of data store operation which attends to a well formulated interaction and interface between system components.

Figure 3 is a high level conceptual model to capture the necessary elements of a weapons pairing component. This aids in the current plan being simultaneously developed, evaluated, refined, and validated, with each iteration providing a higher confidence in an overall effective BMDS.

Without getting into the specifics of how the task should be done, this model focuses on what needs to be done, leaving detail design of individual agents for further work. It is important that this intermediate step be taken in between a high level view of the entire system of systems and implementation of the individual tasks.

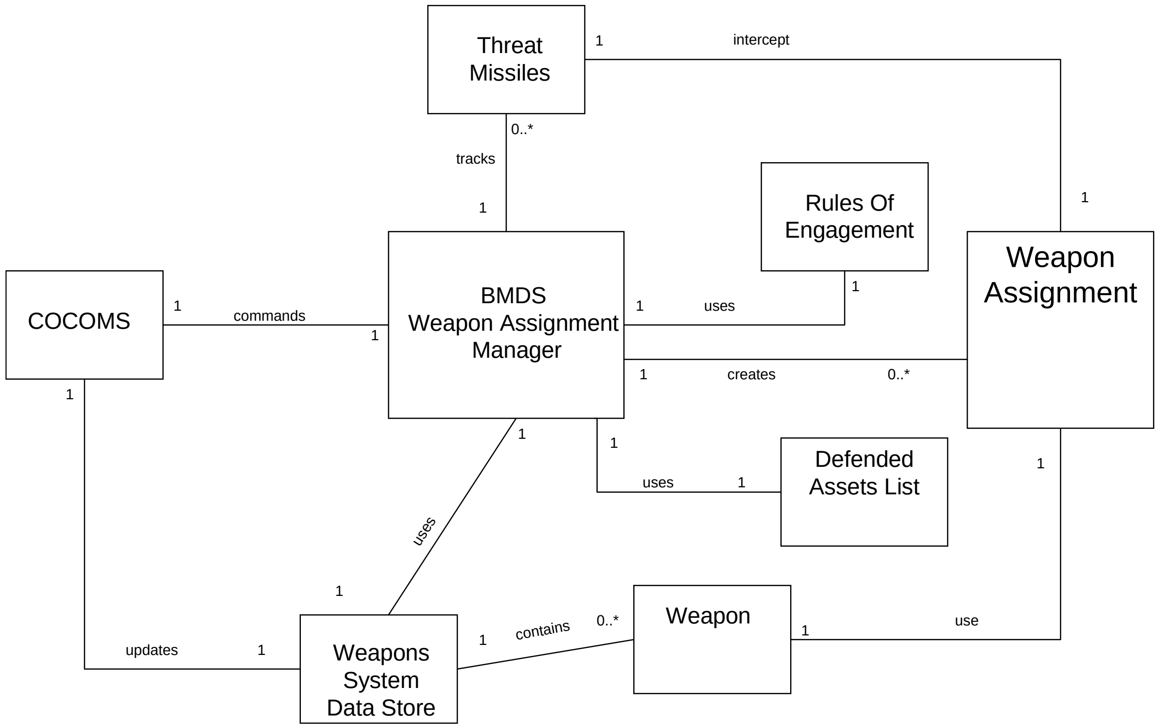

Figure 3: Weapon Pairing Component Model

Combatant Commanders (COCOM) conceptually are the ultimate customers of the entire system; therefore COCOM module represents the tasking to pair weapons.

The BMDS weapon assignment manager component is where the algorithm that actually computes the best weapon for a given target resides. This can be based on probability of kill or a number of other factors and should be designed in such a way that the algorithm is generic and can be replaced with a new one or modified, as necessary.

In order to complete the computation, the weapons assignment manager component, given a threat track, consults the rules of engagement component to ensure that there are no conflicts with the given policy. This may include whether to attack a threat missile over a friendly nation, whether to engage given the calculated launch point, etc. In this depiction, the ROE component also includes the firing policy, though it could be represented as a separate function.

