

**NAVAL POSTGRADUATE SCHOOL**  
**Monterey, California**



**THESIS**

**THAAD RADAR: EXAMINATION OF  
A COST SAVING INITIATIVE**

by

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March 1999

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**ABSTRACT (Maximum 200 words)**

This thesis analyzes two acquisition reform initiatives that made Theater High Altitude Area Defense (THAAD) Radar Product Office's Best of Breed Transmit/Receive Module study a success and examines the risk involved in the pursuit of this study. The initiatives are Cost As an Independent Variable (CAIV) and commercial items in the form of dual-use technology. Analysis of the radar subsystem of THAAD reveals a major cost driver to be the transmit/receive (T/R) module in the antenna equipment. The Best of Breed study examined techniques in the design, engineering, and manufacturing of these modules and its components in order to aggressively reduce the unit cost. Using tenets of CAIV, THAAD Radar Product Office was able to define a study such that the contractor would recommend a low risk solution to achieve cost reductions of almost 50% for the module. Additionally, the Product Office was able to accomplish this without sacrificing performance or schedule. The commercial application of the T/R module was an important factor in motivating the contractor to seek aggressive cost reductions. Lessons from this case may be applicable to other programs seeking to reduce cost.

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COST SAVING INITIATIVE**

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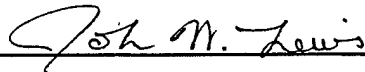
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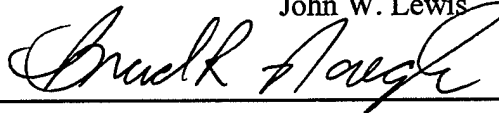
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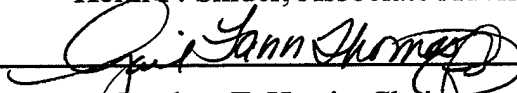
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## ABSTRACT

This thesis analyzes two acquisition reform initiatives that made Theater High Altitude Area Defense (THAAD) Radar Product Office's Best of Breed Transmit/Receive Module study a success and examines the risk involved in the pursuit of this study. The initiatives are Cost As an Independent Variable (CAIV) and commercial items in the form of dual-use technology. Analysis of the radar subsystem of THAAD reveals a major cost driver to be the transmit/receive (T/R) module in the antenna equipment. The Best of Breed study examined techniques in the design, engineering, and manufacturing of these modules and its components in order to aggressively reduce the unit cost. Using tenets of CAIV, THAAD Radar Product Office was able to define a study such that the contractor would recommend a low risk solution to achieve cost reductions of almost 50% for the module. Additionally, the Product Office was able to accomplish this without sacrificing performance or schedule. The commercial application of the T/R module was an important factor in motivating the contractor to seek aggressive cost reductions. Lessons from this case may be applicable to other programs seeking to reduce cost.



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## LIST OF ACRONYMS

ACAT	Acquisition Category
AE	Antenna Equipment
APB	Acquisition Program Baseline
AR	Army Regulation
BMDO	Ballistic Missile Defense Organization
BoB	Best of Breed
BMC4I	Battle Management, Command, Control, Communication, Computers, and Intelligence
CAIV	Cost As an Independent Variable
CAE	Component Acquisition Executive
CEU	Cooling Equipment Unit
DAE	Defense Acquisition Executive
DEMVAl	Demonstration and Validation
DOD	Department of Defense
EEU	Electronic Equipment Unit
EMD	Engineering and Manufacturing Development
EV	Earned Value
F3	Form, Fit, and Function
FRP	Full Rate Production

FY	Fiscal Year
GAO	General Accounting Office
IRR	Internal Rate of Return
KPP	Key Performance Parameters
LCM	Low Cost Module
LMMS	Lockheed Martin Missiles and Space
LRIP	Low Rate Initial Production
MDAP	Major Defense Acquisition Program
MAIS	Major Automated Information System
MESFET	Metal Semiconductor Field Effect Transistor
MMIC	Monolithic Microwave Integrated Circuit
NPV	Net Present Value
O & S	Operation and Support
OCU	Operator Control Unit
ORD	Operational Requirement Document
PDRR	Program Definition and Risk Reduction
PHEMT	Pseudomorphic High Electron Mobility Transistor
PM	Program/Product/Project Manager
PPU	Prime Power Unit
RFP	Request for Proposal

RFQ	Request for Quotation
SOW	Scope of Work
THAAD	Theater High Altitude Area Defense
T/R	Transmit/Receive
T/REA	Transmitter/Receiver Element Assemblies
TRPO	THAAD Radar Product Office
UOES	User Operational Evaluation System



## I. INTRODUCTION

### A. PURPOSE

The purpose of this research is to analyze acquisition reform initiatives that made Theater High Altitude Area Defense (THAAD) Radar Product Office's Best of Breed Transmit/Receive Module study a success and to examine the risk involved in the pursuit of this study. Analysis of the radar subsystem of THAAD reveals a major cost driver to be the transmit/receive (T/R) module in the antenna equipment. The unit cost of the module is not relatively expensive. What makes it a cost driver is the number required for each antenna - 25,344. The Best of Breed study was contracted during the system's extended risk reduction phase of development in anticipation of Engineering and Manufacturing Development (EMD). The purpose of the study was to examine industry techniques in the design, engineering, and manufacturing of these modules and its components in order to aggressively reduce the unit cost. The acquisition reform environment of the past five years played a large part in the success this study. Reform ideas such as Cost As an Independent Variable (CAIV) and the use of commercial items were key in the development and execution of the study.

This thesis will examine the Best of Breed study with those reform ideas in mind. Future programs may benefit from the lessons learned by THAAD Radar Product Office's experience with this cost saving idea.

## **B. BACKGROUND**

The THAAD system is a theater anti-ballistic missile weapon. It is designed to protect deployed U.S. and allied forces from enemy ballistic missile attacks. The THAAD system is comprised of four subsystems: the missile, the launcher, Battle Management/Command, Control, Communications, Computers, and Intelligence (BMC4I), and the radar. All four components are critical to the success of the weapon system. Since 1995, as part of the Program Definition and Risk Reduction (PDRR) phase of development, the system has undergone eight flight tests. The last five of those flight tests were designed to intercept a target missile. The system has failed to succeed in any of the five attempts. Test data revealed that the missile is the source of failure for all five of these attempts. Failure on these tests has caused the program to remain in the PDRR phase of development. THAAD Radar Product Office has used this time to reduce risk in areas of concern while waiting to transition to EMD.

Within the last year, THAAD Radar Product Office has invested in, and switched to, an advanced technology in T/R modules that will allow it to meet the performance requirements for EMD. In doing so, they were able to maintain the average unit price of the module at the same level.

Congressional and public disappointment in the poor results of the THAAD system have caused drastic cutbacks in its funding. Due to these funding

constraints, efforts throughout the program are examining ways to reduce cost. Efforts within the Radar Product Office have focused on reducing the price of its major cost driver, the T/R module.

Analysis of this effort will examine the acquisition reform initiatives that were critical to the viability of this cost saving initiative.

### **C. RESEARCH OBJECTIVES**

The objective of this thesis is to examine the Best of Breed module study conducted by the THAAD Radar Product Office and the risk that pursuit of this study brings to the program. The goal of this study was to drastically reduce the cost of the transmit/receive module on the system's radar antenna. A reduction in cost will result in dramatic life cycle cost savings for the system. Lessons learned from this undertaking will be described. These lessons may benefit other programs seeking to reduce cost in high technology areas.

### **D. RESEARCH QUESTIONS**

#### **1. Primary Research Question**

What acquisition reform initiatives were most instrumental in the cost saving initiative being undertaken by the THAAD Radar Product Office in their Best of Breed T/R Module study?

## **2. Subsidiary Research Questions**

- How was Cost As an Independent Variable applied to the THAAD Radar development?
- How did dual-use technology enhance the Best of Breed study?
- What is the overall risk of the Best of Breed study to program cost, schedule, and performance?
- What are the benefits of the THAAD Best of Breed study?

### **E. SCOPE**

Analysis of the Best of Breed study has focused on the risk associated with the study and not on the execution of the ideas. Much of the information contained in the study is considered competition sensitive by the radar subcontractor, Raytheon. Cost figures given in the thesis are approximate figures and should not be construed as exact figures.

Completed in December 1998, the study shows the feasibility of achieving the cost objective for the module. As yet, funding for the implementation of the ideas contained in the study is lacking.

### **F. METHODOLOGY**

This thesis is a case study of the Best of Breed module study conducted by THAAD Radar Product Office and the associated program risk. A review of books, magazines, electronic databases, and other library information sources was

conducted in order to obtain background information on the THAAD system and acquisition reform. Documents were found through research conducted at the Naval Postgraduate School Library and through the internet. Specific information regarding the THAAD radar and the Best of Breed study was obtained from the THAAD Radar Product Office and through interviews with members of that office and the radar subcontractor, Raytheon.

The concepts of Cost As an Independent Variable and commercial items in the form of dual-use technology are developed and then applied to the Best of Breed study. Additionally, the basics of risk assessment are addressed and then a risk assessment is conducted on the Best of Breed study.

#### **G. ORGANIZATION OF STUDY**

Chapter I is the introduction of the thesis. Included are the research questions, scope, and methodology of the thesis.

Chapter II provides background information on the THAAD system and its components. A detailed discussion of the radar and recent challenges to its development conclude the chapter.

Chapter III examines the acquisition reform initiatives of Cost As an Independent Variable and commercial products. The dual-use concept within the commercial products initiative is emphasized.

Chapter IV analyzes the Best of Breed module study within the framework of the acquisition reform initiatives CAIV and commercial products and examines program risk associated with the Best of Breed study.

Chapter V includes the recommendations and conclusions of the thesis. It answers the research questions and addresses areas for additional research.

## **II. THEATER HIGH ALTITUDE AREA DEFENSE (THAAD) PROGRAM**

### **A. INTRODUCTION**

This chapter provides an overview of the THAAD system. A discussion of the Ballistic Missile Defense Organization (BMDO) and its missions is necessary in order to understand how THAAD fits into the architecture of tactical missile defense. System component descriptions are provided in order to understand the importance of each subsystem to the overall system effectiveness. Finally, a detailed discussion of the radar and the recent efforts in development are provided to understand the focus of a current cost-saving initiative.

### **B. THAAD PROGRAM OVERVIEW**

The proliferation of ballistic missiles and weapons of mass destruction has given rise to concerns by the United States on ballistic missile protection of both the United States and our deployed forces. To address these concerns, the Department of Defense (DOD) created the Strategic Defense Initiative Organization (SDIO) which later became the Ballistic Missile Defense Organization (BMDO). The priorities of BMDO are Theater Missile Defense (TMD), National Missile Defense (NMD), and Advanced Technology. Consequently, BMDO has organized itself around these missions. [Ref. 1:p. 1]

The primary mission of NMD is to defend the U.S. against a ballistic missile threat. The role of advanced technology programs is the development of technologies for future missile defense systems, as well as development of technology that existing missile defense programs may need.

