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Critical Success Factors For Evolutionary Acquisition Implementation

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CRITICAL SUCCESS FACTORS FOR EVOLUTIONARY ACQUISITION
IMPLEMENTATION

by

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ABSTRACT

Due to extensive challenges to the efficient development and fielding of operationally effective and affordable weapon systems, the U.S. employs a complex management framework to govern defense acquisition programs. The Department of Defense and Congress recently modified this process to improve the levels of knowledge available at key decision points in order to reduce lifecycle cost, schedule, and technical risk to programs. This exploratory research study employed multiple methods to examine the impact of systems engineering reviews, competitive prototyping, and the application of a Modular Open Systems Approach on knowledge and risk prior to funding system implementation and production. In-depth case studies of two recent Major Defense Acquisition Programs were conducted to verify the existence and relationships of the proposed constructs and identify potential barriers to program success introduced by the new process. The case studies included program documentation analysis as well as interviews with contractor personnel holding multiple roles on the program. A questionnaire-based survey of contractor personnel from a larger set of programs was executed to test the case study findings against a larger data set.

The study results indicate that while some changes adversely affected program risk levels, the recent modifications to the acquisition process generally had a positive impact on levels of critical knowledge at the key Milestone B decision point. Based on the results of this study it is recommended that the Government improve its ability to communicate with contractors during competitive phases, particularly with regard to requirements management, and establish verifiable criteria for compliance with the

Modular Open Systems Approach. Additionally, the Government should clarify the intent of competitive prototyping and develop a strategy to better manage the inevitable gaps between program phases. Contractors are recommended to present more requirements trade-offs and focus less on prototype development during the Technology Development phases of programs.

The results of this study may be used by policy makers to shape future acquisition reforms; by Government personnel to improve the implementation of the current regulations; and by contractors to shape strategies and processes for more effective system development. This research may be used by the Government to improve the execution of acquisition programs under this new paradigm. The defense industrial base can use this research to better understand the impacts of the new process and improve strategic planning processes. The research methodology may be applied to new and different types of programs to assess improvement in the execution process over time.

This work is dedicated to my wife Sarah who supports me in all that I do;

my children Isaac, Eric, and Daphne who inspire me to succeed;

my mother Judy who taught me the value of an education;

and the brave men and women of the United States Armed Forces whose efforts and sacrifices make this research both necessary and possible.

ACKNOWLEDGMENTS

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LIST OF ACRONYMS

Acronym	Definition
CMMI	Capability Maturity Model Integration
CFA	Confirmatory Factor Analysis
COTS	Commercial Off-The-Shelf
CSF	Critical Success Factor
DAG	Defense Acquisition Guidebook
DAPAR	Defense Acquisition Performance Assessment Report
DAWIA	Defense Acquisition Workforce Improvement Act
DoD	Department of Defense
DODI	Department of Defense Instruction
DTM	Directive-Type Memorandum
EMD	Engineering and Manufacturing Development
FASA	Federal Acquisition Streamlining Act
FY	Fiscal Year
GAO	Government Accountability Office
GDP	Gross Domestic Product
GOTS	Government Off-The-Shelf
IOC	Initial Operating Capability
JCIDS	Joint Capability Integration & Development System
MDAP	Major Defense Acquisition Program
MOSA	Modular Open Systems Approach
MRL	Manufacturing Readiness Level
NASA	National Aeronautic & Space Administration
NDAA	National Defense Authorization Act
NDIA	National Defense Industrial Association
OSJTF	Open Systems Joint Task Force
PPB&E	Planning, Programming, Budget & Execution
RDT&E	Research, Development, Test, and Evaluation
TD	Technology Development
TRL	Technology Readiness Level
USD (AT&L)	Under Secretary of Defense for Acquisition, Technology, & Logistics
W-SARA 2009	Weapon System Acquisition Reform Act of 2009

CHAPTER I: INTRODUCTION

1.1 <u>Problem Statement</u>

The acquisition of military systems by worldwide federal defense departments presents challenges that are unique and distinct from those of commercial enterprises. In particular, the U.S. Department of Defense (DoD) faces unprecedented barriers to the execution of effective weapon-system procurement due to its size, prominence, strategy of technological superiority, and level of global commitments (Schwartz, 2009). The U.S. defense acquisition system faces the challenges of reconciling the impacts of the varying perspectives, goals, and values possessed by a diverse range of process stakeholders (Meier, 2009) while attempting to satisfy the demanding technical requirements of the systems imposed due to environmental conditions and necessary capabilities. The DOD's need to integrate systems into an extremely large, complex network consisting of layers of new and legacy components, coupled with its desire to incorporate advanced technology into products in order to maintain technological superiority conspires to present seemingly insurmountable technical and organizational barriers to the efficient acquisition of defense products (Defense Acquisition Performance Assessment Report [DAPAR], 2006). The vast amount of capital that is transferred among entities involved in this process leads to a need for a rigidly structured management system with high levels of visibility in order to limit the potential for fraud, waste, and abuse.

The U.S. defense acquisition process is executed in a unique environment with cost, schedule, and administrative regulations and oversight proscribed by law with high visibility and integral involvement of political elements. This environment includes a monopsony market with the U.S. Government as the sole customer served by an oligopoly of major defense contractors (Watts, 2008). This situation exists due to consolidation of existing major defense firms and high barriers to entry into the large-scale prime-item development market.

As a result of these and other factors, the Government Accountability Office (GAO), which is charged with observing and reporting on the effectiveness of the defense acquisition system, has reported that for the 96 Major Defense Acquisition Programs (MDAP) in the 2009 U.S. portfolio, the average delay in projected delivery of capabilities is 22 months and the average projected total acquisition cost overrun is 25% from initial baselines (GAO, 2009). In recent years, multiple high-profile individual programs have been canceled or significantly reduced in scope due to technical and resource management issues. These include the Air Force's F-22 Raptor Fighter Jet Aircraft, the Army's Future Combat System, the Navy's DDG-1000 Destroyer, and the Marine Corp's VH-71 Presidential Helicopter programs. In 2010, the DoD modified the F-35 Joint Strike Fighter program to extend the development phase, delaying the onset of Full Operational Capability in order to reduce overall program risk (DoD FY 2011 Budget, 2010). One of the key culprits in the failure of weapon development programs is the acquisition system itself, which contributes to consistent budget overruns for system acquisition programs due to ineffectiveness and

inefficiency (GAO, 2008). Proper structuring and implementation of the acquisition process is necessary for the U.S. maintain a strong inventory of effective weapon systems to enable the defense of the interests of the U.S., therefore fixing the DoD acquisition process is a critical national security issue (Defense Science Board [DSB], 2009)

The upward-spiraling costs and multiple failures of Major Defense Acquisition Programs (MDAP), coupled with shifts in the global defense environment have caused the DoD to repeatedly reexamine its acquisition process. The most recent changes to the acquisition process are in the form of regulation modifications in December 2008 coupled with the passage of the Weapon System Acquisition Reform Act (WSARA) in May 2009. These measures placed an increased focus on system engineering, elicitation and inter-service coordination of requirements from end-users, proof of technology maturity, leveraging of commercial markets and standards, and realistic cost estimation (DoD 5000.02, 2008; WSARA, 2009).

With these reforms the U.S. Government has announced a strategic intent to reduce total ownership costs, shorten development times, and increase success rates for acquisition programs through the acquisition of knowledge early in the development cycle. The objectives of the process reforms are to reduce technical, schedule, and cost risk through employment of mature technologies and more realistic initial cost and schedule baselines. These have long been stated goals, but the DoD lacked a comprehensive strategy to drive actions. These changes can be characterized as a transformation from the traditional DoD acquisition approach focused on

technological superiority with little regard for technical feasibility or integration costs to an Evolutionary Acquisition Approach that is capable of delivering highly upgradeable 80% solutions in months rather than 99% solutions in years (DoD, 2010). The DoD system development and procurement budget segments are primarily made up of individual acquisition programs that succeed or fail based in large part on product maturation, system integration, requirements management, and program management factors. Therefore, the success of these reforms will be dependent on the response of individual programs, especially major weapon system development programs (GAO, 2010a).

1.2 <u>Topic Relevance</u>

Due to the criticality of weapon system procurement to military capability and the rapidly changing operational environment, the Defense Science Board considers improvement of the DoD acquisition process to be a national security issue (Defense Science Board, 2009). Economic downturns, the execution of intense overseas operations, and the near tripling of weapon system acquisition spending since the turn of the century put enormous pressure on the defense budget. The defense budget is further stressed due to the fact that defense spending is considered "discretionary" as opposed to mandatory spending which includes Social Security and Medicare. As these entitlements, which are required by law to be funded, continue to grow due to an aging population and increasing health care costs, less is available for discretionary but vital activities such as national defense.

In 2010, the United States government allocated $533.8 billion to the DoD, $80 billion of which was to be spent on development and procurement of Major Defense Acquisition Programs (DoD, 2010). The budgets for defense programs are allocated from a common pool with the rest of the United States discretionary spending. As a result of this fact, every dollar allocated to the DoD that is wasted by an inefficient and ineffective acquisition program is a dollar that is unavailable for research, development, maintenance, or operations cost. Additionally, if the DoD were able to meet its commitments within a smaller budget, the resulting savings could be reallocated to other Government programs or used to further research and development programs and extend capabilities of existing systems. Figure 1.2-1 depicts the stresses placed on the acquisition system and typical results.
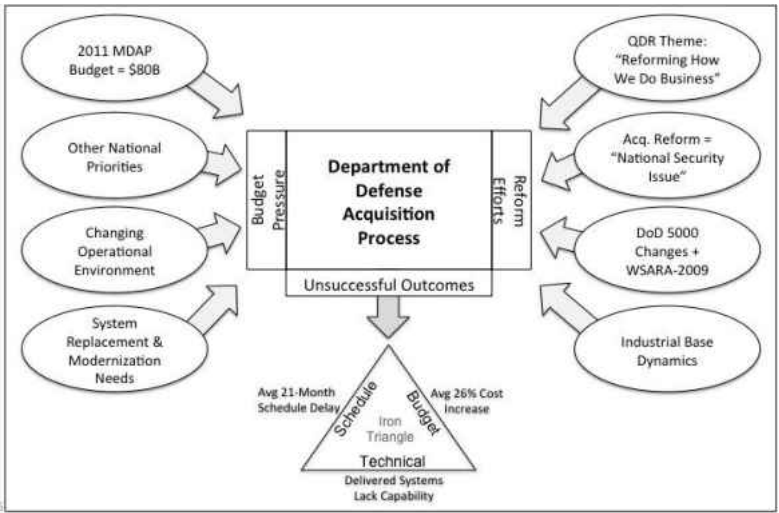
Figure 1.2-1: Stresses on Acquisition Process and Typical Results

An additional reason for this research is the knowledge gap that exists with regard to DoD acquisition policy impacts and effective implementation of these reforms at the program level. Furthermore, not enough time has passed since the process

modifications were enacted for a responsive body of research to accumulate or for programs executed under these new guidelines to be adequately studied. A major contributor to the persistent inadequacy of the acquisition process is the lack of alignment of the process owners, program personnel, and system stakeholders (Defense Science Board, 2009). Understanding of the impacts of the process changes is critical because both the Government and industry must effectively implement the reforms at the program level. Once the reforms are implemented on programs, their impact must be studied to determine whether to maintain, modify or abandon the new course. This research is relevant to industry because despite the significant research available that examines the challenges facing defense acquisition programs, the vast majority of the literature approaches the problem from the viewpoint of the Government. There is little publicly available research that focuses on the perspective of defense contractors. Additionally, the companies that make up the aerospace and defense industry need information on the impact of reforms so that they may align their competitive strategies to the new environment.

1.3 Research Question and Subquestions

The research questions are the driving reason for undertaking the case study. These questions are the starting point that shapes the objectives and outputs of the study, as well as all other parameters of the research design. The research question provides focus in the face of a potentially overwhelming volume of data (Eisenhardt, 1989). It bounds the inquiry by identifying the specific problem elements to be studied. These

boundaries focus the study to ensure that it is feasible and executable within available resources. The primary question to be addressed by this research is as follows:

"What are the critical success factors for the implementation of an Evolutionary Acquisition approach?"