The weapons system data store contains information about the weapons that are available and their overall characteristics. Not only does this include logistical information about their individual inventory and location, but it includes capabilities such as max range, accuracy, etc. This is because hard wiring decisions for which weapons to use for a given threat in the weapon assignment manager component would require a change of the algorithm each time a new system is introduced and oversimplifies the problem. This view allows the capabilities to be polled, basing the decision on which interceptor to use purely on probability of kill analysis, not on platform type.

The defended assets list is the source of information used to prioritize the threats. Conceptually, this could be attached to the threat missiles component, feeding the weapon assignment manager component a pre-prioritized list of threats and relieving some of the computational burden on the primary module. This may seem like a way to streamline the process, but such an approach may actually be more complex. As new threats are introduced, priorities are rearranged respectively which possibly could cause the entire list to be reprioritized and may need to be re-sent, increasing the interaction between the modules.

The following sections expand on what type of information must be considered for each component of the weapon assignment module.

1. Threat Missiles

The Threat Missile Class is the enemy missile that contains warhead of mass destruction: nuclear, chemical, or high explosive munitions. An adversary can launch a threat missile from their area or state. The missile can climb into the exo-atmospheric region of its flight. In addition, the missile may re-enter the atmosphere over our forces or defended assets at which time it may impact at its aim point. (Caffall2) Information regarding the identification, evaluation, and prioritization of threat objects are contained inside which are drawn from the track prioritization computation. Figure 4 captures the classes of the Threat Missile.

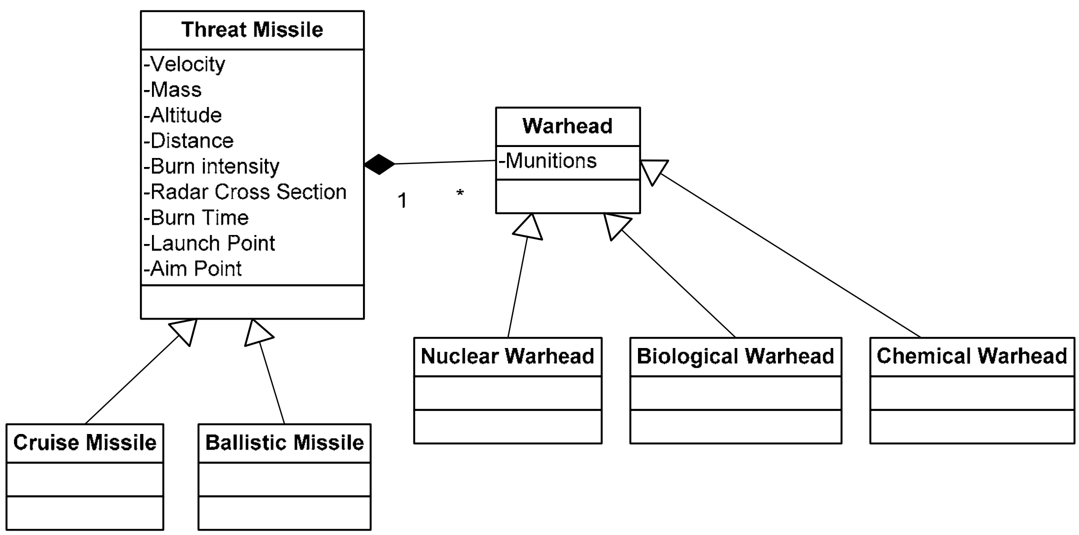

Figure 4: Threat Missile Class Diagram

The threat can be evaluated by determining what objects are candidates for engagement or defensive action. Next, the data received can determine whether engagements or actions are allowed, and assigns relative priorities to those objects designated as threats. Threat evaluation depends directly on track characterization processes which determine track category, type, identification and track kinematics. Threat evaluation comprises doctrinal procedures that are based on prevailing rules of engagement or defensive action. Threat evaluation may be separated into the processes for threat assessment and threat prioritization. Threat assessment includes determining what objects are threats and whether engagements or defensive actions are allowed. Threat prioritization assigns relative priorities to the threats. In addition, when a threat is processed and another target emerges, a weapon previously directed and intended for a lower priority target could be redirected to the emergent target.