Theater Missile Defense programs are designed to protect U.S. and allied forces when operationally deployed. Due to the growing variety of missiles and the complexity of operational scenarios, no single system can respond to the operational need. In response to this complexity, a Family of Systems (FOS) concept is being developed. This concept will use land and sea-based systems capable of operating jointly in order to defeat the threat. [Ref. 1:pp. 1-4] One of these systems is THAAD system. As an upper-tier system of a two-tiered architecture, THAAD's objective is to shoot down missiles at long range and high altitudes. Engagement of targets at great distances will enable multiple engagements of the target, as well as safeguarding friendly forces from falling debris following the successful interception of a hostile missile. The latter is critical should the missile contain a weapon of mass destruction. [Ref. 2:p. 1]

### **Program History**

Interest in a theater missile defense system began in 1987 with the initiation of concept studies by the High Endoatmospheric Defense Interceptor Project Office. These studies explored the feasibility of a hit-to-kill missile employing

key technologies such as infrared seekers, fast response control systems, and cooled seeker windows. [Ref. 3:p. 28] Following these studies, concept definition contracts were awarded to three teams for a THAAD missile. After U.S. and allied forces experiences with Scud missiles during Operation Desert Storm and legislation contained in the 1991 Missile Defense Act, the concept definition contracts were modified to incorporate designs for a complete THAAD system including a launcher and battle management, command, control, communications, and computers (BMC4I). The system's sensor, a radar, was to be provided as Government furnished equipment (GFE). In early 1992, the Defense Acquisition Board (DAB) approved the acquisition strategy for THAAD during a Milestone I review. [Ref. 4:pp. 14-15] Included in this strategy was the decision to develop an operational prototype during the Demonstration and Validation (now known as Program Definition and Risk Reduction) phase of the program. The decision to develop this prototype, known as a User Operational Evaluation System (UOES), was driven by three considerations:

1. To provide soldiers an opportunity to influence the system's design,
2. To conduct early operational assessments of the system, and
3. If directed by national command authority, to provide a theater commander-in-chief with a more robust theater missile defense architecture than exists today. [Ref. 5:p. 16]

The first two factors were to reduce program risk while the last one was to meet a congressional mandate. [Ref. 5:p. 2] [Ref. 6:p. 67] A contract for the demonstration and validation (DEMVVAL) phase of the program was awarded to Lockheed Missiles and Space Corporation, now Lockheed Martin Missile and Space (LMMS), in September 1992. The contract was for the delivery of two UOES systems and the conduct of 10 flight tests.

### **C. THAAD SYSTEM COMPONENTS**

THAAD is comprised of four major subsystems: the missile, the launcher, Battle Management, Command, Control, Communications, Computers, and Intelligence (BMC4I), and the radar.

#### **1. Missile**

The missile incorporates a single-stage solid state booster, a kill vehicle (KV), and a canister. The graphite epoxy canister serves as a housing for the missile to protect it while in storage or undergoing transport. Once the missile is hermetically sealed into the canister, it is then ready for loading onto the Palletized Load System (PLS) Launcher. The booster contains a Thrust Vector Control (TVC) system and deployable aerodynamic flares. The TVC steers the missile towards the target in the boost phase. The flares are designed to provide stability for the missile shortly after launch. When the optimal speed and altitude required for a successful intercept are achieved, the booster separates from the kill vehicle.

Critical components of the KV are the gimbal-mounted infrared seeker and the Divert and Attitude Control System (DACS). The infrared seeker allows the KV to search for and lock onto the target. Once the seeker acquires the target, the DACS will provide final steering capability for the KV to intercept the target. The kill vehicle does not contain a warhead as this has the potential of dispersing chemical or biological warheads over the defended area. Instead, the KV depends entirely on kinetic energy to achieve a direct hit kill of its target. [Ref. 7:pp. 1-2]

## **2. Launcher**

A launcher subsystem is mounted on the existing Palletized Load System (PLS) truck. Use of this system provides commonality with the rest of the Army and takes advantage of the personnel and equipment savings achieved by PLS. [Ref. 8:p. 1] Use of PLS as the launch vehicle, also, takes advantage of PLS's rapid reload capability as demonstrated with current field artillery operational units. The launcher has been successfully used for the last four flight tests. [Ref. 9:p. 1]

## **3. BMC4I**

The Tactical Operations Station (TOS) and the Launcher Control Station (LCS) perform Battle Management, Command, Control, Communications, Computers, and Intelligence. Together these two elements form a Tactical Station Group (TSG). The TOS handles force operations by providing support for

planning, analysis, and logistical considerations in addition to supporting engagement operations such as surveillance and battle management. The LCS provides communication links for the TOS as well as to remote launchers and sensors. The stations are housed in tactical shelters mounted on High Mobility Multi-purpose Wheeled Vehicles (HMMWV). [Ref. 10:p. 1]

#### **4. Radar**

THAAD radar is a solid-state, phased array, X band radar capable of multiple tasks. In order to operate as a critical component of the THAAD system, the radar must acquire and classify targets out to 1000 kilometers, track both target and interceptor, and provide kill assessment. [Ref. 11:pp. 1-2] Additionally, the radar provides in-flight targets updates to the missile and BMC4I. The radar has operated as a back-up radar since flight test three on October 13, 1995. The radar continued to successfully operate in this "shadow" mode for tests four through six and was successfully used as the primary radar during flight test seven. [Ref. 9:p. 1]

### **D. THAAD RADAR PROJECT**

#### **1. Overview**

THAAD radar began as a separate system in the Ground-Based Radar (GBR) Project Office. The office was chartered with acquiring a family of radars that would satisfy the requirements of both a theater and a national missile defense.

A theater version of the radar was to be provided as Government furnished equipment (GFE) to the THAAD program. In September 1992, Raytheon received award of a contract for the DEMVAL phase of the program. As a result of reduced emphasis on NMD and efforts to consolidate, the GBR project office was integrated into the THAAD program office in June 1995. [Ref. 3:p. 31]

## **2. Radar Equipment**

To date, one DEMVAL and two UOES radars have been built. The first DEMVAL radar was never fully operational but was designed as a mock-up. Subsequently, it has been gutted and used for emplacement training by soldiers. The UOES radars are operational and used for testing and training at White Sands Missile Range. [Ref. 12] The radar is comprised of five major elements: the Operator Control Unit (OCU), Prime Power Unit (PPU), Cooling Equipment Unit (CEU), Electronics Equipment Unit (EEU), and the Antenna Equipment Unit (AEU). The configured radar equipment can be seen in Figure 1.

### ***a. Operator Control Unit***

The OCU is housed in a standard shelter mounted on a HMMWV. Inside, the radar operations consoles are used for radar calibration, fault isolation, missions simulations, and live operations. The prime mover tows a 15-kilowatt generator that supplies power to the system. Future plans call for the OCU to be

integrated into the EEU in order to reduce cost and footprint. The OCU is transportable on the C-130 cargo aircraft. [Ref. 3:p. 32]

***b. Prime Power Unit***

The radar system's power is provided by the PPU. The 1.1-megawatt power unit is powered by a 12-cylinder diesel engine. It is housed in a weatherproof semitrailer that is towed by a Heavy Expanded Mobility Tactical Truck (HEMTT). It is also transportable on a C-130. [Ref. 3:p. 32]

***c. Cooling Equipment Unit***

The CEU contains the liquid cooling equipment for the antenna, as well as the radar system's power distribution unit. Cooling functions are accomplished through a liquid-to-air heat-exchange system. Redundant pumps circulate the coolant, a water/glycol mix. Due to a series of valves, maintenance can be performed on one pump while the other pump supports operations. Additionally, an oil-fired boiler is incorporated to warm the antenna equipment if operating in a low temperature environment. [Ref. 3:p. 32]

***d. Electronic Equipment Unit***

The EEU is a modular trailer designed with a nuclear, biological, and chemical (NBC) protective system and an environmental control unit to protect the equipment inside. The electronics consist of signal processing equipment, high-speed recorders, and data processing equipment. The signal processing equipment

receives the digitized radar return and performs spectral analysis and preliminary image processing. The data processing equipment provides computational support for live missions, simulations, and post-mission data analysis using commercial off-the-shelf computers. The high-speed recorders provide a log of operator actions, system updates to the interceptor, and mission profile. [Ref. 3:p. 32]

*e. Antenna Equipment Unit*

The AEU is the transmitting and receiving element of the system. The components of the AEU are the antenna assembly and mobilizer assemblies. The mobilizers are designed for mobility and to orient the antenna aperture for elevation. The antenna incorporates transmitter/receiver elements, power and cooling distribution systems, and beam steerers. Each AEU contains 792 Transmit/Receive Element Assemblies (T/REA) which contain signal, power, and cooling interfaces. T/REAs are designed as line replaceable units (LRUs) for ease of maintenance in an operational environment. Contained on each T/REA are 32 transmit/receive (T/R) modules. This results in 25,344 transmit/receive modules per radar, not including spares. [Ref. 13:p. 6]

**3. Risk Reduction Efforts**

Due to delays in development of the missile, the Program Definition and Risk Reduction (PDRR) phase of the system acquisition has been extended. THAAD Radar Product Office (TRPO) has taken advantage of this delay by

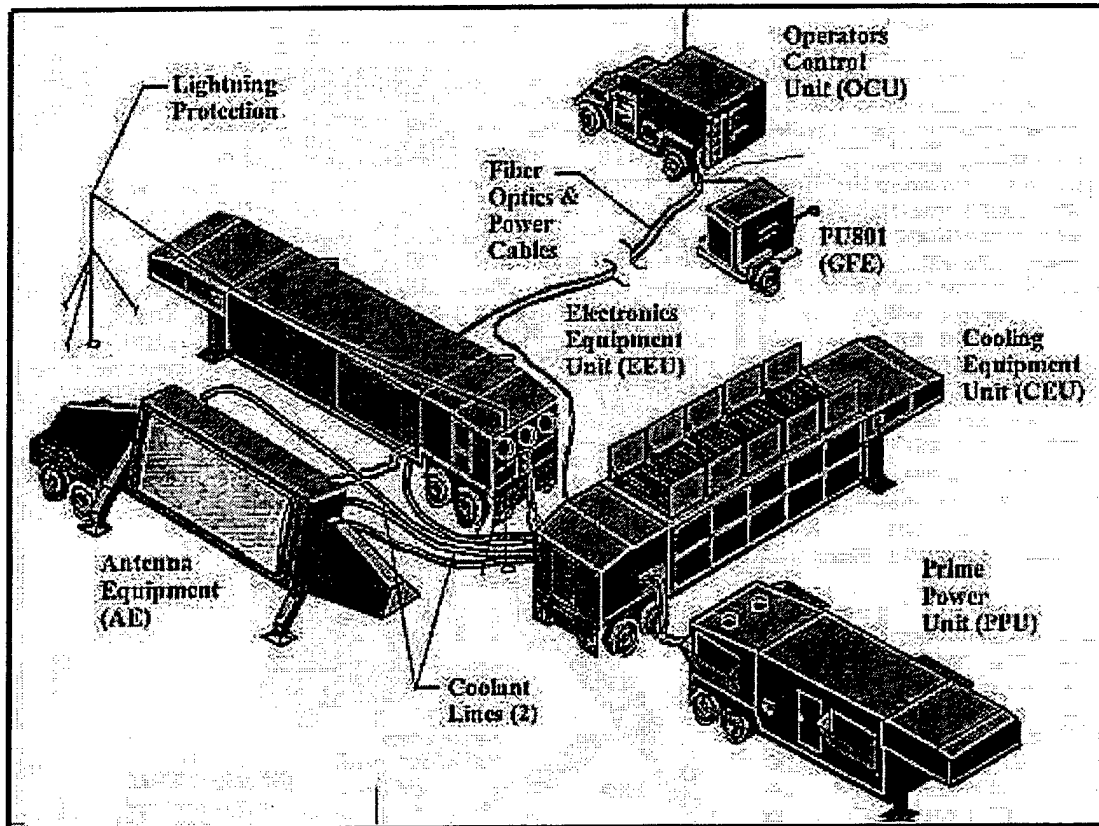


Figure 1. THAAD Radar [Ref. 3:p. 30]

addressing issues it will encounter later in program development. One of these issues was in the area of performance.