The subquestions are used to guide the literature review that provides context to the investigation. The subquestions that arise from the research question include the following:

- *What were the characteristics of the previous environment?*
- *Why is a transition to a modified process necessary?*
- *What are the goals of the transformation?*
- *What are the characteristics of Evolutionary Acquisition implementation?*
- *What are the enablers for effective implementation of Evolutionary Acquisition?*

1.4 <u>Conceptual Model</u>

The conceptual model for the research is a depiction of the constructs and their interactions as identified through review of the literature review. The conceptual model for this study is presented in Figure 1.4-1
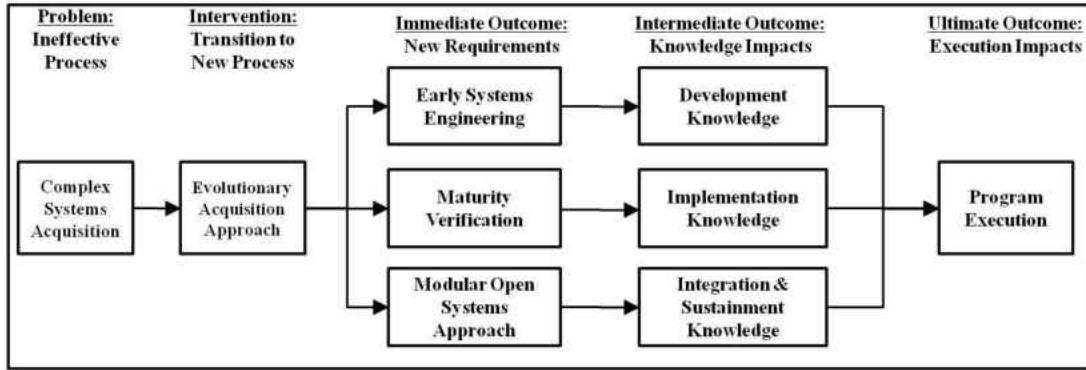
Figure 1.4-1: Conceptual Model

The model incorporates the constructs, processes, and outcomes to be explored by this research. The model presents how the complexity of the system to be developed influences a program's development approach, which in turn drives the emphasis on early systems engineering activity, the level of maturity of the components selected for implementation, and the adherence to Modular Open Systems principles. These elements impact the level of program knowledge regarding system development, implementation, integration, and sustainment which are prime factors in the ultimate outcome of the program.

1.5 Initial Research Hypotheses

The hypotheses of this research are as follows:

H1. *Execution of systems engineering activities prior to full implementation commitment increases development knowledge.*

H2. *Verification of product maturity prior to system detailed design increases implementation knowledge.*

H3. *Application of a Modular Open Systems Approach during development increases integration & sustainment knowledge.*

1.6 <u>Research Objectives</u>

This research seeks to examine the response of individual programs to these new requirements to determine the effectiveness of the changes. The results of the review of individual programs are checked against a wider pool of experience via a survey instrument. The products of this research are described in Table 1.6-1.

Table 1.6-1: Description of Research Products

Products	Description
Literature Review	Survey of the body of knowledge related to defense acquisition and the identified constructs.
Research Models and Hypotheses	Description of elements of acquisition process and their relationships to guide future work
Research Methodology and Instruments for Assessing Impacts of Process Modifications	1. Program documentation analysis sheet 2. Interview questions and protocol 3. Survey instrument
Barriers to Successful Implementation of the Evolutionary Acquisition Approach	Identified program elements that hinder successful programs executed under the modified process.
Suggested Topics for Future Research	Areas related to the problem and conclusions that would benefit from further research

1.7 <u>Research Limitations</u>

The research does not directly address financial impacts related to independent cost estimates, unit pricing, or incremental funding all of which are also within the scope of the recent acquisition process changes. It also does not cover the procurement of minor weapon systems, automated information technology systems, or services. The scope of this research does not include acquisitions by other foreign defense departments or U.S. Government Agencies, though NASA, intelligence agencies, the Department of Homeland Security, and international defense services may face similar challenges and could benefit from this research. The changes to the acquisition

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process covered by this research are those made to the DoD 5000 Series documents in December 2008 and those specified by the Weapon System Acquisition Reform Act of 2009. Changes incorporated into National Defense Authorization Acts (NDAA) are acknowledged, but not directly addressed. As the technical aspects of the execution of the acquisition process are the primary concern of this research, the requirements generation and budgeting aspects of the defense acquisition system are examined only tangentially. Furthermore, the objective of this research is not to propose changes to the enterprise-level acquisition process, but rather to focus on the impacts of changes already implemented at the program level.

The subjects of the research are contractors that have participated on programs executed under the revised acquisition process. As the new regulations have increased the amount of competition on programs, the contractors are often hesitant to provide details of the programs for fear that sensitive data may be exposed to competitors or the Government. Government personnel were not able to participate due to regulation controlling information related to competition among multiple contractors on the programs.

1.8 <u>Research Methodology</u>

The research begins with analysis of the DoD acquisition environment including the challenges faced by the process and measures of success. The changes to the acquisition process are also investigated. These steps address the structure of the process, the environmental drivers for the changes to the process, and the intent of the changes, and the nature of the changes. These components of the research are

primarily supported by a review of the relevant body of knowledge and documentation from recent acquisition programs.

Data is collected from system development practitioners and experts in various aspects of the acquisition process to determine the perception of the changes and their predicted impacts at the program level. Based on this insight, suggested tactics for successfully aligning programs with the goals of the overall acquisition process are proposed and analyzed to yield conclusions regarding improvement of the likely outcomes of programs in the current environment. This methodology is presented in Figure 1.8-1 and includes the following steps:

1. Identify Research Topic: Develop problem statement and research questions
2. Define Scope: Identify research objectives and limitations
3. Review Body of Knowledge: Perform literature review and identify a gap in body of knowledge to be addressed
4. Conceptualize Research: Develop conceptual model and hypotheses
5. Operationalize Research: Define relevant metrics used to measure the identified constructs and relationships
6. Design Research Methodology: Create data collection instruments for the metrics
7. Collect Data: Gather information from sources for analysis
8. Analyze Data: Review data collected to assess hypothesized relationships
9. Develop Conclusions: Present findings and recommendations for future research
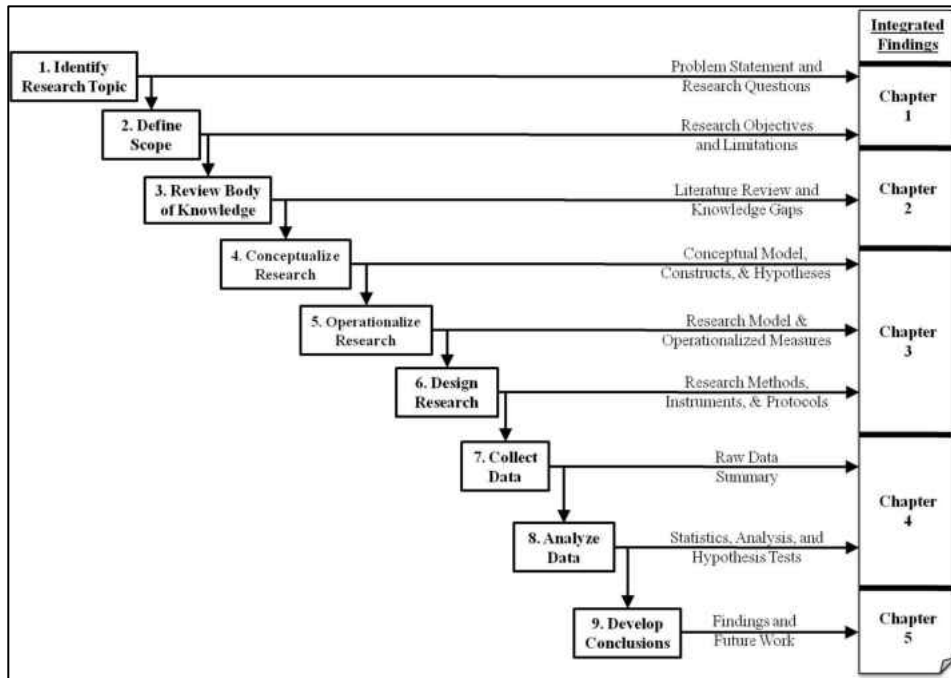
Figure 1.8-1: Research Methodology

The research topic and scope are identified in Chapter I. The literature review is

provided in Chapter II. The conceptualization and operationalization processes and

research instruments are described in Chapter III as well as the overall research

design. A summary of the data collected and the results of the analysis are contained

in Chapter IV. Chapter V provides the research conclusions and the revised

hypotheses and conceptual model, as well as suggestions for future research.

1.9 Definitions of Terms

Table 1.9-1: Definitions of Terms

Term	Definition
Commercial-Off-the-Shelf (COTS)	System components and interface definitions that may be incorporated into the system design without the need for further development.
Construct Validity	"Identifying correct operational measures for the concepts being studied" (Yin, 2009, Pg. 40)
External Validity	"Defining the domain to which a study's findings can be generalized" (Yin, 2009, Pg. 40)
Initial Operational Capability	The point in the system acquisition process when some units and/or organizations have received the system and are able to employ and maintain it. (DAU, 2011)
Internal Validity	"Seeking to establish a causal relationship, whereby certain conditions are believed to lead to other conditions, as distinguished from spurious relationships" (Yin, 2009, Pg. 40)
Major Defense Acquisition Program	A program that is estimated to require eventual total expenditure for research, development, test, and evaluation or procurement that exceeds a pre-determined threshold. May be designated by the Secretary of Defense or acquisition chief for the acquiring service. (U.S. Code X, Section 2430)
Manufacturing Readiness Level	A ten-level ordinal metric used to define manufacturing readiness and risk at the system or subsystem level based on the demonstrated maturity of production processes and equipment for a system. (MRL Deskbook, 2011)
Modular Open Systems Approach	Business and technical strategy characterized by modular design and the use of open standards for key interfaces used for developing or modernizing a system to support evolving capabilities over the system life-cycle (OSJTF, 2004).
Reliability	"Demonstrating that the operations of a study - such as the data collection procedures - can be repeated, with the same results" (Yin, 2009, Pg. 40)
Systems Engineering Review	A multi-disciplined technical review to ensure that the system development can progress within acceptable technical, cost, and schedule risks and that appropriate baselines are established. Reviews held during the Technology Development phase include System Requirements, System Functional, and Preliminary Design Reviews. (Defense Acquisition University, 2011)
Technology Readiness Level	Nine-point metric representing the maturity of a technology based on the level of demonstration of the technology in relevant environments (Mankins, 1995).

CHAPTER II: LITERATURE REVIEW

2.1 **<u>Introduction</u>**

This literature review addresses the structure, environment, goals, and results of the U.S. defense acquisition system, specifically the process for executing Major Defense Acquisition Programs to procure weapon systems. It also provides analysis of the impact to both the DoD and the defense industry of the modified systems acquisition process as defined by DoD regulations and federal law with a focus on the aspects of project/program management, systems engineering, and present strategies for the improvement of major weapons system acquisition project outcomes.

The criticality, uniqueness, dynamics, and scope of the DoD acquisition environment make it a compelling subject area for study. Much has been written about the inefficiencies of the method of weapon systems procurement in the U.S., however most available research has been conducted by the government, as opposed to industry or academia. The primary sources of information regarding the implementation of the Defense Acquisition Management System are Government-funded education and research centers; however studies of commercial project management, engineering management, and project strategy in other domains are applicable to defense acquisitions. Think tanks and industry groups also provide valuable insight into the state of defense acquisition.

Despite this existing research, and due in large part to the dynamic nature and environments of defense acquisition programs, the path to effective weapon system

procurement and fielding is not completely understood. Gansler and Lucyshyn (2005) stressed the importance of creating a more efficient Defense Acquisition System and advocated increasing the percentage of the DoD acquisition budget allocated for research into the defense acquisition process. Their paper posits that a modest increase in research funding could significantly improve the outcomes of projects while enabling the organizations that execute the process to become more agile and capable to adapt to environmental change.

The goal of this literature review is to establish a foundation for the research by identifying relevant constructs and their interrelationships based on existing information related to defense acquisition and adjacent subject areas that facilitates the development and investigation of the research hypotheses. The structure of the literature review is guided by the research subquestions identified in Chapter I. It examines the process of defense military system acquisition, the impetus for transformation to Evolutionary Acquisition, the process changes, and enabling characteristics for successful implementation of the new paradigm.

2.2 <u>The Defense Acquisition Process</u>

The United States defense acquisition process is more complicated than that of most nations due to the country's leadership position in the global community as the sole remaining superpower, the extensive infrastructure required, and the sheer size of major acquisition programs. The DoD's strategy of military technological superiority, the exclusivity of the materiel solutions, and the size of the U.S. Department of Defense budget both in absolute magnitude and in relation to gross domestic product

(GDP) necessitate the use of a complex system of systems with multiple levels of oversight to effectively manage the procurement of weapon systems (Schwartz, 2009). In order to implement and execute an effective system acquisition program, it is critical to understand the structure of the overall acquisition process, the objectives against which program success is evaluated, and the regulation of the process.