2. Defended Assets List

Potential enemies targets critical nodes that are high priority and links within the defended network. Defended Assets List contains the location and status of all defended assets (ground, maritime, and aerospace). It includes all defended objects and zones as well as points or areas on the ground within an area of interest. The assets are identified in the Joint Forces Command (JFC) approved defended asset list (DAL). The DAL is a prioritized listing of assets by phase and is included in the OPLAN and air defense plan. Prioritization for the defended assets is based on established doctrine and/or operator input. The purpose of keeping track of all defended assets in the air or on the surface is to feed into the process of prioritizing threats and determining the best course of action (including determination of best shooter and/or intercept location) based on the defense of forces, Allies, and friendly civilian areas.

In so doing, this ultimately supports the optimized use of warfighting resources. The defended assets information can be displayed to operators and commanders in order to allow them to easily change prioritizations as necessary and take defensive action. Units are designated to protect critical assets or areas of the theater, fleet operating areas, and the battlefield.

3. Rules of Engagement

Rules of Engagement (ROE) must be delineated, published, and disseminated to, and exercised by, alliance or coalition members for compliance and as a planning consideration for future operations. Policy looks upon defining Rules of Engagement as directives issued by competent military authority that delineate the circumstances and limitations under which United States forces will initiate and/or continue combat engagement with other forces encountered. Rules of engagement can contain high and low conditions which has the same level of specificity, or non-specificity, respectively, as included in the commander's intent. There can be no ambiguity, unnecessary detail and fuzziness in the set of ROE which might lead to a delay in responses due to hesitation, confusion, and additional communications needed to clarify the situation.

In addition, ROE should enhance clarity for prediction to reduce "waste" of scarce assets and allow greater speed of response to time critical targets. Appropriate ROE must be established to deal with the potential threats. In addition, an effective combat firing doctrine is important so as to not overuse missile assets in combat. Rules of engagement must include hostile criteria, guidance documents, and the enemy order of battle. A confirmed launch triggers reaction by a preplanned selection of appropriate defensive systems, according to established ROE. Short missile flight times require that all applicable air-, land-, sea-, and space-based sensor and surveillance assets be linked to provide a complete and current air picture. This will be accomplished through the use of shot doctrines, firing triggers and probability of kill. It is important to automate the enforcement of the ROE in Ballistic Missile Defense systems due to the strict time budgets for executing the battle plans.

4. Weapon

The Weapon class contains attributes for developing firing solutions, calculates the probability of kill, and implements the BM/C2 authorization to engage the threat missile by firing interceptors. The weapon class issues release commands to the interceptor and its associated class. Figure 5 captures the classes of the weapon and their association for interface with various systems.

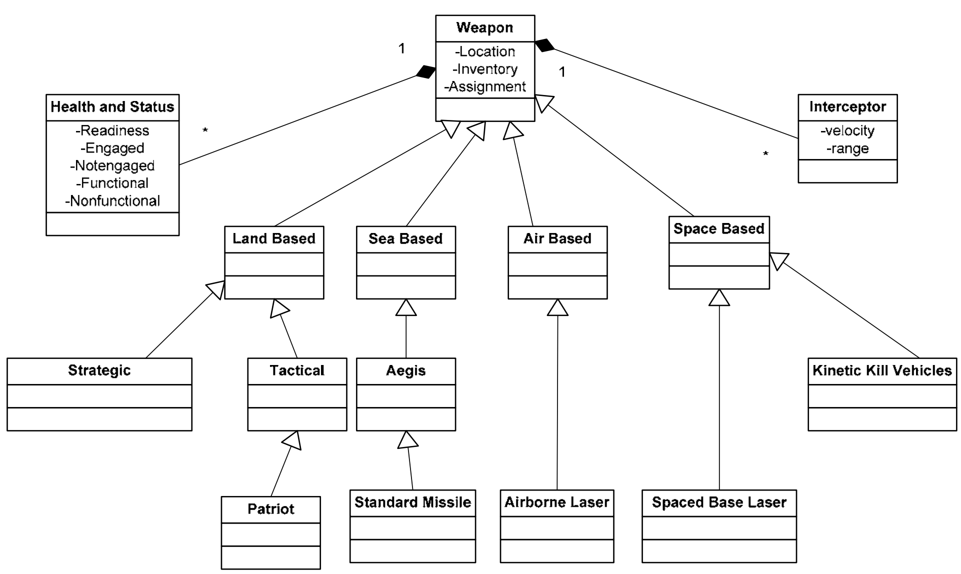

Figure 5: Weapon Class Diagram

The weapon class can be specialized into four major subclasses, represented by the land based, sea based, air based, and space based anti-ballistic missile defense weapon system.