During concept exploration, two areas of radar performance were identified that would not be attainable by prototype radars during PDRR given the technology available. Relief in the requirements for defended area and electronic countermeasures were negotiated for the PDRR and UOES systems. Follow-on radars must, however, meet the thresholds set forth in the Operational Requirements Document (ORD), as illustrated in Table 1. [Ref. 13:p. 4]

THAAD ORD		
	<u>Defended Area</u>	<u>Countermeasures</u>
PDRR/VOES	Negotiated	Negotiated
	Relief	Relief
EMD	Yes	Yes
LRIP/FRP	Yes	Yes

**Table 1. THAAD ORD Matrix [Ref. 13:p. 4]**

Increases in reference range, target handling capability, and in search volume were needed to meet EMD performance requirements. [Ref. 13:p. 5] In order to achieve this, it was determined that the radar would need more transmitted power, more sensitivity, and had to dissipate the same power as the existing VOES systems. [Ref. 13:p. 6] The key component to doing this was the T/R module. The project office undertook developmental efforts to explore the switch from Metal Semiconductor Field Effect Transistor (MESFET) technology to Pseudomorphic High Electron Mobility Transistor (PHEMT) technology on the Microwave Monolithic Integrated Circuits (MMIC) of the T/R modules. [Ref. 13:p. 2] PHEMT technology was relatively new and had yet to be proven in production. [Ref. 13:p. 6] The research determined that switching to the PHEMT technology

would yield the necessary performance necessary for EMD while maintaining the form, fit, and function of the module. [Ref. 13:p. 16] This was important because a reliance on the MESFET technology to meet EMD performance criteria would have increased the antenna aperture, prime power requirements, and cooling requirements. Such increases would have necessitated the redesign of the Antenna Element, Prime Power Unit, and Cooling Unit. Any redesign would have cost more and had the potential of increasing the physical dimensions of that equipment such that it would not be deployable in C-141 aircraft (one of the system requirements). [Ref. 13:p. 5] While PHEMT is more technologically advanced, cost will be comparable to the MESFET module. PHEMT and MESFET MMICs for this application have similar physical structure and, consequently, use similar fabrication techniques. A great deal of manufacturing experience with MESFET modules for the UOES radars has resulted in process improvements that will be applied to PHEMT module production. These improvements will offset any costs due to PHEMT technology's more expensive cost of material. [Ref. 13:p. 16] The result is improved performance at the same cost as the existing module. At a current cost of \$1100 per module, total module costs are \$27.88 million for the T/R modules in just one antenna unit. The next challenge was to reduce the price of this cost driver to make the radar more affordable.

## **E. CHAPTER SUMMARY**

While the threat of Soviet ballistic missiles has gone away, there still exists many nations possessing or developing a ballistic missile capability. The United States and its deployed forces are vulnerable to any hostile nation who decides to employ these weapons. The Ballistic Missile Defense Organization is charged with developing systems that will combat these threats. One of the systems designed to defeat enemy missiles in a tactical theater is THAAD. The radar is the eyes of the THAAD system. Without acquiring and tracking the target, the system is ineffective. Due to the long range capability of the system, THAAD radar faces demanding performance specifications. A critical component in meeting these high system specifications is the T/R module contained in the antenna equipment unit. TRPO has already investigated and transitioned from MESFET to PHEMT technology in order to meet EMD and production performance requirements. Future efforts would be aimed at making the system more affordable without reducing effectiveness.



### **III. ACQUISITION REFORM**

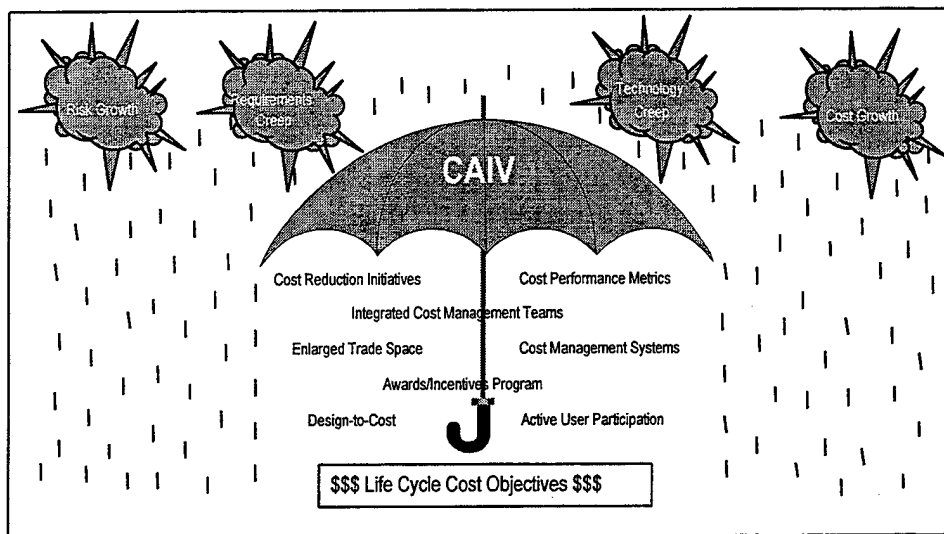
#### **A. INTRODUCTION**

In his June 1994 memorandum, "Specifications and Standards - A New Way of Doing Business," Secretary of Defense Perry initiated a new era of acquisition reform. This memorandum outlined his guidance to abandon use of the existing detailed standards and move toward performance specifications and sound commercial practices. This memorandum set the tone for the revision of the DOD 5000 series which was published in March 1996. [Ref. 14:p. 44] Six major themes were incorporated into these revised documents. They are teamwork, tailoring, empowerment, cost as an independent variable, commercial products, and best practices. The THAAD Radar Project Office (TRPO) has relied on the reform initiatives of CAIV and commercial product use to achieve reductions in the cost of a significant cost driver. While it is acknowledged that other acquisition reform initiatives played a part in this cost reduction effort, the emphasis of this thesis is on the previously mentioned reforms. This chapter will discuss the theory behind these acquisition reform initiatives and introduce the risk management process.

#### **B. COST AS AN INDEPENDENT VARIABLE**

Cost as an independent variable (CAIV) is an acquisition philosophy or strategy that seeks to deliver the greatest amount of performance at an affordable

price. CAIV is an umbrella strategy for managing life cycle cost as a key design parameter. [Ref. 15:p. 6] Included under this umbrella strategy are techniques for achieving cost goals, as shown in Figure 2. Traditionally, the Program Manager must balance three key variables in order to be successful: cost, performance, and schedule. CAIV strives to achieve a balance between life cycle cost, acceptable performance, and a feasible schedule within acceptable risk. To do this, the CAIV concept fixes the cost variable causing performance and schedule trade-offs within the cost constraint.



**Figure 2. CAIV Strategy [Ref. 14:p. 6]**

### **1. Establish Trade Space**

In the past, weapon system development has allowed performance requirements and technology to drive cost. The goal of that environment was the achievement of all the capability that the user wanted. This led to increased cost as

capability was added. CAIV attempts to reverse that mindset. Given limited resources, the developer and user must establish trade space given desired system performance requirements and available funding. This trade space is illustrated in Figure 3. Key performance parameters (KPP) are characterized by threshold and objective values. Thresholds are the minimum performance requirements necessary to fulfill the mission need. Objective values are anything beyond thresholds that represent a desired capability. As the figure depicts, it is most desirable to achieve performance at or near performance objectives with low life cycle cost. The least desirable area is performance at or near the threshold at a high life cycle cost. The trade space is the area defined by the performance and cost parameters. Trade-offs within this area must be conducted in order to obtain the most performance given a cost target. [Ref. 15:p. 2]

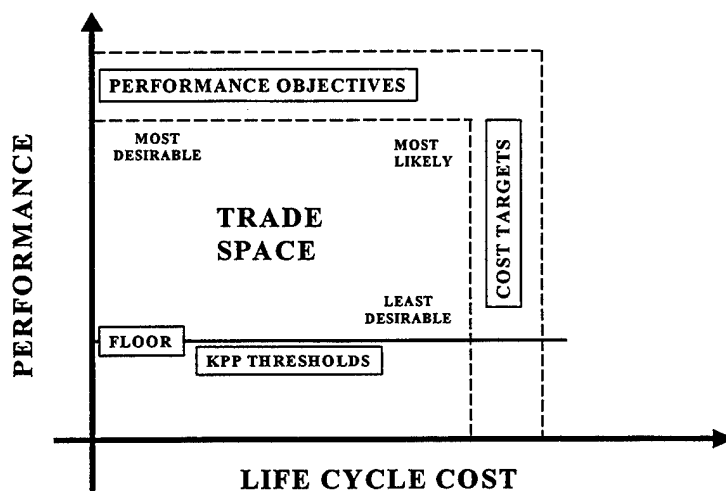


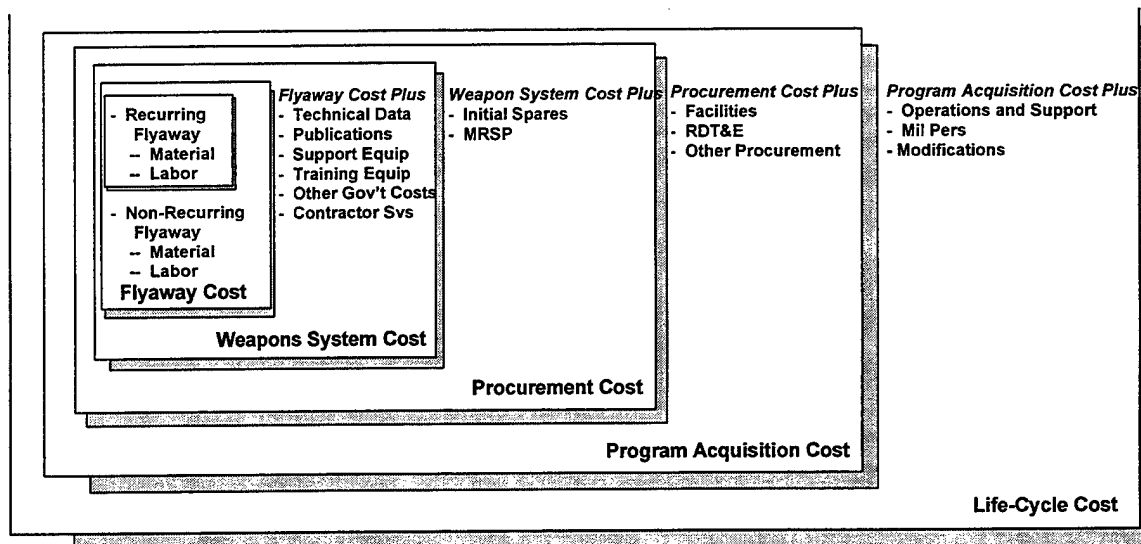
Figure 3. Establishment of Trade Space [Ref. 15:p. 2]

A strong user role is required in this process in order to make decisions regarding cost-performance trade-offs. Dr. Kaminski, Undersecretary of Defense for Acquisition and Technology, formed a CAIV Working Group that sought to better define the principles of CAIV and to outline a process toward achieving the CAIV objectives. The process includes:

- Setting realistic but aggressive cost objectives early in each acquisition program.
- Managing risks to achieve cost, schedule, and performance objectives.
- Devising appropriate metrics for tracking progress in setting and achieving cost objectives.
- Motivating Government and industry managers to achieve program objectives. [Ref. 17:p. 1]

## **2. Setting Aggressive Cost Objectives**

In line with the acquisition reform initiative of DOD use of sound commercial practices, DOD should set cost objectives similar to commercial businesses. In determining a cost objective it is important to note that the CAIV concept addresses total life cycle cost. In today's budgetary environment, it is easy to focus on the near term objective of production, or flyaway cost. As a reminder, Figure 4 is included as a reference to the difference between flyaway and life cycle cost.



**Figure 4. Different Cost Nomenclature [Ref. 17:p. 4]**

Establishment of cost objectives should account for available resources, recent unit costs of similar systems, parametric estimates, developing technology, developing manufacturing techniques, and improved processes. It is important to remember that achieving these aggressive cost objectives in the production and operating phases of the system's life cycle may involve incurring a greater up-front investment in earlier phases of the program. A return on investment analysis may be warranted to determine if the up-front investment has merit. [Ref. 17:p. 4]

### **3. Managing Risk**

A challenge to CAIV implementation is the risk associated with aggressive cost objectives. To effectively implement CAIV in order to achieve lower cost objectives, risks must be identified and managed. In the past, risk management has focused on performance. [Ref. 17:p. 5] Pursuit of aggressive cost objectives now

demand that risk management focus on cost, as well. One method of reducing cost risk is selecting a contractor who is proposing the use of mature processes. A way to measure the maturity of a process and the associated cost risk is to construct a plan that demonstrates achievement of key technologies, processes, and management techniques toward arriving at the cost objective. [Ref. 17:p. 5] The Working Group provided an example of such a plan as seen in Table 2.