2.2.1 Defense Acquisition Process Structure

The U.S. Defense Acquisition System (also known as "Big-A" acquisition) is segmented into three primary components: The Joint Capabilities Integration Development System (JCIDS) which is responsible for identifying and validating requirements; the Planning, Programming, Budgeting, and Execution (PPB&E) process which allocates resources within the acquisition system; and the Defense Acquisition Management System (also known as "little-a" acquisition) which governs the process of developing and acquiring materiel solutions. Figure 2.2-1 depicts the three components of "Big-A" acquisition (Schwartz, 2009). This research focuses on the Defense Acquisition Management System ("little-a" acquisition).
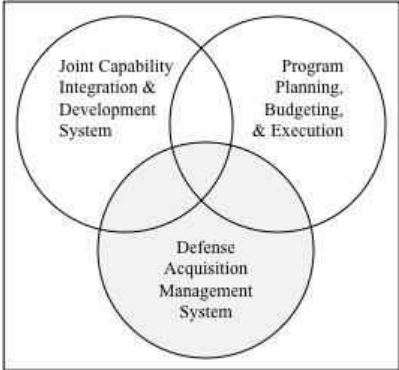
Figure 2.2-1: The Three Integrated Components of DoD Acquisition.

The primary categories of acquisition administered by the Defense Acquisition

Management System are services, automated information systems, and weapon

systems (DoDI 5000.02, 2009). The DoD routinely purchases services from the

private sector to augment its own capabilities and the expertise of civil servants. The

contracts for this type of acquisition are not subject to the same requirements as those

for purchasing weapon systems or automated information system. The procurement of

automated information systems, primarily in the form of information technology

systems, comprises a large portion of the DoD's acquisition budget. It presents a

different set of obstacles than those posed when buying weapon systems. The primary

challenges faced by the information system acquisition process are obsolescence,

integration with other enterprise systems, and order sizes. These are similar to

challenges faced by weapon systems acquisition programs, though they occur on

different scales, in different environments, and with different implications. This

research does not directly address the acquisition of either services or automated

information systems, and instead focuses on the acquisition of major weapon systems

as depicted in Figure 2.2-2.
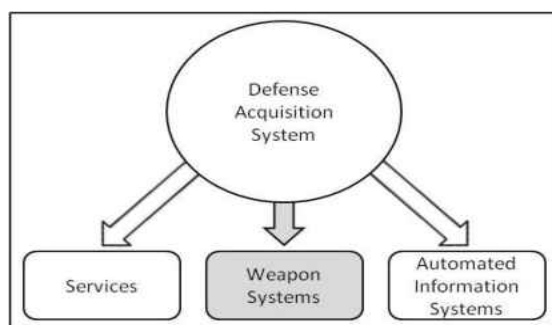
Figure 2.2-2: Categories of Acquisition Governed by DODI 5000.02.

In the U.S., efforts to acquire new weapons systems, which include any system used in combat operations such as vehicles, sensors, ordinance, and tactical communication equipment, are partitioned into programs that are responsible for the budget, schedule, technical capability, and integration of systems with the rest of the defense infrastructure. Major Defense Acquisition Programs are those weapon-system acquisition programs that are "estimated by the USD (AT&L) to require an eventual total expenditure for research, development, test and evaluation (RDT&E) of more than $365 million in fiscal year (FY) 2000 constant dollars or, for procurement, of more than $2.190 billion in FY 2000 constant dollars" (DoD 5000.02, 2008, pg. 33). A program can also be designated as a Major Defense Acquisition Program by the USD (AT&L) or the head of acquisition for a service if it is judged to warrant special interest at the DoD or service level.

Accountability is of particular concern with government programs because they are more open to public exposure (Elder and Garman, 2008). While all DoD programs are subject to a variety of stakeholders and Governmental regulation, MDAP's warrant particularly close attention from both the DoD and industry due to their cost, size, and complexity. A context model for the typical environment of a major defense acquisition program is presented in Figure 2.2-3.
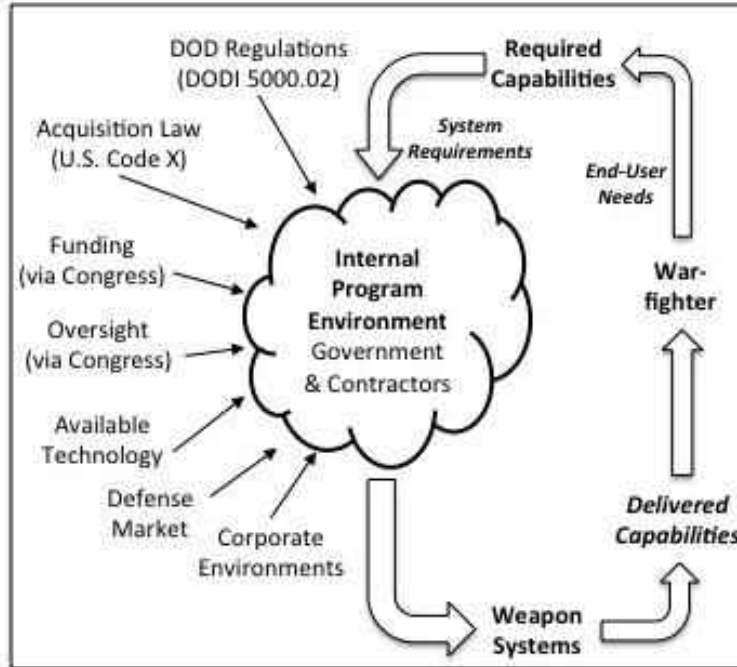
Figure 2.2-3: Major Defense Acquisition Program Context Model

In this model, the warfighter is the source of new capability identification that is provided to the program in the form of system requirements. Other inputs are received by the program from various Government stakeholders including funding, oversight, and system requirements. Factors that are external to the U.S. Government include available technology, the state of the overall world-wide defense market, the commercial market for similar system components, and the environment internal to defense product suppliers. If successful, the output of the process is a weapon system that provides effective capability to the warfighter, is suitable for deployment in the operational environment, is able to be fielded in a timely manner, and is affordable enough to be procured in the requisite numbers.

2.2.2 Defense Acquisition Program Success Criteria

In order for the acquisition management system to be successful at the macro (DOD) level, strategies and tactics must be developed for implementation at the micro (program) level. While a step in the right direction, the reforms that are to be implemented at the enterprise (DoD) level will not be effective if they are not supported by the programs that make up the DoD acquisition portfolio as success at the enterprise level requires alignment of organizational components with the overarching goals of the organization (GAO, 2010b).

The goal of any project is to achieve technical objectives within the allotted time period and within the allocated budget (Kerzner, 2006). The interaction of the traditional success criteria of cost, schedule, and technical project performance is often represented as a triangle due to the inability to modify the magnitude of any factor without affecting at least one other factor. These metrics are also applied to weapon system acquisition programs to provide managerial insight into the execution of the program. While well established as appropriate for tracking the progress of a program during execution, cost, schedule, and technical performance are historical metrics that do not necessarily correlate to future performance. Additionally, the inadequacy of initial cost and schedule estimates established during program planning are rooted in the amount of knowledge available when they are calculated. This management approach leads to a misalignment between the initial planning process and the actual success of the project (Atkinson, 1999).

The shortcomings of traditional project management data for use as leading metrics indicate that additional identifiers of program health are needed for planning and execution purposes. This research incorporates the use of critical success factors to identify leading metrics that can be established during the program planning phase to support successful program execution. Critical Success Factors, as originally defined by Rockart (1979) are the areas of operation where results must be positive for the organization to achieve goals and attain satisfactory performance. If these activities are not completed properly, the project will struggle. Rockart focuses on the use of Critical Success Factors to identify data collection requirements so that the correct areas are being properly monitored. Critical Success Factors are situational and distinct for each project, though there are often overlapping areas for similar organizations or across industries. Development of a project's Critical Success Factors requires data from multiple sets of data, including those from outside of the organization.

Pinto and Prescott (1988) conducted a field study and data analysis to determine the relationship of critical success factors to the life-cycle stage of a project. The results indicate that critical success factors are dynamic in that they evolve as the project proceeds. Boynton and Zmud (1984) posit that Critical Success Factors should be identified at the managers' personal level and then consolidated from across the enterprise to define organizational Critical Success Factors. They suggest that Critical Success Factors are useful for both identifying project strategies and potential implementation issues during the planning process. Properly applied, Critical Success

Factors can act as a link between tactical and strategic goals. They are important for the development of an understanding of key aspects of the organization and the program manager's role in it. It is also important that the correct factors be identified to avoid false indications of success or failure.

Though the majority of research into Critical Success Factors concentrates on private sector applications, there have been some investigations of their applicability to military projects. Elder and Garman (2008) investigated the differences between Critical Success Factors in Government-funded projects (specifically Air Force software projects) and private sector projects. They concluded that much of the research into the use of Critical Success Factors in private-sector projects can be generalized to apply to public-sector programs.

Dobbins and Donnelly (1998) developed a generalized iterative process for the identification of Critical Success Factors specifically for defense program management. In contrast to other sources, they assert that Critical Success Factors should be stated in terms of activities rather than vague areas in order to ensure that they are measurable. The process attempts to account for the integration of the factor set through the performance of an evaluation to ensure that the factors are internally consistent and do not conflict. This process supports risk management in that it allows for the probability achieving each Critical Success Factor to be assessed.

2.2.3 Regulation of Defense Acquisition

The U.S. Government regulates the Defense Acquisition Management System in three primary ways. The first is the DoD 5000 Series of documents that specify how the acquisition process is structured. The second is through public laws, mostly included in U.S. Code 10, that levy statutory requirements on the implementation of the acquisition process. The third is the annual National Defense Authorization Act (Schwartz, 2009). This governance structure is depicted in Figure 2.2-4.
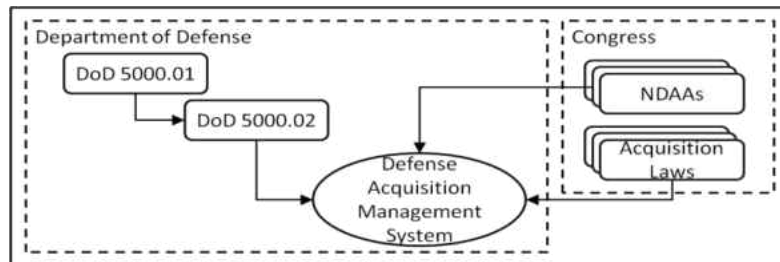
Figure 2.2-4: Regulation of the Defense Acquisition Management System

Modifications to the DoD 5000 documents impose regulatory changes to the system while the passing of laws by Congress establishes statutory requirements. Recently, both paths to acquisition reform have been exercised. In December 2008, the DoD 5000 documents were significantly modified for the first time since 2003. In May, 2009, the Weapon System Acquisition Reform Act of 2009 was signed into law. In response to the mandate by congress, the USD (AT&L) released a Directive-Type Memorandum (DTM) in December 2009 to outline how the statutory changes are to be implemented. These changes were driven by major shifts in the DoD's operational environment, available industrial base, budget priorities, and philosophy towards risk management.

2.3 <u>Acquisition Process Transformation Drivers</u>

The defense acquisition process is consistently attacked for producing ineffective weapon systems behind schedule while exceeding cost estimates. The DoD has admitted that the acquisition process does not satisfy the needs of modern system procurement due to the amount of time and effort required to navigate the process (DoD FY2011 Budget, 2010). Rouse, Kollar, and Pennock (2006) assert that the U.S. Acquisition Process is a strong candidate for the application of transformation efforts and provide a process for determining where resources should be applied to the process in order to effect the most positive change.

The Government Accountability Office (GAO, 2009) found that the estimated total acquisition cost growth of the DoD's portfolio of major weapons acquisition programs has grown from $42 billion in 2000 to $295 billion in 2007 (a 602% increase) even though the number of major acquisition programs increased from 75 to 95 (a 27% increase). Additionally, the average schedule delay in reaching IOC increased from 16 months to 21 months. In addition to unacceptable cost and schedule performance, a high percentage of weapon system programs have been found operationally insufficient in recent years. An area that is particularly deficient is sustainability which impacts the availability of the system to the warfighter once fielded and increases operations and maintenance costs (Defense Science Board - DT&E, 2008). The following sections identify commonly cited factors that contribute to the insufficiency of the acquisition system as implemented.

2.3.1 Threat Environment

Since World War II and throughout the Cold War, the U.S. weapons acquisition process was intended to respond primarily to the threats posed by a single adversary with comparable resources and capabilities, the Soviet Union (DAPAR, 2006). As a result of the decreased prominence and danger posed by a monolithic opponent and the increase in uncertainty due to non-state actors and asymmetrical warfare, the U.S. military has shifted its focus from how to counter specific, known threats and towards the procurement of capabilities that can be applied to a wider range of scenarios. (Bitzinger, 2009). This change in focus from a threat-based acquisition approach to a capabilities-based approach requires the acquisition of new systems and a transformation in the way that those systems are produced and procured. Among the changing requirements for systems are interoperability and communication, requiring systems to work together and share information among platforms and services towards a common goal (Dombrowski, Gholz, and Ross, 2002).