In addition, each weapon has a health and status component and an interceptor component. The health and status information is updated continuously for each weapon to include readiness of weapon system, number of interceptors that are available, and current engagements of the weapon system. Health information is provided in regards to a resource's ability to perform optimally. (For example, the health data of a weapon's sensor may include its current registration, alignment, and calibration information as well as information regarding whether its operation is degraded.) Status information provides update information regarding a resource's current tasking and thus, availability for future tasking. A resource may be on, off, or in standby. Each weapon contains a set of static information which includes the weapon's capabilities (functional and performance) and limitations based on various environments, configurations, and threats or tasks. The interceptor component allows the flexibility of capturing the different capabilities with different weapon configurations.

6. Weapon Assignment

Weapon assignment contains the tasking order of weapon target pairing. It contains information on target identifications, earliest and latest time to commence engagement, launch or shoot time, and intercept depiction which entails figure of merits, defended areas, and current engagement.

7. The BMDS Weapon Assignment Manager

The ABM system must determine the best choice of weapon for the threat and choose from among the assets the available weapon platform that can optimize the overall effectiveness of global ballistic missile defense. This module is further broken down into three submodules, Threat Evaluations, Weapon Pairing, and Engagement Scheduling. The Threat Evaluation module computes the value of potential defended assets damage for each threat. The weapons pairing module assign weapons to each threat to maximize the overall survival value of all the defended assets. The Engagement Scheduling module computes the time and location of the intercept subject to ROE constraints.

All weapon systems and all threats may have different characteristics. For instance, different weapon systems may require a different amount of time to engage a threat; different threats may be moving at different speeds and at different distances. Also, a threat may suddenly change its course. A given weapon’s platform’s projectile has a known probability of hitting any particular target. The value of each target is known.

Within the assumptions, a generic algorithm could be develop using the following factors: number of weapon platforms, number of targets, initial value of the targets, number of available projectile on each weapon platform, the maximum probability of hitting target over time with a projectile sent from weapon platform, and the number of projectile sent from weapon platform and aimed at target. More over, the algorithm must account for ROE policies that may withhold certain weapon against a missile that is not a threat to the assets that the weapon is assigned to defend even though such weapon target pairing will maximize the expected survival value of the defended assets.

THIS PAGE INTENTIONALLY LEFT BLANK

VI. CONCLUSION

A. SUMMARY OF THESIS

The global WMD/missile threat to US and allied territory, interests, forces, and facilities will increase significantly. Russia, China, and North Korea remain the ‘WMD and missile’ suppliers of primary concern. Russia, for instance, has exported ballistic missile and nuclear technology to Iran. China has provided missile and other assistance to Iran and Pakistan. North Korea remains a key source for ballistic missiles, related components and materials. Over time, as other nations such as Iran acquire more advanced capabilities, they too are likely to become important proliferators. Several states of concern in particularly Iran and Iraq could acquire nuclear weapons during the next decade or so, and some existing nuclear states such as India and Pakistan, for instance, will undoubtedly increase their inventories. Chemical and biological weapons are generally easier to develop, hide, and deploy than nuclear weapons and will be readily available to those with the will and resources to attain them. More than two dozen states or non-state groups either have, or have an interest in acquiring, chemical weapons, and there are a dozen countries believed to have biological warfare programs. There should be an expectation that chemical and biological weapons will be widely proliferated and they could well be used in a regional conflict or terrorist attack over the next 15 years.

The potential development/acquisition of intercontinental missiles by several states of concern, especially North Korea, Iran, and Iraq could fundamentally alter the strategic threat. Meanwhile, longer-range theater (up to 3,000 km) ballistic and cruise missile technology proliferation is a growing challenge. The numbers of these systems will increase significantly during the next 15 years in addition to their accuracy and destructive impact.