Factor	Indicators
Design Simplification (Mission/Complexity)	<ul style="list-style-type: none"> <li>- Mission simulation complete</li> <li>- 80% solution analysis complete</li> </ul>
Mature Manufacturing Processes (Cost/Yield)	<ul style="list-style-type: none"> <li>- Scalable process demo-ed</li> <li>- Statistical process controls in place</li> </ul>
Technology (cost trends, cost/performance)	<ul style="list-style-type: none"> <li>- Product available</li> <li>- Market prices established</li> </ul>
Effective Integration (Errors/Redesign)	<ul style="list-style-type: none"> <li>- 100% 3-D product model exists</li> <li>- Test articles available</li> <li>- Software available</li> </ul>
Commercial Processes and Components (Cost/Performance)	<ul style="list-style-type: none"> <li>- Environmental suitability established</li> </ul>
DOD Prototype	<ul style="list-style-type: none"> <li>- Integration verified</li> </ul>
Elimination of (unnecessary) DOD Unique Business Practices	<ul style="list-style-type: none"> <li>- Low-cost business processes employed</li> </ul>

**Table 2. Factors and Indicators in Reducing Risk [Ref. 17:p. 6]**

The factors all contribute toward mitigation of cost risk. The indicators provide a measure of achievement for that specific factor. For example, when a contractor demonstrates a manufacturing process then cost risk associated with that process is reduced.

Though the Working Group never explicitly states it, the example plan is one of the first steps in a good risk analysis plan. Table 2 identifies risk events in the factors column and attempts to quantify those events in the indicator column. A more formal effort at analyzing risk will be examined in Chapter IV.

#### **4. Metrics**

In order for CAIV to work best, it must be implemented early in the acquisition life cycle where trade-offs of cost and performance can be easily incorporated in the design. Opportunities to reduce costs should not end there, however. In order to assist in management of CAIV implementation, the Working Group encourages the use of metrics and observables. The matrix in Table 3 is an example of such a tool. Use of such a tool will allow for assessment by management on the progress of CAIV initiatives. This matrix is not all encompassing. A matrix for risk reduction should be established for those areas in which the program office feels that oversight is warranted.

#### **5. Motivating Managers and Industry**

DOD 5000.2-R, Mandatory Procedures for Major Defense Acquisition Programs (MDAP) and Major Automated Information System (MAIS) Acquisition

METRIC	OBSERVABLE
<ul style="list-style-type: none"> <li>• Are cost objectives defined and consistent with requirements programmed and projected fiscal resources?</li> </ul>	<ul style="list-style-type: none"> <li>- Out-year resources identified? (\$)</li> <li>- Production and O&amp;S cost objectives included in the RFP?</li> <li>- Key tradeoff issues addressed?</li> </ul>
<ul style="list-style-type: none"> <li>• Is DoD managing to achieve cost objectives?</li> </ul>	<ul style="list-style-type: none"> <li>- Request For Proposal (RFP) contains a strict minimum number of performance specifications?</li> <li>- Cost/Performance-Integrated Product Team (IPT) functioning; tradeoff space identified in program baseline and RFP?</li> <li>- Risks to achieve cost objectives identified and program steps to address these defined? (risk plan )</li> <li>- Incentives for achieving cost objectives included in the RFP and contract? ( % relative to total contract \$'s )</li> <li>- Mechanism for contractor suggestions to reduce production and O&amp;S costs in place and operating?</li> <li>- Allocation of cost objectives provided to IPTs and key suppliers</li> <li>- Measurement and estimation of reliability and maintainability</li> <li>- Robust contractor incentives plan in place?</li> </ul>
<ul style="list-style-type: none"> <li>• Are contractors managing to achieve cost objectives?</li> </ul>	<ul style="list-style-type: none"> <li>- Providing appropriate tools for cost-performance tradeoffs (including incentives for corporate management) and participates in cost-performance tradeoff process</li> <li>- Identifying (and when appropriate implements) new technologies and manufacturing processes that can reduce costs</li> <li>- Identifying procedural/process impediments to cost reduction measures</li> <li>- Establishing strong relationship with vendor base, including sound incentives structure</li> </ul>

**Table 3. Metrics and Observables [Ref. 17:p. 8]**

Programs, requires CAIV be addressed in all acquisition strategies. It specifies in Part 3, paragraph 3.3.4,

CAIV is a process that helps arrive at cost objectives (including life-cycle costs) and helps the requirements community set performance objectives. The CAIV process shall be used to develop an acquisition strategy for acquiring and operating affordable DOD systems by setting aggressive, achievable cost objectives and managing achievement of these objectives. Cost objectives shall also be set to balance mission needs with projected out-year resources, taking into account anticipated process improvements in both DOD and defense industries. [Ref. 18]

Furthermore, Army Regulation 70-1, Research, Development, and Acquisition Army Acquisition Policy, echoes DOD policy in that CAIV be applied to acquisition category (ACAT) I, II, and III programs and be used as a guideline for ACAT IV programs. [Ref. 19] Program Managers, therefore, are obligated to implement CAIV. However, CAIV will be difficult to implement unless the Program Managers and contractors are motivated to seek realistic and significant cost objectives. The CAIV Working Group states that,

the Program Manager needs the encouragement of the users, CAEs (Component Acquisition Executive), and DAE (Defense Acquisition Executive) to accept risks associated with aggressive cost objectives, and promotion policies must recognize and reward good tries as well as successes...by far the best incentive for managers is an environment that promotes goal setting, teamwork, and recognition of accomplishments from the management chain. [Ref. 17:p. 6]

Encouragement to take risk may not be enough, though. In a zero-defect environment, "good tries" may be translated as failures. In an interview, Dr. Kaminski describes a hypothetical situation in which a PM invests funds today to reduce life cycle cost. He states,

If the system operates in a way so that a Service or a PEO or a Program Manager has to put up funds today to make that improvement, and then when the out-year savings are realized those funds are swept up by the financial community or elsewhere and those funds are not available to the program or to the Service, then you have to ask yourself, 'Why do that? Why take this risk of investing up-front dollars and not be able to realize any benefits downstream?' [Ref. 20:p. 11]

He advocates returning a portion of those savings back to the organization in order to create an environment where PMs will take risk. [Ref. 20:p. 11]

Motivating industry to reduce cost is a difficult task, also. Dr. Kaminski stated, "I cannot help but wonder where the incentives are in the system for the producer to reduce unit price when that is simply going to result in less revenue." [Ref. 20:p. 11] According to the CAIV Working Group, the answer to this lies in competition. Competition to attain business and associated profit can be used to motivate industry toward achieving cost objectives. In order to initiate competition, the request for proposal (RFP) should include cost objectives for the system. Based on the stated cost objectives, the offerors may then provide credible solutions with acceptable risk. In order to maximize the leverage of competition, it

should be employed as long as reasonably possible in the acquisition cycle. [Ref. 17:p. 7]

Once a contractor is selected, there are a variety of mechanisms to motivate it toward cost savings. Mechanisms include contract incentives and value engineering programs. The contract can be structured such that continuing efforts to reduce cost are rewarded. Depending on the acquisition phase, a fixed price incentive fee or cost plus incentive fee contract may be appropriate. In lieu of incentive fees, award fees may be offered that place emphasis on achieving cost or on cost reduction efforts as part of award fee criteria. [Ref. 17:p. 7]

Value engineering is the analysis of a program or product by a contractor in order to improve life cycle cost. There are two approaches to value engineering. The first is an incentive arrangement where a contractor voluntarily uses its own resources to develop and submit change proposals that will reduce life cycle cost. The contractor will share in any savings if the change proposal is accepted. The other approach is mandatory value engineering. In this approach, the Government requires and pays for a specific level of contractor effort associated with any value engineering efforts. As with the voluntary approach, the contractor shares in savings, but at a much lower rate. [Ref. 21:Part 48, para. 101] An alternative way to motivate the contractor is by appealing to its corporate financial and market strategy. This will be addressed in the next section.

### C. COMMERCIAL PRODUCTS

This acquisition reform principle acknowledges the shrinking defense industrial base. Faced with declining defense budgets, traditional defense contractors have had to expand into commercial markets in order to survive. This trend has resulted in DOD no longer being a dominant customer. DOD can no longer exercise its influence as a large customer to get what it wants. [Ref. 22:p. 7] Additionally, DOD has recognized the cost and time savings if development of an item can be avoided by purchase of a commercially available item that meets a validated need. Transfer of commercial items, technologies, and processes for a military need describes what has become known as dual-use technologies.

Most often the trend for technology transfer within a dual-use technology concept involves the application of a commercial product or process to a program. Recent legislation encourages technology transfer between commercial and Government endeavors. [Ref. 23:pp. 22-23] There are many cases, however, where defense technology is used to build or improve a commercial capability. Supporting this idea, Executive Order 12591 states that "the head of each Executive department and agency, to the extent permitted by law, shall encourage and facilitate collaboration among Federal laboratories, State and local governments, universities, and the private sector, particularly small business, in order to assist in the transfer of technology to the marketplace." [Ref. 24]

## **1. Benefits of Dual-Use Technology To DOD**

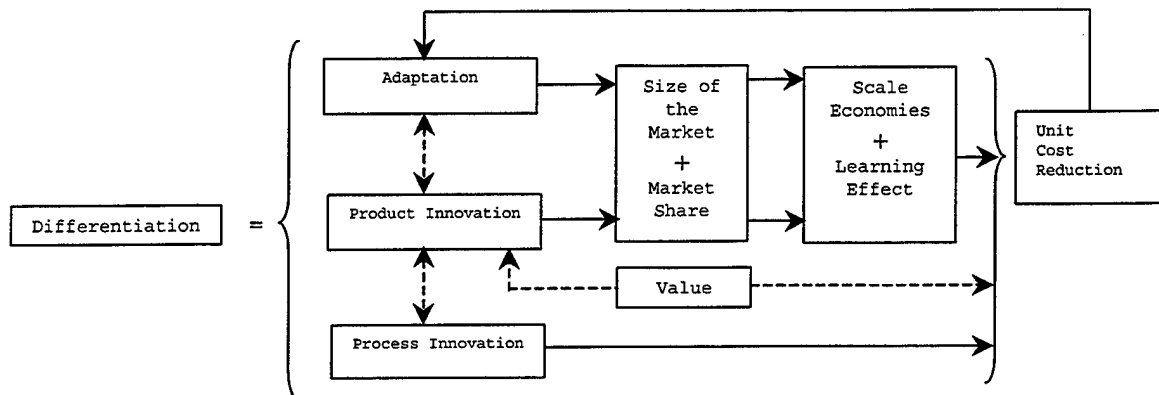
If a DOD capability is transferred to a commercial segment, DOD benefits in three ways. First, DOD benefits due to the economies of scale generated by the commercialization of the product. These economies of scale should result in a lower unit cost for DOD. Second, commercialization helps to maintain production of the item should it be necessary for future defense needs. In the past, DOD requirements normally generated small production runs of an item. In order to maintain the manufacturing capability for future use, DOD would pay a price. If a manufacturer achieves commercial success with a DOD product, then the commercial segment maintains the manufacturing base and DOD does not bear the cost. Finally, commercial application of military hardware may motivate manufacturers to seek improvements of the product in order to appeal to the commercial sector. Furthermore, the manufacturer may seek ways in which to reduce the manufacturing cost of the product in order to improve its profit. Such improvements can benefit DOD by improving performance of the product or lowering procurement costs on subsequent buys. [Ref. 22:p. 19]

## **2. Benefits of Dual-Use Technology To Industry**

Adaptation of a defense technology to a commercial market may greatly benefit the manufacturer, as well. Minimizing or eliminating development costs for an item improves the firm's profit and return on investment. Investment by

DOD to improve the performance or reduce the cost of a high technology item fits in perfectly with a firm's financial and market strategy.