This effect is compounded by the focus on new system development and the current threat environment with its decreased equipment attrition rates that do not require immense production runs of systems. The resulting profits from development contracts are small and there is no guarantee of production contracts (Watts, 2008). This environmental change requires the industry to adapt due to the fact that the Government is no longer willing to pay for maintenance of overhead expenses (Carter, 2010) or excess capacity, despite the fact that large production runs are the key source of profit for defense companies. Additionally, the shrinking defense budget leads to

extreme levels of financial risk for contractors because it costs millions of dollars to position for and execute a contract bid.

The DoD has not properly managed the industrial base in the face of a changing environment to maintain an effective and efficient source of military capability. The Defense Science Board (2008) recommended that the U.S. Government transform the defense industrial base, its own business processes, and the DoD/industry relationship in order to cope with a flat or declining budget and an urgent need to modernize existing weapon systems.

2.3.2 Defense Industrial Base

The acquisition process is not wholly self-contained within the Government and must support and be supported by a robust industrial base that is charged with delivering systems. A dedicated industrial base must be maintained to support the comparatively long life cycles and environmental extremes to which defense systems are subjected relative to commercial products requiring that issues that are not present in private-sector system development such as military sustainment and disposal be addressed during the development and procurement process (Watts, 2008). Since World War II, the development and production capacity provided by the U.S. industrial base have provided a strategic advantage to the DoD (Watts, 2008). The U.S relies on the defense industrial base to deliver capability to the warfighter so much so that the continued security and prosperity of the U.S. requires a healthy industrial and technology base (DoD FY2011 Budget, 2010). For the military to be successful in transforming the way it fights, the industrial base must make corresponding changes to

the methods used to develop systems and capabilities (Dombrowski, Gholz, and Ross, 2002).

The Defense Science Board (2008) has called for a redefinition of the customer-supplier relationship between DoD and industry that emphasizes competition to lower costs while improving delivered systems. Gansler and Lucyshyn (2005) also point out that the Government must properly manage the industrial base and ensure that profitability is attainable in order for the relationship to properly function. If the Government fails to do so, the result could be a reduction in the development capabilities available to the Government due to vendors leaving the market or being forced to merge with a more successful company.

Bitzinger (2009) examined the transformation of the Department of Defense's strategy during the 2000's and predicts that despite the popular conception that the "Revolution in Military Affairs" during the first decade of the 21st century would bring about wholesale changes in the structure of the defense industry, large traditional defense firms (e.g., United Technologies, Raytheon) continue to be the dominant players in the U.S. market. Oligopolies have developed in response to a monopsony market with fewer opportunities and high overhead due to required research and development costs and government oversight. For example, two firms, Northrop Grumman and General Dynamics, own all of the U.S. military shipyards; Lockheed Martin is the only U.S. contractor with fifth-generation fighter jets under development, the F-22 Raptor and the F-35 Lightening II; and Boeing is the only current producer of large jet aircraft (Watts, 2009).

The GAO (2005) stated that the DoD expected significant savings due to industry consolidation, however Smirnoff and Hicks (2007) developed an empirical model based on a review of service-specific cost data from 1979-2002 to explore the causes of cost overruns on defense programs and found no evidence that defense industry consolidation led to reductions in program costs overruns. Instead, the consolidation of the defense industrial base has reduced the U.S.'s ability to procure systems in a competitive environment to reduce costs and the barriers to entry of commercially oriented companies into the U.S. military market have never been higher. The relatively small numbers of units acquired per program eliminates economies of scale while the criticality of performance to personnel safety requires an extreme level of precision and attention to detail while maintaining a systems view and focusing on long-term capability to be provided (Watts, 2008). Companies that do not conduct a large percentage of their business with the Government often have trouble balancing the satisfaction of unique Government technical and procedural requirements while remaining competitive in the commercial marketplace, which may limit the military's ability to leverage the latest technology in a timely manner (Aerospace Industries Association, 2008).

Lack of options limits competition and requires the Government to award sole-source contracts, pay for development of these capabilities with less-experienced companies, or procure systems from foreign firms which contributes to the erosion of the U.S. industrial base. The Government further exacerbates this problem by routinely awarding contracts solely on the basis of program needs without consideration for the

impacts to industrial base capability (Watts, 2008). The lack of competition and increased importance of winning each program pursued has led to more aggressive bids by contractors, causing to increased execution risk and exacerbating program cost and schedule growth (Meier, 2009).

2.3.3 Budget Pressures

The near-term funding levels for the DoD is not expected to continue its historical trend of yearly increases. This change is due to the reprioritization of the U.S. budget with a focus on domestic issues such as health care, an increase in operational cost, and the increases in the costs associated with system acquisition. The impact of this situation is that less money available due to higher deficits, which causes budget instability. The DoD asserts that budget stability is critical to the efficient development and procurement of weapon systems. The biggest hurdle to budget stability, however, is the inaccuracy of cost estimates with a heavy bias toward under-budgeting (DoD FY2011 Budget, 2010).

Smirnoff and Hicks (2009) found that funding instability led to cost overruns on defense procurement programs. One of the primary issues with the identification of initial cost and schedule estimates is that it must occur at the beginning of the program when the least is known about the program (Atkinson, 1999). This fact is exploited by both Government program offices and defense contractors by providing low-cost estimates with poorly defined or high levels of risk. This approach consistently leads to problems during execution. Congress is more likely to approve additional funds for a program with high sunk costs than a new-start program with high development costs

regardless of actual risk level. Additionally, the DoD and Congress have been reluctant to cut funding from a program during execution due to the perceived importance of the delivered capability (Kwak and Smith, 2009).

2.3.4 Program Risk

Per the DoD Risk Management Guide (2006, pg 1), "risk is a measure of future uncertainties in achieving program performance goals and objectives within defined cost, schedule and performance constraints." Risks have three primary components that include the root cause, the probability of occurrence, and the impact or the realization of the risk. Risks are often divided into three categories based on the program performance measurement that is impacted upon realization of the risk (DoD Risk Management Guide, 2006).

Cost risk is the probability and magnitude of increased cost due to uncertain future events. The cost risk in Department of Defense programs largely stems from the inability of the Government and contractors to produce realistic cost estimates and scope the program to the available funding (DAPAR, 2006). This deficiency in the process leads to the selection of low-cost bids with higher levels of risk. Unrealistic cost and schedule baselines have been forwarded as a key cause of defense program failure (DoD FY2011 Budget, 2010; Christensen and Gordon, 1998). Cost is often the most important factor in source selection and is much easier to quantify than risk. Bids including most-likely cost estimates with substantial risk reduction and management activity are less likely to be chosen than low-cost offers with more actual risk.

Schedule risk is the probability and magnitude of schedule slippage due to uncertain events. Realized schedule risk leads to delays in the delivery of systems and associated capabilities to the warfighter. According to Ford and Dillard (2009) the goal of the acquisition process is to provide capability to the warfighter as soon as possible after the capability need is recognized. Therefore, they assert that the most important objective of the transition to Evolutionary Acquisition is the reduction of cycle times between product development start and fielding.

Performance Risk is the probability and impact of problems occurring during the development, testing, or integration of a system due to failure of the technical performance of a product in the required environment. The realization of performance risk often leads to the inability of the desired system to meet performance requirements within cost and schedule constraints requiring that development be extended along with program cost and schedule increases. The alternative is that an inadequate system be fielded then replaced or upgraded sooner than expected.

In order to manage the significant amount of risk inherent to the acquisition of advanced systems, the GAO recommends a knowledge-based approach to system acquisition and development (GAO, 2008). Knowledge-based approaches are characterized by early management and technical reviews coupled with technology development activities to replace risk with knowledge and reduce first-time events and program uncertainty. Knowledge-based approaches also require periodic reassessments as knowledge is obtained, which continually reduces uncertainty as the program progresses. Knowledge provides decision authorities with greater degrees of

certainty, increasing the probability that the system will provide the required capabilities to the warfighter and be delivered on cost and schedule (Defense Acquisition Guidebook, 2011).

2.4 <u>Acquisition Process Transformation</u>

In response to these challenges, the DoD and Congress made substantial changes to the defense acquisition process between 2008 and 2010. The stated goal of the DoD's attempts to reform the way that it buys systems is "to achieve predictable cost, schedule and performance outcomes based on mature, demonstrated technologies and realistic cost and schedule estimates." Additionally, the DoD adds that "[o]ur intent is to provide the warfighter with world class capability while being good stewards of the taxpayer dollar" (FY2011 Budget, 2010, Pg. 5-3).

In 2010, the DoD took the step of canceling numerous high-profile programs due to poor performance or misalignment of program objectives with warfighter needs. These cancellations were made necessary due to costs and schedule overruns and perceived unsuitability of the program objective due to either lack of jointness or a misalignment with changing mission needs (GAO, 2010c). The cancellations are projected to save hundreds of billions of dollars, however much of those savings will be invested in new programs to fill the valid requirements that the canceled programs were supposed to address (DoD FY2011 Budget, 2010). These cancellations also represent decades of effort and billions of dollars in sunk costs that have been lost. These programs will likely be replaced with new Evolutionary Acquisition programs

intended to develop new systems to provide the current operational needs more rapidly and in a more cost-effective fashion.

The DoD is attempting to institutionalize a rapid acquisition process while maintaining disciplined systems engineering methodologies and leveraging mature technology to increase the amount of knowledge that is available at critical decision points. The logic guiding the implementation of the transformation effort is that improvement of the DoD's position to effectively defend the interests of the U.S. requires improved performance of individual acquisition programs. A logic model representing the Government's transition approach is presented in Figure 2.4-1.
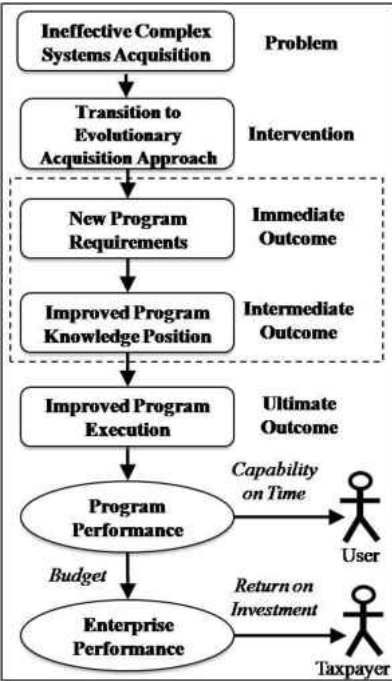
Figure 2.4-1: Logic Model for the DoD Acquisition Process Modification

At the enterprise level, the DoD has initiated an intervention by adopting an Evolutionary Acquisition approach to developing complex systems with an emphasis

on early Systems Engineering, demonstration of product maturity, and a Modular

Open Systems Approach. The immediate outcome of this action is new program

requirements with regard to these subjects. The intended intermediate effect is an

increase in program knowledge coupled with a commensurate reduction in program

risk. The goal is for the ultimate outcome to be increased program performance during

execution yielding more capability delivered to the warfighter in less time with an

increased return on investment to the taxpayer.

2.4.1 Modifications to Department of Defense Instruction 5000.02

The instruction governing the Defense Acquisition Management System (DODI

5000.02, 2008) has been modified in an effort to improve the process the DoD uses to

procure weapon systems. The changes are primarily manifested in modifications to the

requirements for programs to advance past the three defense acquisition process

milestones. These milestones are designated by the letters A, B, and C and represent

decision points at which the Government must decide if it will fund the next

development phase or cancel the program. Advancement through the milestones

indicates increased maturity of the program and thus reduced levels of risk. Figure

2.4-2 depicts the changes to the structure of the Defense Acquisition Management

System required by the modifications to DoD 5000.02 (Defense Acquisition

University, 2009).
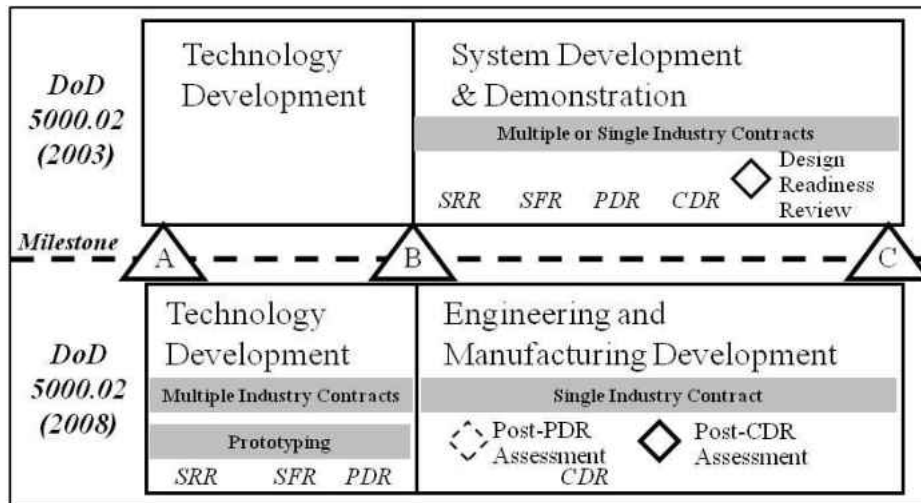
Figure 2.4-2: Transformation of the Defense Acquisition Management System

In the interest of reducing technical risk and requirements instability, the DoD now requires all major programs to enter the acquisition process at Milestone A unless the solution has already been demonstrated to be producible and effective in the relevant operational environments. Requirements and preliminary design are now developed and requirements, architectural, and preliminary design reviews have moved to a Technology Development phase that precedes Milestone B. Competitive prototyping during the Technology Development phase is now required to ensure that the preferred solution does not rely on immature critical technology and that the system is producible. The prototype development and test effort occurs in parallel with the development of the production system design. Multiple competitors are selected to participate in the Technology Development phase culminating in prototype demonstrations and a preliminary design review.