Chapter I provided an overview of the research conducted on the history and background leading up to a weapon target assignment and purpose of study. Inside Chapter II, an analysis of the Advanced Battle Manager weapon assignment system was depicted with an overall overview of the current proposed weapon assignment processing components. A brief narrative providing information on four of the basic systems of TMD were explored within the constraints of the thesis. Chapter III involved looking at the Aegis system and its concept of operation focusing on advantages and disadvantages of sea based operation. The Aegis attributes were expounded upon as well as its future role in a Global Ballistic Missile Defense. This thesis provided ample information determining that sea-based defense is a mission enhancer. Naval forces will generally be the first units to arrive in a crisis area. Their inherent mobility and flexibility combined with a multi-mission Aegis capability will provide extensive coverage to support air, land and sea operations. Sea-based forces are unobtrusive, are not restricted by foreign basing rights, can remain on station indefinitely, and are not dependent on strategic lift. To achieve the defense-in-depth and the extensive defended footprint necessary to support the Joint TMD framework requires the synergistic effect of sea-based and ground-based TBMD forces.

Chapter IV provided information of the Patriot missile defense system and background overview. The various attributes were provided along with the different configuration changes of the PAC-3. In addition, the success of the system and its current role in a Global Ballistic Missile Defense was provided. Chapter V displayed a high-level object-oriented design of a weapon assignment weapon module. The chapter explained the model and design with multiple diagrams for more detailed view of class components.

In regards to the role of automated military weapon decision support systems, former undersecretary of defense for research and engineering and engineering professor, William J. Perry, known as the father of stealth technology, argued that humans, not machines, should make the final decision when striking targets and states, "I hope we are wise enough to use automation appropriately, which means keeping well-trained, thoughtful humans in the loop". **(CUMMINGS)**

The land attack cruise missile (LACM) threat against North America is a topic of considerable debate and little consensus. However, regardless of perceptions of the immediate threat, a number of facts still exist that causes concern. The effectiveness of such missiles, as demonstrated by the U.S. in its last several wars, has not been lost on potential adversaries, and proliferation continues. More than 70 countries have cruise missiles, with an estimated total inventory exceeding 80,000 worldwide. Since no worldwide tracking system seems to exist, there is no certainty as to how many of these missiles have been produced or converted to land attack capability. But experts postulate as many as 20 countries could possess them in the next 10 years.

For decades, the U.S. was engaged in a Cold War with the Soviet Union, and the air defense architecture built for the country was optimized for a large-scale-war scenario. Ground-based radars were built around the continent, and still serve as the basis for our air defense system. These radars are limited in range to line-of-sight to the horizon and optimized for larger radar cross-section targets at high altitude that is intruding aircraft. They cannot detect a cruise missile 100 m above the ground until it is too late.

B. RECOMMENDATIONS

In this thesis, research has been presented in an informal way of addressing analysis of an ABM weapon assignment module that is essential ingredients for a general ABM system. There is a need to incorporate vulnerability and reliability inside the analysis which will dictate the success of the distributed architecture. Although our ability to predict the future is limited, as the U.S. continues to demonstrate its dominance on the conventional battlefield, there exist assumptions where future adversaries will learn and adapt their strengths to attack our perceived weaknesses. They will look for new ways to attack our interests, our forces, and our friends and allies. Asymmetric methods to counter U.S. superiority, including WMD and the means to deliver them may be perceived as viable means to affect U.S. power projection and coalition-building capabilities. This research contributed to highlighting some shortfalls in efforts to integrate capabilities and desired capabilities as the missile threat evolves. Once highlighted, DOD could then address these integration shortfalls individually or collectively and thereby have the ability to significantly increase the ABM readiness.

1. ADVANCED RESEARCH IN ENGAGEMENT SURVEILLANCE

Surveillance systems are ground-based with severely limited detection range against low-altitude targets. Intercept and engagement capabilities have to be continuously improved upon as new information and intelligence reports come available.

2. TESTING CONSIDERATION FOR ALLOCATING ASSETS

Since initial research has addressed allocating assets, there is a need for more automation in regards to tool support for testing and developing for greater accuracy and concrete results for use with the system.