Roland Calori formulated a model (see Figure 5) to describe the relationship between product differentiation and cost for high technology,



**Figure 5. Differentiation and Impact on Cost [Ref. 23:p. 25]**

emerging industries. Porter first described emerging industry as one with technological newness and uncertainty. [Ref. 25:p. 22] Calori states that, "emerging industries may be in the introduction or growth phase and they have several high differentiation opportunities based on research and development." High technology is defined in terms of entry barriers into the industry. These entry barriers are characterized by:

- A high minimum critical mass of research and development
- High research and development costs

- High technological uncertainty (products and processes)
- Technological knowledge is difficult to find on the labor market

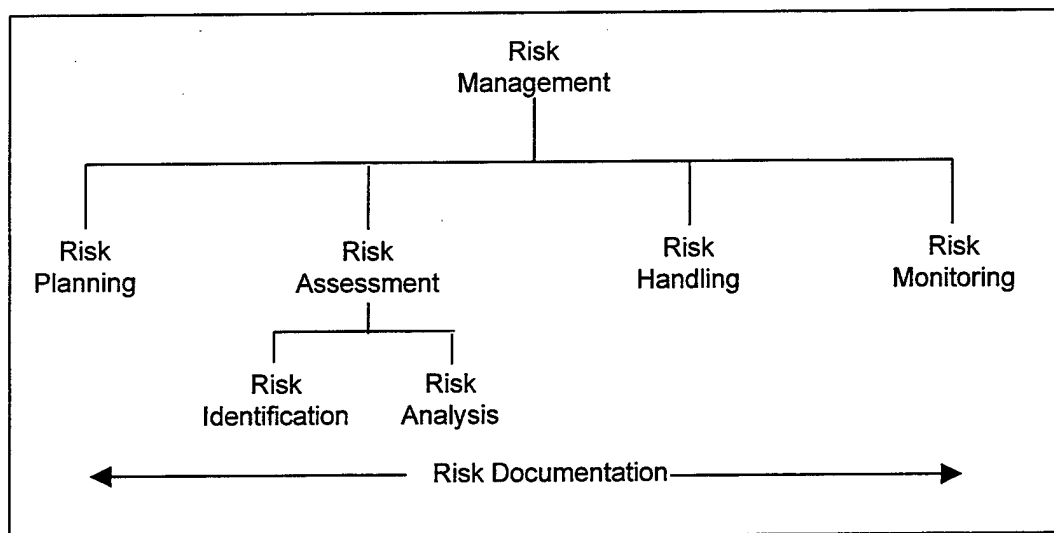
In this model, differentiation is a result of product innovation, process innovation, and adaptation to new market segments. Adaptation and product innovation garner a larger market share that leads to greater economies of scale. Greater economies of scale, in turn, can lead to a reduction in unit cost. Innovation of the process may also lead to reduced manufacturing cost. This reduced cost may lead to new markets and the cycle repeats. Product differentiation can be exhibited through quality, delivery time, enhanced features, greater performance, or even lower cost. Efforts to improve the performance of a product and reduce unit cost will serve to differentiate the product. [Ref. 25:p. 25]

An example of a DOD technology that has been applied to a commercial market is the FOREWARN© system installed on school buses. This system makes use of MMIC technology developed by DOD's Advanced Research Projects Agency (ARPA) for military radars and communications. At the time this technology was developed, the Air Force chose a phased-array radar that uses MMICs for the F-22. Delco Electronics, a subsidiary of then General Motors Hughes Electronics, saw the potential for such technology in a commercial application. This application was collision avoidance for vehicles; more specifically, in school buses which have large blind spots immediately in front. Each year, there are fatalities when children are run over by their own bus. The

FOREWARN© system senses objects and alerts the driver of the obstruction. Delco Electronics benefited in the Air Force's expenditure of funds in the development of the technology, while the Air Force benefits in the volume that the commercial market will bring to the production of MMICs. [Ref. 22:p. 20]

#### D. RISK MANAGEMENT

As stated in the Defense Acquisition Deskbook, "Inherent in the CAIV concept is the realization that risks are present and must be managed in order to achieve performance, schedule, and cost objectives." [Ref. 26] An understanding of the risk management process is necessary before undertaking any cost saving initiative. Figure 6 provides an overview of the risk management process.



**Figure 6. Risk Management Structure [Ref. 27:p. 5]**

"Risk is the measure of the potential inability to achieve overall program objectives." [Ref. 27:p. 5] Risk management is the practice of dealing with risk.

It is comprised of the four elements seen in Figure 6. Risk planning deals with developing an overall strategy for dealing with risk in a program. Risk assessment is subdivided between identification and analysis. Risk identification is the process of examining the program areas and identifying potentially risk areas. Risk analysis determines the impact of each of the identified risk areas on the program in terms of cost, schedule, and performance. Once the impact of an event is determined, methods to reduce risk to acceptable levels are examined. These methods are known as risk handling methods. Risk monitoring occurs after risk handling techniques are implemented. Risk monitoring attempts to track and evaluate the effectiveness of these techniques against established metrics such as those outlined by the CAIV Working Group. Finally, all risk management activities should be documented during the process. This is illustrated as risk documentation in the figure. [Ref. 27:pp. 4-5]

## **E. CHAPTER SUMMARY**

Within the last five years a revolution has occurred in the acquisition of weapon systems for DOD. Spurred by Dr. Perry's efforts, the acquisition community has looked toward commercial business for ways to acquire equipment better, cheaper, and faster. These acquisition reform initiatives have been incorporated into Department guidance for the acquisition of systems. THAAD Radar Product Office used two of these initiatives to initiate a cost saving effort.

They are CAIV and the use of commercial products as embodied by dual-use technology. CAIV is not simply a technique that one applies, but instead, a philosophy for managing life cycle cost of a system. The pursuit of aggressive cost objectives brings with it a certain amount of risk. The amount of risk must be identified and reduced to acceptable levels before efforts are undertaken. The risk management process plays a critical role toward that end. The use of commercial products implies dual-use technology. Dual-use technology goes two ways, however. Normally, dual-use means the application of commercial items to meet a military need. There are many instances where military items have been modified for use in the commercial market. It will be shown in the next chapter that the THAAD Radar cost savings study incorporated both of these initiatives to achieve its goal.

## IV. ANALYSIS

### A. INTRODUCTION

In early 1998, the idea for a Best of Breed (BoB) T/R module study took root. The study was to investigate methods to produce a less expensive module than was currently being used in the radar. The tenets of CAIV will be used to analyze this initiative. Additionally, the dual-use nature of T/R module technology will be addressed as a motivator for the contractor. Finally, an assessment of risk to program cost, schedule, and performance will be conducted.

Development of the scope of work (SOW) for the BoB study began in April and was completed in early May 1998. It is important to note that SOW development was done jointly in conjunction with Raytheon, subcontractor for the radar. THAAD Radar Product Office has contracted with Mitre Corporation for the consultation services of a microelectronics expert. This expert has provided TRPO with valuable input into areas of potential cost savings for the radar. A request for quotation (RFQ) was sent to THAAD's prime contractor, LMMS, on 7 June 1998. The study began in late July 1998 as an adjunct to the existing LMMS/Raytheon contract. [Ref. 28]

The SOW contains four ground rules for development of the low cost module (LCM) concept. These ground rules are:

1. The THAAD Antenna Equipment array architecture will not be affected below the T/REA level.
2. Technology and processes consistent with current insertion points.
3. The recurring cost estimate for the module concept(s) will be developed from a detailed cost analysis based on experience where available and recognized cost models where new processes, materials, etc. are required.
4. The contractor will mitigate risk in his approach by avoiding speculative technologies, maintaining parallel approaches where appropriate, and by a thorough and careful analysis of estimated module costs. [Ref. 29]

## **B. TRADE SPACE**

THAAD Radar Product Office did not seek to establish trade space in the classic CAIV sense. The acquisition strategy for the radar called for increased performance for the next acquisition phase. Due to this increase, TRPO did not have performance to trade off to reduce cost. Cost reductions had to come from a source other than performance trade-offs.

## **C. COST OBJECTIVE FOR BEST OF BREED STUDY**

The SOW states as its primary objective the definition of a module "that will provide significantly lower cost for production while meeting or exceeding EMD performance." [Ref. 29] Reduction in cost of the T/R module impacts not only production cost of the radar, but also spares. Recall that T/REAs were designed as line replaceable units. With 32 T/R modules per T/REA, reduction in

unit cost of each module will affect the support costs of the system in the future. Later, it defines "significantly lower" as "greater than 2:1 reduction in cost...for LRIP and beyond." [Ref. 29] A 50% reduction in the cost of a significant cost driver can certainly be deemed aggressive. Of greater interest is how they arrived at this goal. Recent improvements in the contractor's knowledge base and costs of similar components of different programs served as a starting point for establishing the cost objective.

Much has been written about recent mergers within the defense industry. Conventional wisdom suggests that with the creation of mega-corporations through mergers that competition will be reduced. [Ref. 30:p. 25] [Ref. 31:p. 2] There may be, however, a period following these mergers that acquisition managers may take advantage of the recent conglomeration of talent and technologies now under one roof. Companies that previously brought different approaches to a system under a rivalous relationship may now be merged into one corporation. In a competitive proposal environment, federal acquisition regulations prevent Government officials from revealing competitor's technical approaches and processes to others. Once acquired through merger, the Program Manager may direct the examination of what was once a rival's approach.

Just this situation occurred in the BoB module study. Recent acquisition by Raytheon of Hughes Electronic Systems and Texas Instruments Defense Company

pooled a large amount of expertise in MMIC manufacturing technology. Realizing the potential for cost reduction due to the increased knowledge base of Raytheon, the TRPO initiated this study. [Ref. 28]

Familiarity with technological advances in chip manufacturing also drove the setting of cost objectives. TRPO was aware the prices of T/R module being worked on by Raytheon West (formerly Hughes) and Raytheon East in conjunction with the Navy Affordable Module program. Estimated cost for this module was \$300. While this module did not meet all of the THAAD radar performance requirements, it did illustrate the feasibility of a low cost module. Other developing programs using T/R modules, such as the F-22 module program and the HF-4 module program were looked at as benchmarks as well. [Ref. 28]

In order to achieve these cost objectives, TRPO realized that it may incur an investment up-front to develop the technology necessary to reduce life cycle cost. The BoB study was designed not only to determine the feasibility of reducing the module unit cost, but also to determine the investment required to do so. Once this is known, analysis can be done to determine the merit of the cost reduction efforts.

#### **D. MANAGING RISK IN THE BOB STUDY**

In implementing any cost saving initiative care must be taken so that the baseline is not increased. In the case of BoB, the baseline was the current cost, schedule, and performance of the existing PHEMT T/R module. This meant that

any concept must not cost more than \$1100 per module, the module must meet EMD performance specifications, and insertion of the LCM must not cause a production slip of the currently scheduled first LRIP radar beginning in FY2003.

Rule one stated that the THAAD AE array architecture will not be affected below the T/REA level. In other words, T/REAs with the LCM will have the same form, fit, and function (F3) as the current PHEMT T/REAs. [Ref. 29] As discussed previously, any change in the T/REA F3 may necessitate a costly redesign of the antenna equipment. Redesign of this component may drive a redesign of the power unit and/or the cooling unit. Also, any increase in size, due to a redesign, may violate the current transportability requirement. In stipulating this rule in the SOW, TRPO stabilized the physical architecture of the radar system. In doing so, they reduced the risk of incurring high costs, schedule slips, and transportability problems potentially associated with a redesign of the antenna array.

The second rule addressed concerns with the maturity of the examined technologies and processes necessary to achieve the cost objectives. As the CAIV Working Group points out in their paper, "...production cost objectives can only be achieved by demonstrating and bringing to maturity key manufacturing processes." [Ref. 17] With this in mind the rule caused only technologies and processes that will be sufficiently mature at the desired insertion points to be used. There are two

options for insertion of the LCM into the radars. Option one is for two sub-arrays populated with the LCMs to be inserted into the second EMD radar prior to near-field range calibration. This will provide test data for the module prior to insertion into production radars. The second option is for the first LRIP radar to be fully populated with LCMs. [Ref. 29] In creating this parameter for the study, TRPO mitigated its risk in the areas of schedule and cost. In stipulating this rule, TRPO sought to avoid speculative technologies that will not be mature at the desired point of insertion. If a pursued technology or process is not mature when wanted, there are two alternatives. The first is to delay the schedule until the technology is mature. Normally, delays translate into increased costs. This is an unattractive alternative for a program that is already very expensive and years behind schedule. The other alternative is to insert the LCMs into later radars. In other words, if the technology to produce the LCM is not ready by LRIP 1, then produce the LRIP 1 radar with the \$1100 module and insert the LCM into the next radar after technology maturation. The problem with this option is that every radar produced without the LCM is an opportunity lost. Each radar produced with the \$1100 module instead of the LCM is \$13.9 million more expensive. If too many opportunities are lost the return on investment becomes suspect. Rule two sought to avoid these pitfalls by requiring use of viable, mature technologies and processes when they are needed.