To ensure that requirements are properly established at the beginning of the program programs must conduct a Preliminary Design Review (PDR) prior to full program

initiation and funding at Milestone B (DoD FY2011 Budget, 2010). This requirement causes that the Government and vendors apply Systems Engineering activities earlier in the program to increase knowledge and maturity of the proposed solution. Programs that hold system engineering technical reviews prior to Milestone B encounter lower levels of cost growth and delays to reaching Initial Operational Capability (GAO, 2009). At the end of the Technology Development phase, the competitors submit proposals based on their system preliminary designs to be selected to finish development of the system during the Engineering and Manufacturing Development (EMD) phase. In order to advance past Milestone B, the proposed system cannot be dependent on technology that has not been demonstrated in a relevant environment.

2.4.2 Weapon Systems Acquisition Reform Act of 2009

Even though the DoD is a component of the Executive Branch of the U.S. Government, Congressional authority to oversee the defense acquisition process is derived directly from the U.S. Constitution, which empowers the legislature "to make rules for government and regulation of the land and naval forces" (Constitution of the U.S., Article X). Congress approves the DoD's budget via the Annual National Defense Authorization Act. Reforms to DoD policy, including acquisition policy, that are mandated by Congress are often dictated within the contents of these bills. Additionally, Congress is empowered to pass laws that place statutory requirements in the defense acquisition process.

 The Weapon Systems Acquisition Reform Act of 2009 (WSARA, 2009), which was signed into law in May 2009, raised many changes already specified in DOD 5000.02

from regulatory to statutory requirements. The WSARA also created multiple director-level positions within the DoD to oversee the acquisition and operation of defense systems including a Director of Systems Engineering, a Director of Developmental Test and Evaluation, and a Director of Program Cost Assessment and Evaluation. These positions were created in order to place more emphasis on the role of these elements within the defense acquisition process. The WSARA emphasizes the importance of competition throughout the system life cycle to control costs and requires demonstration of products prior to full program initiation.

In response to the WSARA-2009, the DoD issued a Directive-Type Memorandum (DTM) on Dec 4th, 2009. This memorandum amended DOD 5000.02 to comply with the acquisition system changes mandated by Congress. The DTM requires program acquisition strategies to include increased considerations for competition during both the development and Operation and Maintenance phases of the system's life cycle. Rather than requiring specific tactics to attain this goal however, the DTM provides suggestions for ensuring the presence of competition including requirements for the use of Modular Open Systems Approach, procurement of complete technical data packages to allow for build-to-print production, re-competition of subsystem-level components and increased program oversight via business and technical reviews. The law encourages the philosophy of fielding systems in a rapid and cost-effective manner and upgrading them over time through component replacement or capability extension. These new statutory requirements align with and support the DOD's Evolution Acquisition Approach.

2.4.3 Evolutionary Acquisition Approach

The description of Evolutionary Acquisition contained in the DoD 5000.02 instruction is as follows: "An evolutionary approach delivers capability in increments, recognizing, up front, the need for future capability improvements. The objective is to balance needs and available capability with resources, and to put capability into the hands of the user quickly. The success of the strategy depends on phased definition of capability needs and system requirements, and the maturation of technologies that lead to disciplined development and production of systems that provide increasing capability over time." (DoD 5000.02, 2009, Pg. 13).

Evolutionary acquisition limits the scope of acquisition cycles in order to reduce overall program cost, schedule, and technical risk. The key to the success of the strategy is the proper definition of capabilities, assessment of their priority, and the level of risk associated with their delivery, grouping them into complementary sets, and assignment of the capabilities to deliverable increments.

The Evolutionary Acquisition approach is distinct from the "spiral development model" which is no longer used as a strategy for system development (DAU, 2009). Spirals are similar in that capabilities and features are added to the system baseline over time with multiple deliveries; however the goals of spirals are not planned until right before the spiral begins. Each increment of the process must be militarily useful and able to be fielded to provide the warfighter with a required capability. In short, it must provide value to the warfighter even if no future increments are fielded. Evolutionary development seeks to provide capability to the warfighter quickly while

incorporating the inherent upgradeability offered by the spiral development process. In order to achieve these benefits, it is necessary to ensure that the architecture is well defined, incorporates technology that can be implemented without extensive further development, and allows for capability extension and the resolution of obsolescence-related issues.

2.5 Enablers for Effective Evolutionary Acquisition

The GAO (GAO, 2008) asserts that a lack of knowledge regarding program-critical technologies and requirements at the outset of programs contributes to cost growth. It is common for programs to establish infeasible requirements, essentially over-promising system performance to ensure survival when competing with other programs for funding, without identifying proper cost levels to achieve them.

In an effort to identify factors that may contribute to addressing this problem, this research specifically concentrates on the effects of three primary technical aspects of the process transformation as identified by the literature: 1) increased emphasis on Systems Engineering early in the development cycle, 2) verification of product maturity prior to implementation, and 3) employment of a Modular Open Systems Approach. These factors have been identified by the DOD, industry, and academia as essential elements to the successful implementation of an Evolutionary Acquisition process.

2.5.1 Systems Engineering

The definition of Systems Engineering varies widely among, and sometimes within, technical organizations. To address this ambiguity, DoD 5000.02 (2008) includes an enclosure specifically dedicated to Systems Engineering. The enclosure outlines the high-level requirements for the integration of Systems Engineering into Defense Acquisition programs throughout the system development lifecycle. The requirements indicate problem areas that the DoD is currently facing as well as the overall structure of Systems Engineering efforts in acquisition programs. The enclosure addresses specific elements of Systems Engineering programs such as leadership positions for System Engineering personnel, plans, and reviews. Elements specifically required to be included in Systems Engineering efforts include Requirements Management, System Architecture, Developmental and Operational Testing, Environmental Safety and Occupational Health, Item Unique Identification, and Configuration Management.

Vanek, Jackson, and Grzybowski (2008) conducted an analysis on the literature related to systems engineering processes and metrics. Their literature review references a wide range of studies across a large segment of product development organizations that indicate the value of systems engineering to project performance. They state that the purpose of systems engineering as applied to product development is to improve the outcome of the development effort. They found that application of Systems Engineering principles is an accepted practice in the defense and aerospace industries while it is not widely accepted in the commercial product development sector. The difficulty in evaluating the impact of systems engineering practices on

project performance is that successes usually cannot be directly linked to steps in the systems engineering process, but failures can be associated with the lack of completion of systems engineering activities.

Kludze (2003) conducted survey research to determine the project-level impacts of systems engineering. The study used perception of cost, schedule, and technical performance and risk as an indirect indicator of the benefits of systems engineering. It showed a strong belief among the 379 respondents that the application of systems engineering principles has a positive impact on these measures and that the earlier in the project that they are applied, the greater the derived benefit. These findings support the tactic of incorporating more Systems Engineering scope in the beginning stages of programs to allow for increased levels of knowledge to reduce risk levels.

The Software Engineering Institute (SEI) and the National Defense Industry Association published a joint study (Elm, et al 2008) of the effectiveness of systems engineering processes as applied to system development projects executed by defense contractors. The study attempted to identify the correlation between project performance and systems engineering capability as defined by the developing organization's level of competency in 12 areas of best practices identified by the SEI as part of the Capability Maturity Model Integration (CMMI). The SEI study found that while a low level of project management challenge was more strongly correlated with project success than high level of systems engineering capability, the combination of a low-challenge project and a high systems engineering capability was very strongly correlated with successful project performance. Another finding that is

indicated, but not supported by sufficient data, is that the acquiring organization's systems engineering capabilities has an effect on project performance. This inference is supported by the logic that the common link among failed defense programs is the role of the Government as the acquiring organization.

Gallagher and Shrum (2004), also of the Software Engineering Institute, assessed the application of the SEI's Capability Maturity Model directly to defense acquisition to develop the CMMI-Acquisition Module. They found that the maturity of the processes of both the acquirer and developer is critical to low-risk system acquisition. Deficiencies in either process set exist, the uncertainty and unpredictability of project outcomes increases significantly. These deficiencies are a possible source of problems for the acquisition of military systems as may large contractors have implemented CMMI, but the Government does not have a corresponding stable process initiative.

Dahmann, Bhatti, and Kelley (2009) applied business process modeling to the early stages of the defense acquisition process to address the following questions:

1. "From an SE perspective, what are the important engineering activities and products during the two early acquisition phases for implementation by an early program office?"
2. "How do these SE activities relate to the other [Defense Acquisition Guidebook (DAG)] activities recommended for programs at the same times?"
3. "What are the impacts of the SE activities on acquisition decisions?"

As a result of this effort, they developed the Acquisition Guidance Model to facilitate the application of "systems thinking" by process stakeholders. The research supports the view that early system engineering technical reviews are critical to the success of major defense acquisition programs. The paper also identifies challenges within engineering management that arise from the changes in the global business environment. A similar cause-and-effect relationship exists within the DoD acquisition community including System Program Offices, the Office of the Secretary of Defense, test organizations, research labs, prime contractor organizations, suppliers, and acquiring services.

The high number of stakeholders for each program may lead to requirements changes made to satisfy parochial interests without regard for the programmatic and technological impacts (Meier, 2009). These findings indicate a need for baselines to be established early in the program. Configuration steering boards are employed to ensure that requirements changes are necessary and that their impacts to the entire program are assessed before implementation (FY2011 Budget). Configuration steering boards and the establishments of well defined baselines early in the program provide the benefit of requirements and design stability, which is particularly necessary in programs with long development timelines. Such programs can fall victim to scope creep due to evolving user needs and the advent of new technology during development. Therefore, proper controls must be placed on the types of technologies that can be used in development programs.

2.5.2 Product Maturity Verification

Product Maturity is a measure of the extent to which the technologies in a product and its ability to be manufactured have been demonstrated. The GAO recommends that a pre-determined level of maturity be demonstrated via prototyping or other testing before integration of the technology into product development programs. Since 2006, when demonstration of a program's technologies in a relevant environment prior to Milestone B became a statutory requirement, the number of programs with mature critical technologies has increased (GAO, 2010a).

The GAO has found that programs that employ immature technology at the origination of defense acquisition programs are associated with more severe schedule slips, reduced capability in the delivered systems, and greater cost growth when compared to initial plans (GAO, 2010a). The GAO recommends that the maturity of new technologies be demonstrated prior to employment in acquisition programs. According to the GAO, it is vital that program managers be empowered to reject the use of immature key technologies on their programs.

Department of Defense Instruction 5000.02 (2008) establishes a requirement for competitive prototyping in acquisition programs that enter the defense acquisition management system at Milestone A. One of the key drivers of the prototyping requirements is the DoD's desire to gain knowledge to displace program risk (GAO, 2009). The requirement can be waived if cost of prototype development and testing program are anticipated to be greater than the benefits to the overall procurement program during production, operations, and maintenance. Advanced maturity of core

product technologies is a prerequisite for the reduction of cycle times in defense acquisition (Sherman and Rhoads, 2010). Conversely, lack of maturity increases program risk and may result in delays in development schedules. Additionally, these authors suggest that concurrent development activities are also critical for cycle time reduction.

The increase in size and reduction of numbers of total programs has caused defense firms to focus more tightly on identified future system requirements as opposed to growing robust problem-solving and technological capabilities. In recent years, defense firms have been less willing to invest in research and development without a clear business case (Watts, 2008). Competitive prototyping provides a case for early investment to lower Government risk and increase the chance of vendors being awarded contracts. Prototypes can provide information on technical Critical Success Factors to support an assessment of the achievability of the programs goals (Boynton and Zmud, 1984).