3. FURTHER STUDY FOR ADVANCED DESIGN WEAPON SYSTEMS

The analysis presented here needs further development to determine not only their feasibility but their usefulness to the Battle Managers. Further research needs to be done to determine whether the system can accurately perform under the time constraints required for weapon pairing.

4. IMPLEMENT FUTURE ALGORITHMIC METHODS

Developers must continually search for innovative ways to improve interchangeable algorithm for optimization. A feasible solution must always be reached in order for a high probability of success for weapon assignment and resource allocation to minimize complexity and constraints.

5. IMPROVISE TESTING, MODELING, AND ENGAGEMENT STRATEGIES

More realistic modeling, testing, and evaluation would be required to demonstrate the effectiveness and reliability under all engagement conditions for encountering and interception of a given threat. Allocating defensive resources to maximize the probability of survival requires further comparative evaluation for the ABM. The ABM weapon assignment components will have to manage the use of the integrated resources to ensure all time critical events are processed efficiently. Much of the work that has been accomplished within the forces of TBMD area is either classified or the level of detail is beyond the scope of this thesis.

LIST OF REFERENCES

[AIAA] The Cruise Missile Conundrum
Retrieved January 2006 from
http://www.aiaa.org/aerospace/Article.cfm?issuetocid=309&ArchiveIssueID=35

[ASHLEY] J. Ashley Roach, "Rules of Engagement," *Naval War College Review*, vol. XXXVI, No 1, January-February 1983, p. 46

[ANT] First Steps toward Global Missile Defence, Theater Missile Defence
Retrieved October 2005 from
http://www.antenna.nl/amokmar/pdf/PENN-TMD01.pdf

[BARBERA] Barbera, Richard. The Patriot Missile System: A Review and Analysis of its Acquisition Process FY2003 Report for the Office of the Director, Operational Test & Evaluation [19 MB PDFP]

[BERGER] The Resolution of an Open-Loop Resource Allocation Problem Using a Neural Network Approach J. Berger Command and Control Division Defence Research Establishment Valcartier

[CAFFALL] Caffall, Dr. Dale S. (2005, March). "Developing Dependable Software for A System-Of-Systems" (PHD Dissertation, Naval Postgraduate School)

[CAFFALL 2] System-of-Systems Design from an Object-Oriented Paradigm, Radical *Innovations of Software and Systems Eng. in the Future*, US Army Research Office Oct. 2002

[CCRP] An Agent Based Framework to Model Ballistic Missile Defense Strategies
Retrieved Nov 2005 from
http://www.dodccrp.org/events/2005/10th/CD/papers/339.pdf

[CIR] Cirincione, Joseph (2006). Brief History of Ballistic Missile Defense and Current Programs in the United States, Carnegie Endowment

[CNDC] Commander, Naval Doctrine Command, “The Commander’s Handbook on the Law of Naval Operations,” *NWP 1-14M*, Norfolk, Va.: 1995), p. 5–3

[CON] Proceedings of the 27th Conference on Decision and Control Austin, Texas December 1988

[CUMMINGS] Cummings, M. Human Value-Centered Design for a Command and Control Supervisory Interface, Massachusetts Institute of Technology, Cambridge, MA USA

[DTIC] Deploying Missile Defense: Major Operational Challenges
Retrieved January 2006 from
http://stinet.dtic.mil/cgi-bin/TRDoc January 2006

[ELLIS] Ellis, Dennis R. (2001, Fall/Winter). Offensive Defensive Mission Planning: Detailed Plan Optimization Using Genetic Algorithms, Technology Review Journal

[FM44-100] FM 44-100 US Army Air Defense Operations 15 Jun 1995, Joint Pub 3-01.2

[GARWIN] Garwin, R. L., (2004, November). Holes in the Missile Shield, Scientific American

[GLOBSEC] A Simple Model for calculating Ballistic Missile Defense Effectiveness
Retrieved Oct 2005 from
http://www.princeton.edu/~globsec/publications/pdf/8_2Wilkening.pdf

[HER] Retrieved Feb 2006
http://www.heritage.org/Research/MissileDefense/BG1384.cfm