Rule three addressed the cost projections of the study. It required the contractor to provide a detailed cost analysis for the recurring costs of a production LCM. Historical data was to be used when available and recognized cost models used for any new processes and materials. Use of such data provided a more accurate and reliable unit cost on which to base decision making. [Ref. 29] Provision of this data will allow TRPO to conduct a cost realism analysis. In so doing, they will be able to determine the viability of achieving the cost estimate given the concept. Approval of the cost data after analysis by cost analysts will reduce the risk of the cost estimates being revised upward over time. Verification of the cost data will also allow life cycle cost savings to be predicted more accurately. Reliable cost savings data is critical when performing investment analysis.

Another component critical to investment analysis is the initial investment. The SOW required the contractor to develop and submit cost estimates for non-recurring effort associated with development of the LCM. These estimates will also be subject to cost realism analysis in order to be used as a basis for budgeting and analysis.

Finally, rule four directly addressed risk mitigation. In mandating the avoidance of speculative technologies, maintaining parallel approaches, and analyzing carefully all estimated module costs, TRPO covered risk to cost,

schedule, and performance. Speculative technologies imply technologies or processes that are currently theory and have not yet been proven feasible. Use of such technology would incur great risk - risk in the development of the technology costing more than initially estimated; risk in the technology not achieving the estimated cost savings; risk in the technology not yielding the expected performance; and risk in the technology taking longer to develop than initially anticipated. All of these risks jeopardize meeting the Acquisition Program Baseline (APB) for cost, performance, and schedule.

The parallel approach requirement also sought to reduce risk in cost, performance, and schedule. The SOW states, "The BoB concept can be one or more module embodiments if a 'multi-prong approach' helps mitigate the risk...." [Ref. 29] The contractor is not locked in to one solution. If more than one solution looked promising, then both could be pursued in order to spread the risk. If more than one viable approach is developed, the greater the chance that one approach will produce the desired cost, schedule, and performance. In this manner, a parallel approach could reduce the risk of not achieving the goal.

Finally, rule four addressed the topic of estimating costs. This appears to be a reinforcement of rule three but, also served as a reminder to the contractor to be accurate and complete in cost estimating. Introduction of risk due to poor cost estimates is anathema to the concepts of CAIV and cost reduction.

## **E. METRICS IN ACHIEVING COST OBJECTIVE**

Analysis of this initiative is occurring during the concept study phase. As of this date, the study has been completed and cost reduction ideas to achieve the target cost proposed. The decision to fund this initiative and proceed with the LCM concept is pending. As such, development of metrics to track progress is premature. Should approval be granted and funds obligated, metrics should be instituted immediately in order to monitor progress in achieving the cost objective with the stated performance within the timeline established. The table of metrics presented earlier is a good starting point. This table should be tailored, however, to cover the particulars of this initiative. Use of an earned value (EV) system tailored to this initiative may also be beneficial in determining progress.

## **F. MOTIVATING GOVERNMENT AND INDUSTRY MANAGERS**

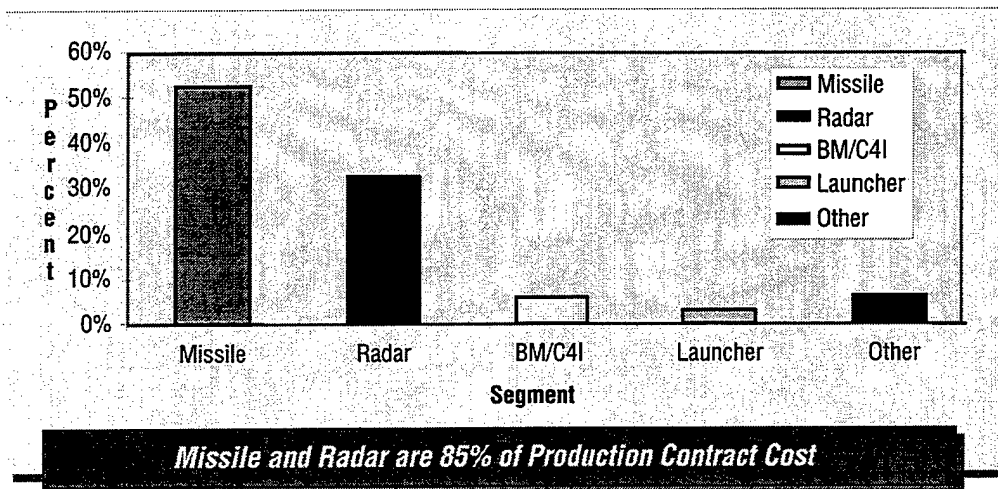
### **1. Government Managers**

Regulatory mandate for the use of CAIV was not the genesis of TRPO's efforts with the BoB study. Motivation to reduce cost in this effort was driven by external pressures. LTG Lyles, the BMDO Director, presented THAAD Program Office with a challenge to reduce cost. [Ref. 28] The challenge was an outgrowth of the reduced funding that THAAD received for FY 1999. With no intercepts in five attempts, public and Congressional support is beginning to wane.

	FY 97	FY98	FY 99
Budget Request	\$481.8	\$556.1	\$821.7
Appropriated	\$621.8	\$406.1	\$387.1

**Table 4. THAAD Funding for FY97-99 (TY, \$M) [Ref. 32]**

Congressional support for THAAD is decreasing as evidenced by its reduced funding as shown in Table 4. In response to these funding reductions, ways had to be found to reduce cost. Analysis of costs by the THAAD Project Office revealed that 85% of costs for future production were associated with the missile and the radar as illustrated in Figure 7. [Ref. 33:p. 3] These two cost drivers were candidates for cost reductions. Examination of the radar reveals that 80% of the costs are in the antenna equipment, with the cost driver being the T/R module. [Ref. 28]



**Figure 7. Breakdown of Cost Drivers [Ref. 33:p. 3]**

A survey of service efforts in T/R module technology showed a wide disparity in costs. Granted each service was developing a module for vastly different missions, but LTG Lyles felt that common items should be closer in cost than they currently were. [Ref. 28] All of these pressures have served to motivate managers to seek ways to reduce cost.

Lacking external pressure, there is little incentive to seek cost reduction. Other than the regulatory requirement to implement CAIV, there is little incentive for Program Managers to aggressively pursue cost reduction. This lack of incentive is due, in large part, by the fiscal Darwinism that has become the reality today. We hear stories telling managers to obligate funds early, for if you don't the comptroller will surely take those funds. We are reminded to build in a management reserve but not to call it such or it will be taken away. Dr. Kaminski admits that the financial community sweeps up out-year savings realized from today's cost saving initiatives. In the aggregate, a Program Manager is rated on how well he manages the cost, schedule, and performance parameters of a system while under his leadership. Given the conditions described before, what PM would risk his career in pursuit of cost objectives that are inexorably tied to performance and schedule? Once cost objectives are set, they can now be used as the basis for program funding. For a program that already had a funding baseline, reductions to that baseline based on new cost targets become fair game for the

financial community. This leaves the PM without a safety net should there be difficulties in the development of the cost saving idea. The PM would be more motivated if some of those funds remained at the program office as a reserve in case developmental problems were encountered. The current environment does not motivate PMs to seek large cost reductions, if any at all. Instead, they will seek small reductions with corresponding minimal risk. In order to achieve large, meaningful reductions, the PM must have a sense that funding is available if he or she gets in trouble.

## **2. Motivating Industry**

Industry gathers its motivation to reduce cost from many sources. Influences such as customer interest and encouragement, competition, contract incentives, and ability to increase market share all motivate industry to seek cost reductions of a product. [Ref. 34] Additionally, reductions to manufacturing costs have the potential to improve profit.

In this case, the BoB study was initiated by the TRPO in response to the pressures discussed earlier. In trying to meet the customer's needs, Raytheon undertook the study. In doing so, they also meet their own needs. As discussed previously, the SOW for this study was developed jointly between the contractor and TRPO. One of the many benefits of working jointly is that each side gains insight into the concerns of the other. This knowledge and efforts on this contract

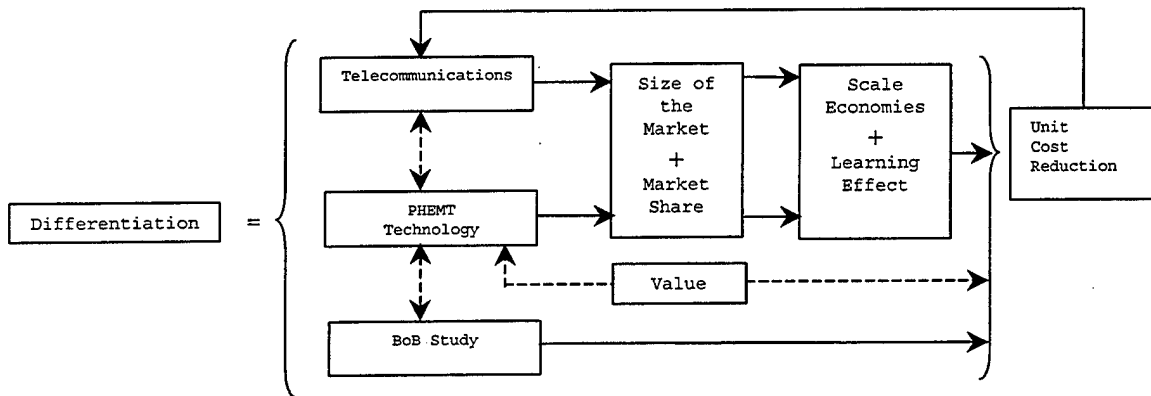
give Raytheon an advantage over its competition for future contracts. Discussions with TRPO also revealed that TRPO plans on using a cost-plus award fee contract for EMD. Award fee structure will probably incentivize module cost savings. [Ref. 12] Cost reduction efforts that Raytheon undertakes now will benefit them when they enter the EMD phase of the program.

Competition with other manufacturers also motivates Raytheon to seek cost reductions. Raytheon understands that if they don't seek to reduce cost, their competitors will. If their competitors do reduce the cost, then Raytheon will lose the business and any associated profits. [Ref. 34]

The final area that motivates contractors to reduce cost deals with financial and market strategies. A lower priced product with equal or better performance than a competitor's will increase market share. Greater analysis of this factor as a motivator for Raytheon will be conducted in the next section.

## **G. DUAL-USE TECHNOLOGY**

The model in Chapter III will be used to analyze one of the motivating factors for Raytheon. The industry needs to be high technology in nature in order for this model to apply. The applications of PHEMT technology to MMICs is a relatively new technique. Combine this technology with the high operating frequencies of the THAAD radar and it now meets the criteria set forth for high



**Figure 8. Modified Model**

technology industry. DOD investment in PHEMT technology and the BoB study has allowed Raytheon to explore innovation of product and process with little risk to Raytheon, given the cost-plus award fee contract. Following the model, as illustrated in Figure 8, product innovation in the area of increased performance due to PHEMT technology will lead to an increase in markets. Increased markets lead to higher manufacturing rates where scale economies and the learning effect drive unit cost down. Likewise, any process innovation as a result of efforts on a low cost module for TRPO will result in lower unit production costs for T/R modules.

In discussing Raytheon's motivation for undertaking the BoB study, Mr. Joseph Neville, Raytheon T/R module manager, states,

Military applications of PHEMT technology are the most demanding and technologically sophisticated, given the frequencies at which we must operate. Less sophisticated PHEMT applications at lower frequencies therefore benefit from Uncle Sam's prior investment and contractor experience gained, and open up commercial markets. But Uncle Sam wins too since building high volume commercial chips in our foundry lowers the cost of all chips, including Government

product, even though it comes nowhere near commercial volumes.  
[Ref. 34]

Mr. Neville sums up nicely the benefits of dual-use technology to both the Government and industry. Raytheon benefits in DOD's investment in technology and cost reduction efforts. This reduces their development costs and improves their profit margin for the product. As Mr. Neville stated, it also opens up potentially new markets for Raytheon to exploit.