 An analysis performed by Dubose, et al. (2007) quantitatively relates the technology maturity to the risk of schedule slippage in NASA acquisition programs. For the 28 programs that were examined, a lower demonstrated level of maturity was shown to correlate to an increase in schedule slippage. The observation of this relationship provides a measure of empirical evidence to support the intuitive assertion that increased technological maturity decreases schedule risk.

A paper from the Australian Defense Science and Technology Office (Moon, et al, 2005) proposes the use of technology maturity assessments as a tool for the identification and management of risk. Australia buys more off-the-shelf and foreign products than the U.S. due to its smaller defense budget and lower threshold for technological superiority. Moon examines emergent properties of several systems with respect to the maturity of their components. A multiple-pass process for using technology maturity metrics to assess technical risk to defense programs is also presented.

Once a technology is well understood and capable of being integrated into a system with predictable performance characteristics, the system must be produced in sufficient quantities and quality to be fielded. Kerr, et al, (2007), found that the U.S. and other countries are increasing their use of technology insertion into existing platforms as a tactic to reduce costs and development risk. The paper explains the value of technology insertion to overcoming obsolescence-related issues and the rapid development of new capabilities to be integrated into existing systems for delivery to the warfighter. It also touts the return on investment governments may receive with regard to systems' total life-cycle cost.

2.5.3 Modular Open Systems Approach (MOSA)

The Modular Open Systems Approach (MOSA) and the related concept of Open Architecture (OA) are the Government's preferred business and technical strategy for system development or modernization that incorporates modular design and the use of open standards for the implementation of key interfaces (OSJTF, 2004). Eisenmann,

Parker, and Van Alstyne (2008) define "open" as lacking restrictions on participants in the development of a platform or product. The paper defines the following roles with respect to "openness": End-user, application developer, hardware/software bundle provider (integrator), and designer (intellectual property owner). It also differentiates between two primary strategies for opening a platform. The vertical openness strategy includes backwards compatibility, platform and category exclusivity, and absorption of complementing products. Horizontal openness takes the form of increased interoperability with competitors to invoke network effects, licensing to expand a market through differentiation, and sponsorship to reduce research and development costs and allow for a more diverse solution space.

 MOSA is characterized by a reliance on industry standard interfaces, use of off-the-shelf components, and modular software and hardware development and integration. The key benefit is that it limits the ripple effect of changes through a system. Isolating volatile components using stable and robust interfaces, allows for modification or replacement of those components with minimal impacts on the rest of the system (OSJTF, 2004). This approach allows for the initial development of the system with older, proven technology, because developers know that they can insert more advanced technology later to offset obsolescence and extend the capabilities of fielded systems. MOSA is appealing because it seeks to reduce both recurring and non-recurring cost in system development, operations, and maintenance (Open Architecture Contract Guidebook, 2004).

Dillard and Ford (2009) found that integration of MOSA with an Evolutionary Acquisition approach increases requirements, technology development, integration, and manufacturing costs, but reduces problems, and thus costs, later in the program. They also developed a model that suggests that rework due to problems discovered during system development increases, but that quality assurance efforts would be more effective due to the use of standards and that the total scope of development work decreases substantially. It should be noted that the development phase of the program is when problems are preferred to be found due to the dramatically increased cost of rework after fielding of the system.

Simulations developed by Dillard and Ford (2009) to gauge the impact on the Javelin missile development program indicate that the combination of Evolutionary Acquisition and MOSA will yield more schedule benefits than the implementation of just Evolutionary Acquisition. Additionally, Open-Systems-related work performed at the onset of the program yields schedule and cost benefits in subsequent increments, essentially providing a substantial return on early investment for the entire life cycle of the system. The simulation suggests that errors in integration of systems must be addressed by the programs to be successful. One of the impediments to the implementation of MOSA in DoD acquisitions is the increase in initial costs. Increased up-front systems architecture work, reduced control with regard to standards, increased standard instability, and reduced control over designs and requirements due to the leveraging of commercial products lead to hesitance on the part of the DoD to fully embrace MOSA. To date, MOSA has not been completely

integrated with the Evolutionary Acquisition approach. This fact makes it difficult to conceptualize the way that these concepts and principles will affect each other (Ford and Dillard, 2009).

Rendon (2009) reviewed assessments of 32 Navy acquisition programs of varying size to determine the level of "openness" designed into the systems. These programs were assessed for two primary factors, programmatic and technical, for the degree of implementation of MOSA. Of the 32 programs, 16 were judged to have a high degree of openness. The number of programs determined to have medium and low levels were 14 and 2, respectively. Though this analysis is based on a limited data set, it can be inferred that tying MOSA implementation to the acquisition policy has a positive effect on the degree of openness in system development.

Boudreau (2007) executed a case study on the use of MOSA on the U.S. Navy's Acoustic Rapid COTS Insertion program. The program is described as evolutionary acquisition's "poster child" due to the cost and schedule performance achieved through the extensive use of commercial components despite a highly dynamic product baseline. This approach is made possible through the development of federated systems with a modular architecture. A vital activity for this approach is the identification and control of key interfaces to partition volatile components from the rest of the system. This control mechanism allows the modification or replacement of system modules without greatly impacting the other system components. This approach requires the program manager to be both technically savvy and highly involved in the systems development process. Additionally, vendors must align their

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business models with the Government's requirements of minimal proprietary data and extensive cooperation among competitors. The payoffs for the Governments implementation of this process are decreased software sustainment and logistics costs leading to a lower overall life-cycle cost.

Kerr (2007) identified two primary mechanisms for enabling technology insertion into existing systems. The first is planning for insertion by identifying components to be upgraded based on projected benefit to the total ownership cost of the system. Planning includes the selection of an optimal replacement strategy such as attrition or recall. The second is designing for insertion through the use of a modular open systems approach including the employment of interface standards, modularity, and commercial-off-the-shelf (COTS) components where possible. While the amount of published information regarding MOSA is growing, additional investigation into the implementation of this evolving development philosophy is necessary, especially with regard to the interaction of these requirements with other tenets of the evolutionary acquisition approach. Sherman and Rhoads (2010) assert that use of open architectures during system design provide reduced cycle times for both the initial development phase and subsequent generations. They state that the use of standardized or commercial-off-the-shelf components is a particularly factor in the potential reduction of defense system acquisition cycle times.

2.6 <u>Literature Gap</u>

A disconnect exists in the literature between DoD-level strategy from the business viewpoint and the implementation of the new program requirements. Further, what

research that has been done focuses on the DoD at the enterprise level. While research

is conducted by Government academic institutions and federally funded research and

development centers, the topic can benefit greatly from the diversity of thought,

methods, and perspectives offered by multiple university research programs working

in parallel (Gansler and Lucyshyn, 2005). This research is made necessary by

increased pressure on the federal discretionary spending budget (of which the DoD is

a part); increased scope, complexity, and technical requirement advancement of

developed systems; changing landscape of defense operations and environment; the

decrease in competent prime contractors due to mergers and acquisitions; the

increased "jointness" required of systems under development which increases the

number of stakeholders for each development program.

A research gap exists with regard to DoD acquisition policy impacts and effective

implementation of these reforms at the program level. While there is significant

research available that examines the challenges facing defense acquisition programs,

the vast majority of the literature approaches the problem from the viewpoint of the

Government. There is little publicly available research that focuses on the perspective

of defense contractors due to the fact that the primary sponsor of this research in this

area, the U.S. Government, is understandably most concerned with the DoD's

operation within the federal guidelines and budget. Also, most industry-sponsored

research is not disseminated outside of the limits of the commissioning corporation for

competitive reasons. Furthermore, not enough time has passed since the December

2008 revision of the Defense Acquisition Management System and the passage of the

Weapons System Acquisition Reform Act of 2009 for a responsive body of research to accumulate or for programs executed under these new guidelines to be adequately studied. Both government and industry must implement the strategic reforms mandated by Congress and the DoD at the program level in order to know whether the new acquisition regulations and strategies will achieve their desired effects. Table 2.6-1 summarizes the identified gap in the existing body of knowledge as determined through the review of relevant literature.

Table 2.6-1: Literature Gap Summary

Literature Deficiency	Cause	Research Gap
Program-Level Research	• Focus on enterprise level; • R&D Research is focused on private sector	Current research does not connect DoD program-level issues
Defense Acquisition Research Base Focus	• Need for increase in academic research; • Most published research conducted by Government; • Industry research base unavailable to public	Perspective is exclusively focused on DoD impacts
Recent Changes to Process	• Recent modifications to DoD 5000.002 modifications; • WSARA-2009; • Uncertainty to program-level reactions	Impact of recent changes have not been fully explored

The changes enacted to the DoD Acquisition process in response to these challenges are too recent for a significant number of studies to be completed. In order to understand whether the changes are having the desired effect of decreasing risk and thus improving performance in acquisition programs, programs that are operating under the new guidelines must be examined. Such investigations may also indicate if

some of these changes should be reexamined due to emergent problems or if other steps are necessary to address issues not affected by the process modifications.

New program requirements regarding the execution of early Systems Engineering activity, the employment of mature technologies, and the use of a Modular Open Systems Approach are intended to increase requirements and design knowledge, decrease technology implementation risk, and decrease integration risk, respectively. This research study seeks to measure the impact of these process changes as implemented on multiple programs executed under the revised acquisition framework and identify the correlation with identified knowledge and risk factors. The focus is placed on determining whether the implementation of Evolutionary Acquisition has the desired effect of increasing the amount and quality of knowledge available to decision makers, lowering program risk, and increasing the likelihood of successful program outcomes.

CHAPTER III: METHODOLOGY

3.1 Introduction

This chapter describes the methodology employed to address the previously stated problem and research question. This methodology is used to examine the validity of the constructs identified in the conceptual model and the hypothesized relationships among them.

3.2 High-Level Research Methodology

The research methodology described in this section is developed to bound the scope of the research, identify the key variables and their relationships, and ultimately test the hypotheses. This process is depicted in Figure 3.2-1.
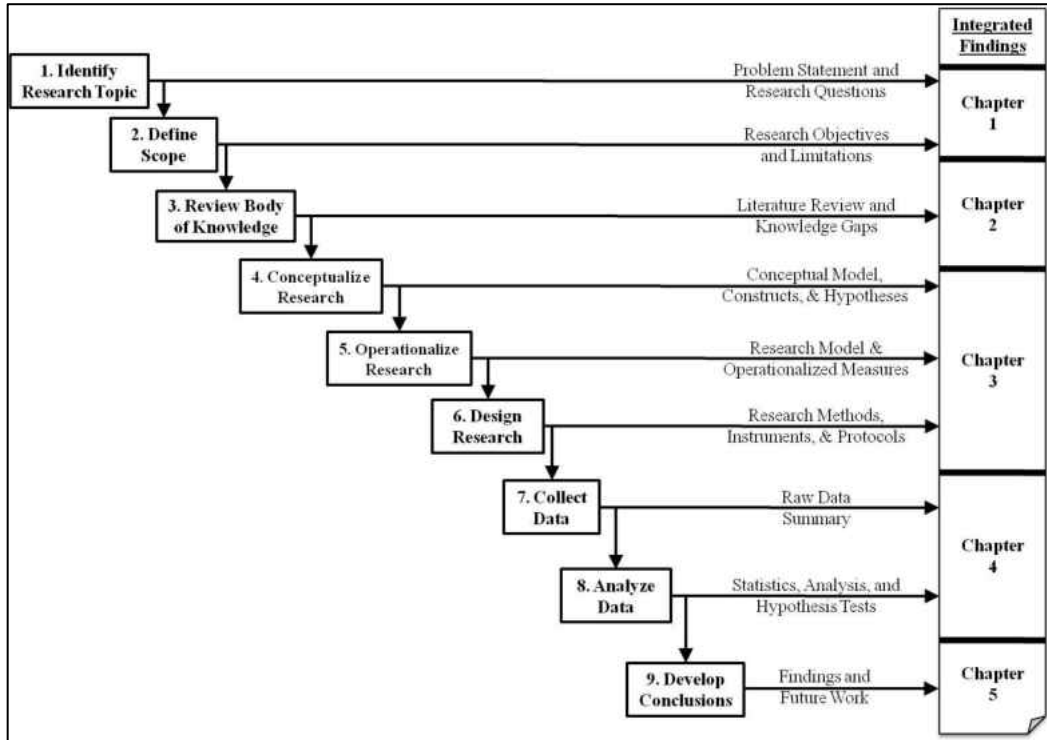
Figure 3.2-1: Research Methodology

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The first step is to identify the focus of the research, leading to the initial problem statement and research questions. The second step is to establish the limits of the research to set the bounds of the scope of inquiry. Thirdly, a focused literature review is developed that identifies the knowledge gaps that are addressed by the research. The fourth step is to identify the constructs relating to the problem space and their hypothesized relationships to each other based on the surveyed body of knowledge. After conceptualization of the problem and solution spaces is complete, the fifth step involves the designation of operationalized measures to evaluate the impact and interaction of the identified constructs. A research methodology is designed in the sixth step to develop and assess the measures resulting in the development of research instruments. These instruments are used to collect data during the seventh step. This data is analyzed in the eighth step with the goal of producing conclusions with regard to the constructs and hypothesis, which are documented and reported during the ninth and final step. Conclusions are developed and the conceptual model and hypotheses are revised. Recommendations for future research are documented during this step.