[HIGGINS] Higgins, Eric John. Executive Summary Expeditionary Warfare, Force Protection

[HOFMANN] Hofmann, Martin O., Daria Chacón, Gerard Mayer, Kenneth R. Whitebread. CAST Agents: Network-Centric Fires Unleashed, Advanced Technology Laboratories, Camden, NJ 08102

[JANES] Janes 2005 Retrieved September 2005 from http://www.janes.com

[KOLITZ] Kolitz, Stephen E. Analysis of a Maximum Marginal Return Assignment Algorithm, University of Mass at Boston

[MACFADZEAN] Macfadzean, Robert H. M. Surfaced Based Air Defense System Analysis

[METLER] Metler, W.A., Preston, F.L., Hofmann, J., (1990). "Weapons Allocation and RF Spectrum Management", Naval Research Laboratory, contract No. NOOO14-87-C-2035, AT&T Bell Laboratories, N.J.

[MISSILE] Aegis Ship Based Missile Defense Retrieved April 2005 from http://www.missilethreat.com/systems/aegis_usa.html

[MITRE] Evaluating Distributed Combat Decision Algorithms Retrieved December 2005 from http://www.mitre.org/news/events/tech03/

[LAMERT] Lambert, Charles E. THE CRUISE MISSILE CONUNDRUM *Aerospace America* February 2003

[LIBICKI] Libicki, Martin, Johnson, Stuart (1995, October). Dominate Battlespace Knowledge, National Defense University

[LYLES] Lyles (1997, March). Statement of Lieutenant General Lester L. Lyles, USAF Dir BMDO before the Subcommittee on Research and Development Committee on National Security

[RATHEON] Retrieved May 2005, www.ratheon.com

[SARTER] Sarter, N. B., & Schroeder, B. (2001). Supporting Decision Making and Action Selection under Time Pressure and Uncertainty: The Case of In-Flight Human *Factors, 43*, 573-583

[SENATE] Statement of RADM Mullen before the Subcommittee on Seapower, Littoral Force Protection and Power Projection
Retrieved July 2005 from http://armed-services.senate.gov/statemnt/1999/990324mm.pdf

[SKITKA] Skitka, L. J., Mosier, K. L., & Burdick, M. D. (1999). Does Automation Bias Decision-Making? International Journal of Human-Computer Studies, 51(5), 991-1006

[STORY] Third World Traps and Pitfalls -- Ballistic Missiles, Cruise Missiles, and Land-Based Airpower, William C. Story, Jr Air University Magazine

[TPP] FM 301 Introduction to Patriot TPP [70.76]

[WELLER] Weller, D. B. (2005 March). “Command Structure of the Ballistic Missile Defense System” (Master’s Thesis, Naval Postgraduate School)

[WIL] Wilkening, Dean A. A Simple Model for Calculating Ballistic Defense Effectiveness

[WIK] MIM-104 Patriot, Retrieved March 2006 from Wikipedia

INITIAL DISTRIBUTION LIST

1. Defense Technical Information Center
   Ft. Belvoir, VA

2. Dudley Knox Library
   Naval Postgraduate School
   Monterey, CA

3. Dr. James Bret Michael
   Computer Science Department
   Naval Postgraduate School
   Monterey, CA

4. Professor Man-Tak Shing
   Naval Postgraduate School
   Monterey, CA

5. Dr. Dan Boger
   Information Science Department
   Naval Postgraduate School
   Monterey, CA

6. Dr. Peter Denning
   Computer Science Department
   Naval Postgraduate School
   Monterey, CA

7. Dr. Phil Pace
   Electrical and Computer Engineering Department
   Naval Postgraduate School
   Monterey, CA

8. Dr. Murali Tummala
   Electrical and Computer Engineering Department
   Naval Postgraduate School
   Monterey, CA

9. Dr. Dale Scott Caffall
   Missile Defense Agency
   Washington, D. C.

10. LTC Thomas S. Cook
    Computer Science Department
    Naval Postgraduate School
    Monterey, CA

11. Dr. Robert G. Watkins
Electrical and Computer Engineering Department
Naval Postgraduate School
Monterey, CA