Some commercial markets that benefit from Raytheon's T/R module research include air traffic control and telecommunications. An example of a telecommunications system is IRIDIUM©. IRIDIUM© is a global telecommunications network that uses T/R modules in its antenna to transmit information to subscribers around the world. Raytheon was selected to develop the main mission antenna and produces the L-band T/R modules with PHEMT technology for the system. [Ref. 34] [Ref. 35]

The Government benefits as well. Now as a low volume customer, DOD benefits from the production of T/R modules for commercial applications. Combined, the production of military and commercial T/R modules allows the Government to benefit from economies of scale that would not be present with a military-only product.

## H. STUDY RESULTS

The BoB study is complete and Raytheon found that the cost objective can be achieved. Cost reductions come from improvement in yield of PHEMT MMICs, integration of several MMMICs into a single MMIC, and reduction in the size of the T/R module. Integrating the MMICs and reducing the size of the module will reduce the material and labor costs necessary for manufacturing. This cost reduction does not come cheaply, however. The study determined that development of the low cost module would take three years at a cost of approximately \$8 million per year. This up-front investment would yield cost savings in the production of EMD, low-rate initial production (LRIP), and full rate production (FRP) radars. Recent schedule slips in the program would enable full population of the first EMD radar with the low cost module if efforts began immediately. This schedule slip will allow cost savings to be achieved on two more radars than originally anticipated. [Ref. 12]

Calculation of the net present value (NPV) of this investment will determine if it makes sound business sense. An investment with a negative NPV would be of little value. Current plans call for the production of two EMD, four LRIP, and seven FRP radars for a total of 13 more radars. With an estimated average unit production price for each T/R module of \$550, the savings will be approximately \$13.9 million per radar compared to using the current T/R module

with a price of \$1100. Using a 5.38% discount rate (current treasury rate for a 10 year bond), calculation of the net present value of this initiative results in a savings of \$78.9 million in current year dollars. [Ref. 36] Further calculation reveals an internal rate of return (IRR) of 34% if this cost saving effort is undertaken and realized. This NPV and IRR are based on production cost savings only. Recalling that CAIV is concerned with life cycle costs, a better calculation of these figures would include the savings in spares. At the time this research was conducted, data on spares over the life of the system was unavailable. Inclusion of spare cost savings in these calculations would cause the NPV and IRR to only increase if usage rates were comparable. Sound business sense tells you that anticipated returns alone should not influence investment. Another element to consider is the risk involved in the investment. The investment may be wasted if the likelihood of achieving success is low. Analysis of the risk involved in the project should be conducted to determine if the investment should be made.

## **I. RISK ASSESSMENT**

Essential to setting realistic cost objectives is an understanding of the risks involved in order to reach that cost objective. In examining TRPO's efforts on this initiative, it was found that no risk assessment had been conducted. TRPO accepted Raytheon's assessment of the proposed concepts as low risk and this assessment was validated by an Independent Review Team. However, no separate

formal effort was taken to determine the risk associated with implementing the recommendations of the BoB study.

According to the DSMC risk management process, risk assessment is a two-step process. The first step is risk identification followed by analysis. Risk identification serves to identify the risks inherent to the project and describe them in an understandable way. One method is to brainstorm the tasks to be accomplished and in this manner, identify those activities that may contain risk. Another, more structured method is to use the Work Breakdown Structure (WBS) to identify risk events. The WBS is used to do this because it includes all activities associated with completion of a project and provides an encompassing structure. Each identified event falls into a category of cost, schedule, or performance for evaluation. The next step is to analyze the risks. [Ref. 27:pp. 10-14]

In analyzing risk, two components must be addressed. The first is the likelihood of the event occurring. The second is, given that the event occurs, what is its impact on the program in terms of cost, schedule, and performance. The DSMC Risk Management Guide recommends that a group of experts familiar with the risk areas accomplish these ratings. The criteria they use for rating each component of risk should be based on experience and include a range of possibilities in order to discriminate adequately. Once the risk events are rated according to the criteria, a plot of event likelihood versus consequence can be

made for each of the categories of cost, schedule, and performance. [Ref. 27:pp. 15-17] In the past, there has been a tendency to assign numerical importance to the criteria and to develop a single number to portray the risk. This is possible if both scales used cardinal values that reflect absolute numerical differences between ratings. Often, ordinal scales are used to assess risk. These scales measure relative standing between ratings and not absolute numerical differences. Attempts to perform mathematical operations and assign an overall numerical risk value when using ordinal scales is wrong and could be misleading. [Ref. 27:p. 17]

Risk events for the Best of Breed assessment were created through brainstorming, as no WBS was available. Input from experts within the TRPO was solicited and incorporated into the questionnaire. The questionnaire (Appendix) was sent to TRPO with instructions to assess the impact to the overall program if the implementation of the BoB study results were pursued. The criteria in Tables 5 and 6 were used to assess risk on the implementation of the Best of Breed study results. [Ref. 27:pp. 15-16] A matrix containing combinations of consequence and likelihood ratings assigned an overall rating of high, medium, and low was used. [Ref. 27:p. 16] See Figure 9. TRPO responses were plotted for the areas of cost, schedule, and performance. These plots are illustrated in Figures 10-12. In this case, ordinal scales were used and, as discussed earlier, any attempt to develop a single number for risk would be misleading. Instead,

comparison of the plots to the matrix in Figure 9 was done to determine an overall risk rating for the category.

Likelihood	5	L	M	H	H	H
	4	L	M	M	H	H
	3	L	M	M	M	H
	2	L	L	L	M	M
	1	L	L	L	L	M
		1	2	3	4	5
		Consequence				

**Figure 9. Overall Risk Rating [Ref. 26:p. 17]**

**Likelihood Rating**

Likelihood Event Will Occur	Rating
Remote	1
Unlikely	2
Likely	3
Highly Likely	4
Near Certainty	5

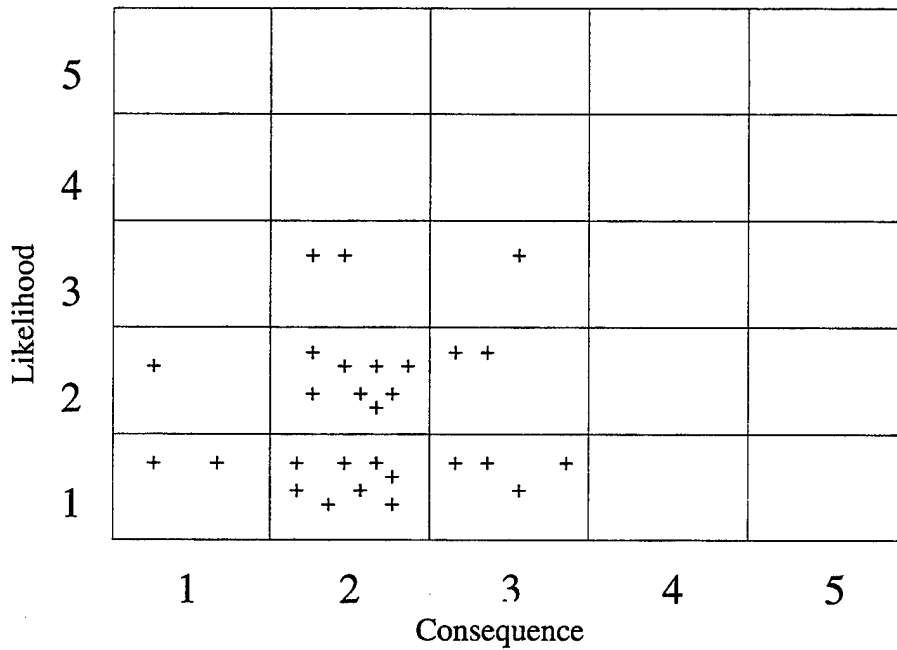
**Table 5. Likelihood Criteria [Ref. 27:p. 16]**

### Severity of Consequence

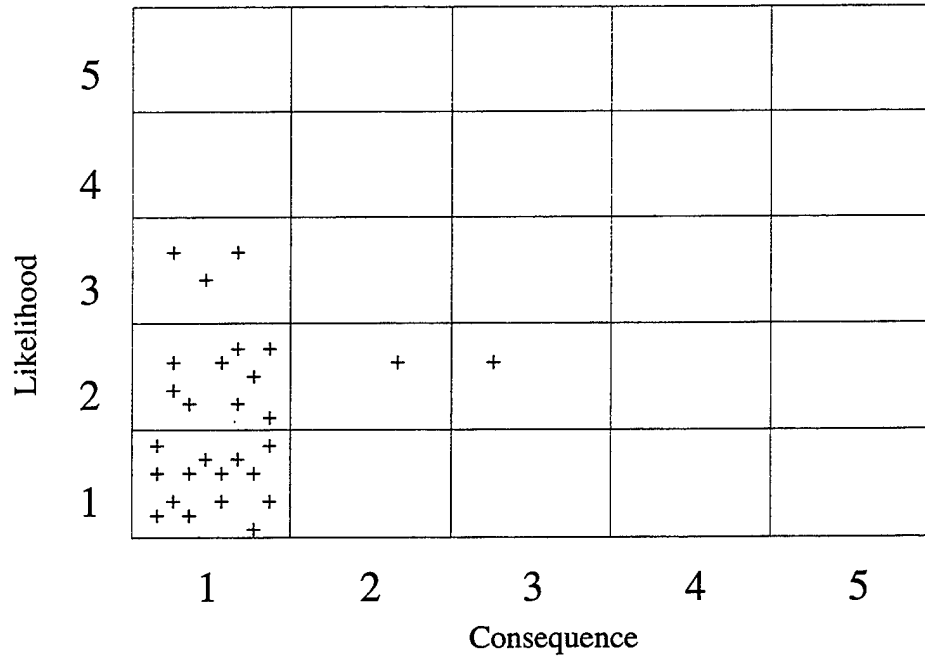
Given that the risk is realized, what is the magnitude of the impact?

Cost	Schedule	Performance	Rating
< 5%	Minimal or no impact	Minimal or no impact	1
5 % - 10%	Additional resources required; able to meet dates	Acceptable with some reduction in margin	2
11% - 15%	Minor slip in key milestone	Acceptable with significant reduction in margin	3
16% - 20%	Major slip in key milestone or critical path impacted	Acceptable; no remaining margin	4
> 20%	Can't achieve major program milestone	Unacceptable; will not meet performance requirements	5

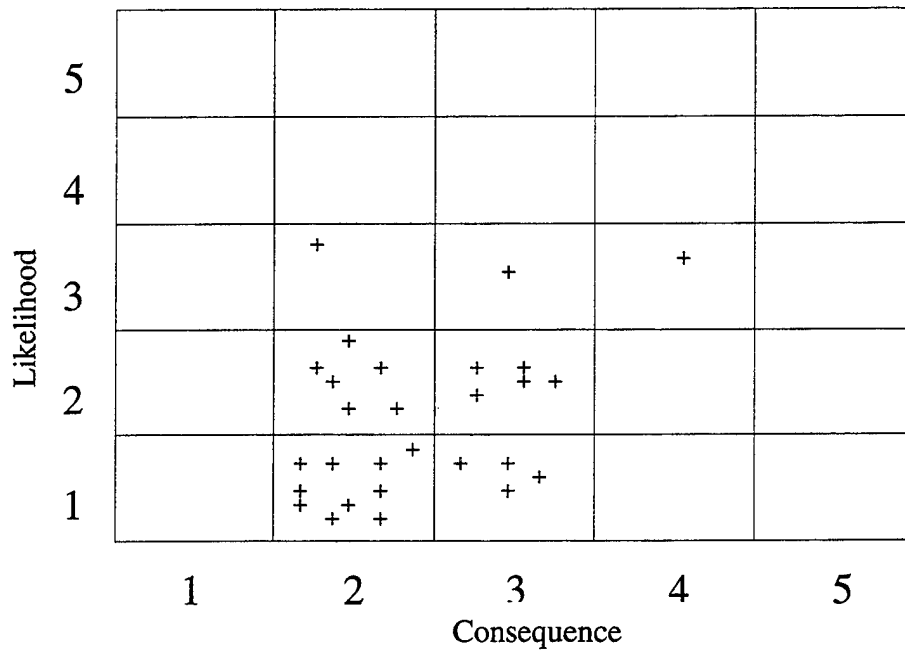
**Table 6. Consequence Rating [Ref. 27:p. 16]**



**Figure 10. Cost Risk Matrix**



**Figure 11. Performance Risk Matrix**



**Figure 12. Schedule Risk Matrix**

Analysis of the cost risk matrix reveals that the majority of risk events were evaluated as low risk. There are some risk events that fall in the moderate risk category, however. They are:

- Implementation of recommendations requires state-of-the-art advances.
- Contractor experiences loss of key personnel in technical and management positions for the design, engineering, and manufacturing of LCM.
- Program Office lacks funding for LCM development.