The results of the first three steps in the research plan are documented in Chapters I and II. This chapter focuses on the conceptualization, operationalization, and design of the research.

3.3 <u>Research Conceptualization</u>

Conceptualization is the process of developing constructs to represent aspects of the problem and its environment. Constructs are intangible factors within the case context that are of interest to the research question. The research question, along with a review

of the relevant literature, guides the development of constructs that are to be measured during the course of the study. The hypotheses being tested or developed by the research relates to the existence of dynamics among the constructs. In theory-building research studies it is helpful to establish *a priori* constructs to provide a starting point for inquiry. Establishing constructs based on the literature early in the study allows for the measurement of constructs during all phases of data collection (Eisenhardt, 1989). If the constructs are significant, multiple data sources will provide convergent evidence (Yin, 2009). Constructs are refined throughout the study based on data collection and analysis.

"Overdescription" of elements and the environments related to critical processes is a potential issue with systems engineering research. To counter this issue, constructs representing new phenomena are often best explained with a focus on a small set of essential factors (Friedman and Sage, 2003). In order to provide a basis to manage the complexity of the problem domain, the related literature is studied to identify the technical concepts critical to the defense acquisition process and their interaction leading to the development of the conceptual model depicted in Figure 3.3-1.
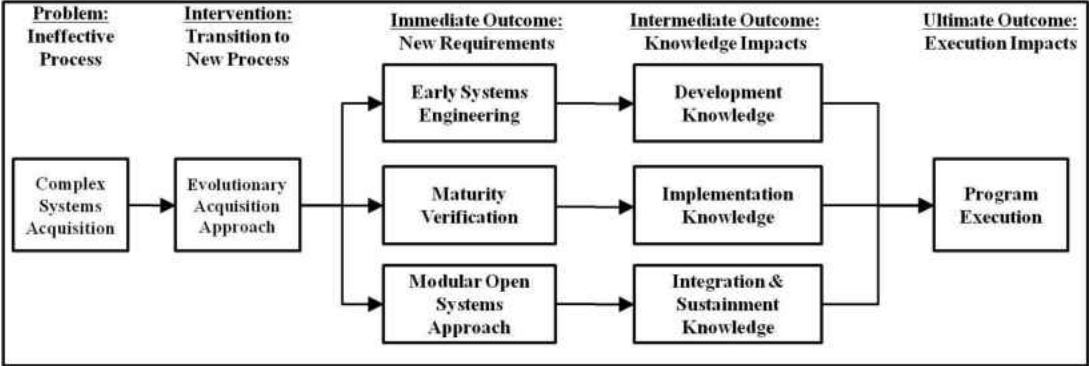
Figure 3.3-1: Conceptual Model

The logic model presented in section 2.4 serves as the foundation for the conceptual model. This model represents the process of complex systems acquisition in which the implementation of an Evolutionary Acquisition Approach places increased requirements related to Early Systems Engineering, Maturity Verification, and a Modular Open Systems Approach on acquisition programs. These factors, as described in the literature review, influence the levels of Development Knowledge, Implementation Knowledge, and Integration and Sustainment Knowledge on the program. The reviewed literature suggests that the levels of program knowledge have a positive impact on the technical, cost, and schedule performance of a program.

Multiple unidentified factors undoubtedly are also impacted by the process change and in turn affect the program's levels of knowledge and risk, but they are not addressed directly by the research design and are considered as part of the program environment. The constructs identified in the conceptual model are described in detail as part of the literature review presented in Chapter II. Description of the constructs as they pertain to the research design and the measures used to evaluate them are contained in the section on Research Operationalization.

3.4 <u>Research Operationalization</u>

Operationalization is the process of translating the abstract concepts into measurable indicators and variables. As constructs cannot be measured directly, operational measures must be developed to allow for determination of their prevalence, impacts, and dynamics. These operational measures are analyzed to test existing theories or support the development of new theory. Operational measures derived from constructs

provide the logical links between data and propositions that are critical for valid

research (Yin, 2009). The research model is developed as an extension of the

conceptual model during this process to map the operational measures to the

constructs that they represent and illustrate the hypothesized relationships among the

constructs. The research model is depicted in Figure 3.4-1.
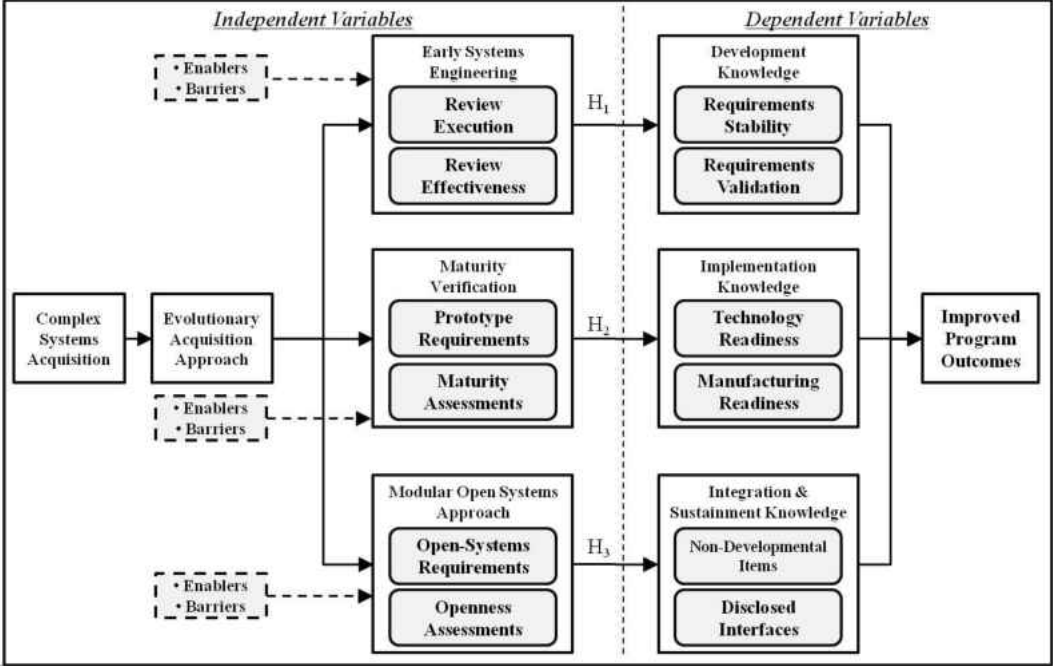
Figure 3.4-1: Research Model

The research model also divides the constructs and operationalized measures into

dependent and independent variables with regard to the hypotheses. Each of the

independent constructs relates to an aspect of system development that is purported to

improve acquisition outcomes by increasing the knowledge and reducing uncertainty

with regard to some aspect of the program. Each of the dependent constructs

represents a type and level of programmatic knowledge that is critical to the effective

development and fielding of a system solution. The hypothesized nature of the

relationships among the constructs is included in the research model as represented by H_1, H_2, and H_3. All three of these hypotheses assert a positive correlation between the independent and dependent constructs. As knowledge is proportional to program success (GAO, 2008), the hypotheses posit that the proper implementation of the independent constructs lead to improvement in program knowledge and risk positions and ultimately to improved program outcomes.

To test the existence of the hypothesized relationships among the variables, each construct is assessed through two operationalized measures. These research elements are described in the subsequent sections, grouped by the relevant hypothesis. In each section, the hypothesis is stated, followed by a description of each construct and the operational measures that are used to evaluate the prevalence of the constructs. The hypotheses, constructs, and measures described in the subsequent sections are used to develop research instruments that are employed to gather data related to the identified constructs. That data is then used to test the identified hypotheses.

3.4.1 Hypothesis 1 (H_1)

The first hypothesis proposes that a positive relationship exists between the execution of systems engineering activities early in the product lifecycle and knowledge necessary for the successful development of complex systems. This hypothesis is stated as follows:

H_1: Execution of systems engineering activities prior to full implementation commitment increases development knowledge.

This hypothesis is assessed by measuring the relationship between the independent "Early Systems Engineering" construct and the dependent "Development Knowledge" construct.

3.4.1.1 *Measurement of the "Early Systems Engineering" Construct*

For the purposes of this research, Early Systems Engineering is defined as activities that occur during the Technology Development phase that seek to develop requirements, establish a baseline for a preliminary solution, and lead to the satisfaction of technical requirements within cost and schedule constraints. Although the importance of systems engineering activities prior to the Technology Development phase has been established (National Research Council, 2009), the decision process is almost entirely Government-driven. Industry is not substantially involved with the system solution to provide insight into the impact of decisions at the implementation level until after award of Technology Development contracts as depicted in Figure 2.4-2. The involvement of contractors is crucial to developing an understanding of the cost, schedule, technologies, and risk involved in the implementation of the Government's requirements and delivery of the system solution to the warfighter. This construct is an independent variable within this research.

In order to measure the presence of this construct on a program, focus is placed on the Systems Engineering Technical Reviews held during the Technology Development phase. System Engineering Technical Reviews are major events on programs that include multiple stakeholders including the contractor, acquiring program office, operational users, system support personnel, and technical experts. They include a

summary of the system development activity status and serve as the decision point for the establishment of baselines. Generally they are hosted by the contractor and facilitated by off-program Government representatives. The contractor provides the majority of the material to be assessed by stakeholders and experts. Artifacts of these reviews include agenda, review presentation material from the Government and contractor, and review minutes. Table 3.4-1 describes the systems engineering reviews prescribed by the Defense Acquisition Guidebook (2011) during technology development.

Table 3.4-1: Systems Engineering Reviews During Technology Development

Review Name	Review Objectives	Associated Baseline
System Requirements Review	Ensure that the system can proceed into initial development with acceptable risk and that all requirements derived from warfighter requirements are defined, testable, and consistent with cost, schedule, risk, technology readiness, and other system constraints.	Requirements Baseline
System Functional Review	Ensure that the system has a reasonable expectation of satisfying warfighter requirements within the currently allocated budget and schedule and that Integrated Product Teams are prepared to start preliminary design.	Functional Baseline
Preliminary Design Review	Ensure that the system under review has a reasonable expectation of being judged operationally effective and suitable and that the hardware, software, human/support systems and underlying architectures are capable of satisfying the requirements within the currently allocated budget and schedule.	Allocated Baseline

Both the manner in which the reviews are executed and the effectiveness of those reviews is assessed to determine the prominence of the construct.

3.4.1.1.1 *"Review Execution" Measure*

This measure is used to assess the number, type, nature, and goals of reviews held during the Technology Development phase of the program. It assesses the focus of the

review on the appropriate baselines, as opposed to implementation concerns, as well as the degree to which program budget and schedule are impacted by design choices. There may be variation among service branches in review execution due to the fact that the procedures used to govern the reviews are often managed by individual services or subcomponents (e.g., NAVAIRINST 4355.19D), however the procedures are commonly based on the process outlined in the Defense Acquisition Guidebook (DAU, 2011).

3.4.1.1.2 "Review Effectiveness" Measure

The goals of these reviews are to identify risk, align cost and schedule with technical requirements, and establish valid requirements and design baselines (DAU, 2011). The effectiveness of these reviews is assessed based on evidence that these goals have been met. This includes examination of whether significant risks have been identified during reviews and whether the reviews concluded that the system as specified is implementable within cost and schedule constraints. Additionally, as part of this measure, it is determined if stakeholders and subject matter experts from appropriate disciplines participated in the reviews which is critical to ensuring that all relevant perspectives have been addressed (DAU, 2011).

3.4.1.2 *Measurement of the "Development Knowledge" Construct*

"Development Knowledge" is the level of understanding present among the program regarding the requirements of the system and the design of the solution necessary to meet those requirements. If the system requirements are not sufficiently defined and

understood to support development of a technically compliant product within cost and schedule projections, the program is placed at significant risk. The potential impacts of insufficient development knowledge are delays to test activities, delays in production, increased development costs, and decreased technical performance due to trade-offs made to ensure operational timeline goals are met. If the cost and schedule requirements of the program are not achievable, then it is unreasonable to expect those requirements to be met. When the risks are realized during execution due to a lack of development knowledge the actual costs of the program become evident, which leads to rebaselining of cost and schedule estimates. Repeated rebaselining is a hallmark of troubled and failing programs (Kwak and Smith, 2009).