While the majority of cost risk events were evaluated as low, an overriding concern is one of initiative funding. Funding was evaluated as a medium cost risk. Without funding none of the other events are even realizable. Based on this one event, cost risk is assessed as medium. Analysis of the performance risk matrix shows that all of the evaluated events fall into the area of low risk and, therefore, receives an overall rating of low. Finally, similar results from the cost risk matrix can be found in the schedule risk matrix. The majority of risk events for schedule fall in the low risk area with three events falling in the moderate risk area. Those three events are the same three that elevate risk in the cost area and should be paid special attention.

Once areas of elevated risk are identified, then risk handling techniques must be addressed. Risk handling relates to methods and techniques to deal with

known risks. Options for risk handling include risk avoidance, risk control, risk transfer, and risk assumption. [Ref. 27:p. 17]

Risk avoidance seeks to eliminate areas of high risk by following a lower risk solution. [Ref. 27:p. 18] In this case, the BoB study and its recommendations are a parallel solution to the existing PHEMT module. Avoidance of all risk to schedule and performance is already covered by the existing technology.

Risk created by reliance on state-of-the-art advances requires control of the risk. Risk control seeks to reduce or mitigate risk. [Ref. 27:p. 18] In this case, use of an earned value (EV) system to monitor progress on the pursuit of the LCM would highlight areas of concern before they become a problem. Use of metrics as suggested in Chapter II, to monitor achievement of critical events in the development of the LCM, would also be useful.

Risk control may also be used to mitigate the loss of key contractor personnel for the design, engineering, and manufacturing of the LCM. The contractor should be made to identify key personnel in the development of the LCM and to notify TRPO when one of those key people is shifted to another project or leaves the contractor.

The third area of elevated risk has been assumed by TRPO. In assuming risk, TRPO acknowledges the existence that they might not receive funding for this initiative and have accepted it. Overall, this assumption of risk does not affect

the program given the existence of the PHEMT module which meets current performance, cost, and schedule baselines.

Overall the risk of implementing the BoB recommendations into the existing program is low. This should come as no surprise given the ground rules spelled out in the SOW. These rules addressed the mitigation of risk and caused the contractor to pursue a low risk solution. An understanding of the recommended solution shows that Raytheon is mainly repackaging the current module into a smaller one in order to reduce labor and material costs [Ref. 12].

## **J. CHAPTER SUMMARY**

Analysis of the Best of Breed study shows that the acquisition reform initiatives of Cost As an Independent Variable and dual-use technology were critical to the success of this cost saving initiative. In pursuing this effort, THAAD Radar Product Office was able to use the tenets of CAIV as outlined by the DOD CAIV Working Group to reduce the cost of a major cost driver without sacrificing performance or schedule. Critical to this success was the motivation of the contractor derived in part from the dual-use nature of the T/R module. The applicability of the this item to commercial segments motivated the contractor to seek reductions in the cost of the item. Furthermore, in keeping with the CAIV principle of managing risk, TRPO was able to constrain the study such that only low risk solutions would be recommended. Assessment of the risks involved in

implementing the study's recommended solution reinforces the low risk nature of this effort.

## **V. RECOMMENDATIONS AND CONCLUSIONS**

### **A. SUMMARY**

This thesis is an examination of the THAAD Radar Product Office's efforts at reducing the cost of a major cost driver of the radar and the risk of doing so. THAAD Radar Product Office (TRPO) has successfully proven the viability of achieving great cost reductions of a major cost driver with a low risk approach. Analysis of this effort within the framework of the tenets of Cost As an Independent Variable reveals that this is a unique opportunity. Due to an iterative approach, TRPO has been able to successively improve performance of the T/R module and then validate the feasibility of decreasing average unit production price by almost 50%. While these efforts do not follow a traditional CAIV model, they have adhered to the spirit of CAIV. This adherence has allowed TRPO to constrain the study so as to pursue a low risk solution in terms of affect on the program's overall cost, schedule, and performance. Moreover, TRPO used the incentive of dual-use technology to motivate Raytheon to pursue cost reductions.

### **B. CONCLUSIONS**

In applying the tenets of CAIV, TRPO was able to define an aggressive, but achievable cost objective for a major cost driver of the radar. Attainment of this

cost objective will save money in prototype and production radars, as well as in the procurement of spares over the life of the system.

Traditionally, CAIV seeks to trade requirements for performance and schedule in order to maintain cost. In this case, performance and schedule have been maintained while cost has been reduced. Such opportunities must be sought whenever embarking on a CAIV initiative. The program does not always have to trade performance or schedule. Seek areas where performance and schedule can be held constant and cost reduced.

One of the CAIV tenets stresses management of risk. The ground rules contained in the SOW for the study follow this tenet. The rules within which the BoB study was accomplished attempted to constrain the study so that a low risk solution would be found. As evidenced by the risk assessment in Chapter IV, the recommended solution is mostly low risk with a few exceptions which can be handled through risk handling techniques.

In analyzing the motivation of both and industry managers in this case, it was discovered that more could be done to motivate managers to take risk in seeking cost savings. In this case, CAIV efforts were motivated by external pressures in the form of budgetary constraints. Additionally, it was found that methods other than those suggested by the CAIV Working Group can be used to

motivate industry. In this case, the commercial application of the technology was useful in causing Raytheon to seek improvements in the cost of the T/R module.

DOD investment in the performance enhancements and cost reductions of the THAAD radar T/R module are in congruence with Raytheon's financial and market strategies. This has motivated Raytheon to participate in the BoB study.

### **C. LESSONS LEARNED**

Analysis of this cost saving initiative reveals some lessons which may be applicable to other programs.

#### **1. Benefit of Mergers**

Recent mergers within the defense industry have given acquisition officials cause for thought on the effects of these mergers on competition. As mergers occur, there are fewer firms to compete for business. Competition tends to drive cost down. With a lack of competition costs may not be driven down. There may be, however, an opportunity to benefit from these recent mergers. As mergers pool a large amount of expertise under one company, defense programs may be able to direct the exploration of cost reduction efforts by the now larger company. Technical approaches of previously not selected contractors may now be investigated if that contractor has been acquired by the program's prime contractor.

#### **2. CAIV Does Not Always Mean Trading Performance**

As demonstrated by the THAAD Radar Product Office, cost reductions can be achieved without trading off performance, while still following the tenets of

CAIV. TRPO approached its challenges iteratively. First they addressed the problems of achieving the EMD performance by investing in PHEMT technology. Once this was proven to be a viable option, they addressed affordability issues. Affordability issues were investigated in the BoB study prior to commitment of any resources.

### **3. Up-Front Investment**

Cost reduction efforts may require up front investment of a considerable amount of resources. In this case, the investment is approximately \$24 million over a period of three years. This investment early in the development cycle is needed so that cost saving technology and processes can be developed and perfected prior to production. While short-term budget constraints may make large up-front investments unattractive, the long-term implications must be kept in mind. In this case the early investment of \$24 million will result in the savings of \$78.9 million in current year dollars. Managers must remember that they are charged with managing for total ownership costs. Additionally, analysis reveals a 34% IRR.

### **4. Dual-Use Technology as a Motivator**

Use of commercial products is an idea that is encouraged in today's reform environment. Another aspect of this idea is the commercialization of military products. Military products with a civilian application serve to motivate

contractors to seek product innovation and reduce production costs. In doing so, they satisfy the firm's marketing and financial goals while at the same time benefiting acquisition of the product.

#### **5. Program Manager Incentives**

With only regulatory and budgetary pressures incentivizing managers, the acquisition system is doing little to incentivize managers. More needs to be done to encourage managers to seek significant cost savings. One way to accomplish this may be through a sharing of future savings between the program office, the Program Executive Office, and DOD. For example, leave funding at a level to procure EMD radars with the PHEMT technology. This will provide program stability should efforts be delayed or fail in the development of the LCM. Once the LCM is developed and being produced, begin to return a greater portion of the realized savings to the Program Executive Office and DOD. Leave a small amount of realized savings at the Program Office in order to pursue other cost saving efforts or to further incentivize the contractor.

#### **6. Need for Technology Expert**

Due to the high technology nature of many of the current DOD acquisitions and the swiftly advancing state of many technologies, an expert in the relevant technology is necessary for the program office. In the case of the TRPO, an expert from Mitre has been contracted to support efforts on the radar development. This

expert was able to bring to the BoB study areas where gains in efficiency might be achieved in order to reduce cost.

#### **D. AREAS FOR FURTHER RESEARCH**

##### **1. Incentives For Program Managers To Seek Cost Reductions**

Conduct of a study to determine if sufficient incentives exist in the current acquisition environment for Program Managers to take risk in seeking aggressive cost savings.

##### **2. Positioning of DOD Management Reserve**

Recently, a management reserve has been created at the DOD level. [Ref. 37] This reserve is intended to help programs that are in trouble. In the researching for this thesis, the issue was raised whether this management reserve was positioned at the correct level to do the most good. It was felt that smaller, lower category programs did not have a chance of obtaining any of this reserve if it stayed at the DOD level. Conduct a study to determine the availability of these reserve funds to lower category programs.

## APPENDIX. BEST OF BREED RISK ASSESSMENT<sup>1</sup>

<u>Risk Events</u> Technical	<u>Likelihood</u>	<u>Consequence</u>		
		Cost	Sched	Perf
1. Contractor will experience difficulty in meeting EMD performance requirements.				
2. Contractor is relying on immature, unproven technology.				
3. Contractor has limited experience in type of development.				
4. Implementation of recommendations requires state-of-the-art advances.				
5. Failure of T/REA to integrate into existing antenna equipment architecture.				
6. Processes, technology, material too complex.				
7. Contractor will not be able to integrate MMICs.				
8. Contractor is relying on immature manufacturing processes.				
9. Contractor will not be able to improve yield of MMICs				
10. Contractor will not be able to reduce module size.				
11. Contractor is relying on outside state-of-the-art advances.				
12. Performance requirements are poorly defined and not understood by contractor				
13. Performance requirements are unstable				
14. Contractor has insufficient time to test thoroughly				
15. Contractor has inadequate quality control program				
<b>Programmatic</b>				
1. Contractor has inadequate plans for managing suppliers				
2. Contractor experiences loss of key personnel in technical and management positions for the design, engineering, and manufacturing of LCM.				
3. Contractor will experience labor problems during development of LCM				
4. Contractor is unstable financially				
5. Contractor lacks capacity to produce at desired rate				
6. Delays in making decisions				
7. Program Office lacks funding for LCM development				
8. Contractor has inadequate plans for long lead items and vendor support				

<sup>1</sup> The format for this matrix was extracted from Hitz, Stephen E., Risk Assessment and Analysis of the M109 Family of Vehicles Fleet Management Pilot Program, Master's Thesis, Naval Postgraduate School, Monterey, CA, December 1997.

<u>Risk Events</u> Technical	<u>Likelihood</u>	<u>Consequence</u>		
		Cost	Sched	Perf
<b>Cost</b>				
1. Contractor ability to generate accurate cost estimates is suspect				
2. Contractor has inaccurate historical cost database on which to base estimates of re-used processes, technologies, etc.				
3. Contractor has poor cost models on which to base estimates of new processes, materials, etc.				
<b>Schedule</b>				
1. Schedule does not reflect realistic acquisition planning				
2. Schedule not realistic and attainable				
3. Contractor lacks resources to meet schedule				

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