The measurement of the "Development Knowledge" construct focuses on the development and management of the requirements set and the success of the program in the Technology Development phase to refine the system requirements and establish an executable allocated baseline. Development knowledge is the degree to which the system requirements, operational environment, and required capabilities are understood by the program and reflected in the system design.

3.4.1.2.1 *"Requirements Stability" Measure*

Requirements Stability is a measure of the amount and nature of change to the requirements set during system development. Changes in requirements during system implementation are a leading cause of cost and schedule overruns as demonstrated on multiple failed programs (GAO, 2011a; GAO, 2006). Costello and Liu (2005) present the requirements quality of volatility (i.e. lack of stability) and suggest the use of such

metrics early in the development life cycle and continuing through system-level test and evaluation. Stability of requirements is also identified as a leading indicator of the success of systems engineering on a program by Roedler, Rhodes, Schimmoller, and Jones (2010). This subfactor measures program characteristics that indicate future requirements changes may occur during the Engineering & Manufacturing Development phase including optional capabilities and requirements that include "to-be-determined" (TBD) parameters.

3.4.1.2.2 *"Requirements Validation" Measure*

Validation of a requirement set, as defined by Bahill and Dean (2009), is the process of determining that the requirements set is complete and consistent; supports the development of an implementable architecture; and can be translated into a real-world system that can be fabricated and tested. Requirements validation indicates the level of understanding of the requirements set and impacts of those requirements on the development and fielding of a system. The validation of the requirement set is also identified as a leading indicator of systems engineering success (Roedler, Rhodes, Schimmoller, and Jones, 2010). A system based on a validated requirements set presents much less development risk than one based on requirements that have not been adequately examined for feasibility of implementation. Discovery that requirements are invalid during implementation leads to sacrificing of system technical performance or delays and cost overruns as new technology is inserted into the system. This subfactor is assessed through examination of the completeness and consistency of the requirements set, the degree to which appropriate verification

criteria have been established, and evidence of a documented system architecture that is achievable within cost and schedule constraints.

3.4.2 Hypothesis 2 (H$_2$)

The second hypothesis proposes that a positive relationship exists between the product maturity verification activities and the successful implementation of complex systems. This hypothesis is stated as follows:

H$_2$: Verification of product maturity prior to system detailed design increases implementation knowledge.

The validity of this hypothesis is assessed by measuring the relationship between the independent "Maturity Verification" construct and the dependent "Implementation Knowledge" construct.

3.4.2.1 Measurement of the "Maturity Verification" Construct

The "Maturity Verification" construct represents activities conducted during the Technology Development phase to determine the readiness of the proposed system with regard to both performance in relevant operational environments and factors related to system producibility. This scope includes the competitive prototyping scope and technology and manufacturing readiness assessments required to be included in programs prior to full funding. (WSARA, 2009). Measurement of this construct includes evaluation of both the requirements on system prototypes and the means by which the maturity of the proposed system is assessed.

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3.4.2.1.1 "Prototype Requirements" Measure

One of the primary purposes of the Technology Development phase is the

demonstration of critical technologies using system prototypes (DOD 5000.02, 2008).

The Department of the Air Force (2008, pg 1) defines prototyping as follows:

"The process of assembling representative hardware and software into a

configuration that can demonstrate and validate both operation and functionality of

key elements of the proposed product or system".

It is critical from an implementation standpoint that key elements and functionality are

included in the prototype. This measure assesses the technical requirements of the

prototype to determine the degree to which it is representative of the proposed system.

The relevant properties include physical characteristics, system performance, specified

environments, and production process requirements.

3.4.2.1.2 "Maturity Assessment" Measure

The manner in which the product is assessed is critical to developing a proper

understanding of system maturity, as evidenced by the requirement for prototypes to

be demonstrated in relevant environments (DOD 5000.02, 2008). This measure

examines the degree to which maturity assessments include test and evaluation of

prototypes in relevant environments and examination of the components in the

proposed system to determine maturity with regard to predictability of performance

and production capability. The level of adherence to the formal Technology Readiness

Assessment (TRA Deskbook, 2009) and Manufacturing Readiness Level Assessment (MRL Assessment Deskbook, 2011) processes are also investigated.

3.4.2.2 *Measurement of the "Implementation Knowledge" Construct*

Implementation knowledge is the degree to which the required tools, processes, and technologies for manufacturing and verifying a system that meets requirements is understood and reflected in the program plan. The GAO recommends that a pre-determined level of maturity be demonstrated before integration of a technology into product development programs. In order to reduce risk, the DoD wishes to match mission needs to mature technologies that are well understood. Appropriate technologies are those that can be predictably implemented to enable the satisfaction of cost, schedule, and technical performance requirements (DoD FY2011 Budget, 2010). To be useful to the warfighter, a technology must be integrated into a system that can be produced in sufficient quantities in an affordable manner. Therefore, the concept of manufacturing readiness is also important to a successful acquisition. The level of Implementation Knowledge acquired by the program is assessed through the operational measures of Technology Readiness and Manufacturing Readiness.

3.4.2.2.1 *"Technology Readiness" Measure*

Technology readiness is a measure of the demonstrated maturity of a technology for a given application in a relevant environment (Technology Readiness Assessment Deskbook, 2009). Use of mature technology in system designs is a recommended best

practice that aids in the avoidance of program cost and schedule overruns (GAO, 2011b).

The primary metric for assessing the maturity of technology used in DoD and National Aeronautics and Space Administration (NASA) acquisition programs is the Technology Readiness Level (TRL). TRL is measured on an integer scale of 1 to 9 with higher numbers denoting a higher level of proven maturity. Levels of demonstrated readiness range from the observation of basic concepts to prototype validation to demonstration of a system during successful mission operations (Mankins, 1995).

This subfactor assesses whether the system's critical technologies have achieved the requisite maturity of TRL 6, which is the minimum recommended level of technology maturity for progression into the Engineering and Manufacturing Development phase (WSARA, 2009). This level of maturity is evidenced by whether its technologies have been demonstrated in an operationally relevant environment through prototyping activities or as part of another system. This subfactor is measured by identifying whether critical technologies have been used in previous systems and whether those technologies have been demonstrated in operationally relevant environments to reduce first-time events prior to system deployment.

3.4.2.2.2 *"Manufacturing Readiness" Measure*

Manufacturing Readiness is a scale used to support assessment of a technology, component, manufacturing process, weapon system, or subsystem to determine

manufacturing maturity and risk (MRL Deskbook, 2011). Once a system is verified to meet requirements and approved for deployment, it must be consistently manufactured at a sufficient rate to meet operational needs and at a predictable cost to support valid budget estimates. It is preferred that production processes be understood and defined early in programs because a lack of manufacturing knowledge is associated with production cost and schedule overruns (GAO, 2009). This measure is assessed by identifying the degree to which the program has achieved the appropriate Manufacturing Readiness Level by sufficiently defining production plans and demonstrating processes.

3.4.3 Hypothesis 3 (H_3)

The third hypothesis proposes that a relationship exists between the use of an open approach and the ability to integrate the system with internal and external components and platforms to obtain an operational capability. This approach is also theorized to facilitate sustainment and growth of capability over the system lifecycle. This hypothesis is stated as follows:

H_3: Application of a Modular Open Systems Approach during development increases integration & sustainment knowledge.

The validity of this hypothesis is assessed by measuring the relationship between the independent "Modular Open Systems Approach" construct and the dependent "Integration and Sustainment Knowledge" construct.

3.4.3.1 <u>Measurement of the "Modular Open Systems Approach" Construct</u>

 MOSA is an integrated business and technical strategy for systems development and maintenance that employs a modular design and defines key interfaces using widely supported, consensus-based standards (OSJTF, 2004). This construct is evaluated by examining the open-systems requirements levied by the program and the nature of assessments conducted to determine compliance with a Modular Open Systems Approach.

3.4.3.1.1 "Open-Systems Requirements" Measure

Open-system requirements are mandatory qualities of a program or system that relate to the use of previously available components and non-proprietary interface implementation. These qualities encourage participation of third parties (e.g., entities other than the vendor and the Government) in system development and sustainment (Eisenmann, Parker, and Van Alstyne, 2008). This subfactor is assessed by identifying the amount and nature of open systems requirements levied on the program, including prohibitions against the use of proprietary components and data (MOSA PART, 2004).

3.4.3.1.2 "Openness Assessments" Measure

Due to the qualitative nature of open-system requirements, assessments are necessary to ensure conformance to a Modular Open Systems Approach (OSJTF, 2004). This subfactor measures the number and type of assessments performed to evaluate the application of standards, identification of relevant components available in the market,

volatility of system components, and the establishment of business cases for the degree to which the system should implement open design concepts.

3.4.3.2 *Measurement of the "Integration and Sustainment Knowledge" Construct*

Once systems are designed and produced, they must be integrated with other systems and sustained in the long term in order to be useful to the warfighter. System Integration and Sustainment Knowledge is the degree to which the required tools, processes, and technologies for connecting the system to external systems and platforms and the resources necessary to maintain those capabilities over the system life-cycle are understood by the program.

Most costs of a system occur during operation and sustainment phase, however these costs are determined through choices made during system development (Blanchard and Fabrycky, 2005). Therefore, it is critical that the development programs account for future change of the required system capabilities and environments. This construct is assessed through the assessment of the inclusion of previously developed and proven components in the proposed system design and the degree to which the implementation details of critical interfaces are disclosed to interested parties.

3.4.3.2.1 *"Non-Developmental Items" Measure*

Non-developmental items (NDI) are components of a system that have been obtained from a commercial source or have been reused from prior programs. The use of NDI significantly reduces program uncertainty because the performance characteristics and behavior of the components have been previously verified. Use of NDI reduces both

the scope of development work and the uncertainty that the component is compliant to specifications (Steves, 1997). This subfactor is assessed by examining the use of non-developmental hardware and software components in the system design.

3.4.3.2.2 *"Interface Disclosure" Measure*

Interface disclosure is a tenet of MOSA that seeks to ensure that interfaces are implemented in such a way as to support integration with other systems and system capability growth (OSJTF, 2004). This measure is evaluated by determining the degree to which the system interface implementation definitions are available to interested parties, comply with published standards, and support future capability growth and component replacement (MOSA PART, 2004).

3.4.4 Additional Barriers and Enablers

For each of the dependent constructs, there exist a set of currently unknown barriers and enablers to the successful implementation of an Evolutionary Acquisition approach. While these factors are not part of the primary line of questioning, the research design includes elements that attempt to identify them.

3.5 <u>Research Design</u>

The complexity of defense systems and time lines associated with their development discourage the application of experimental methods by limiting the researcher's ability to isolate variables and control the project environment. Research into systems and processes with a high level of complexity limit the use of control cases, the isolation of variables, and the ability to apply standardized methodology (Valerdi and Davidz,

2009). Verification of product maturity and MOSA as components of a comprehensive systems-engineering approach share similar issues with regard to the development of effective research designs. As the concepts are difficult to objectively quantify, individual perception of their meaning, applicability, and implementation are the most valid measures available for these qualities.

Qualitative methods are applicable to problems dealing with human systems, particularly for studies exploring organizational effects because people are dynamic, individualistic, and capable of misalignment (Avison, et al, 1999). Therefore, qualitative research methods are appropriate for application to the study of the defense acquisition process to collect evidence regarding theory and application of principles. Because the objects of the study are humans rather than inanimate objects, it is critical to capture the subject's frame of reference when collecting data. Therefore, the research plan is implemented to measure the constructs using a qualitative, mixed-methods multiple-case-study methodology based on Eisenhardt (1989) and Yin (2009) to investigate the impact of the acquisition process changes at the program level. The case studies are augmented by survey methods that collect data from a larger variety of programs. The integrated research methodology is depicted in Figure 3.5-1.

Case Studies

Document Analysis
- SOW
- Specs
- SEP/SEMP
- Review Mat'l

CONTEXT

Interviews
- Prog Mgr
- Engineer
- Tech Mgr
- Logistics

2 Programs

3+ Programs

Survey Question Revision

Surveys

Sample
- N ~ 60
- Govt & Ctr

Format
- Web-based
- 4-point Likert
- Free-response background Q's
- 65 Questions
  - 8 per construct
  - 11 Background
  - 6 General

Construct Validity	High
Internal Validity	High
External Validity	Low
Reliability	Low

(Gable, 1994)

Are Constructs and Hypotheses Valid?

Are Constructs and Hypotheses Supported by Evidence?

Construct Validity	Low
Internal Validity	Low
External Validity	High
Reliability	High

(Gable, 1994)

CONSTRUCTS AND HYPOTHESES

Figure 3.5-1: Integrated Research Methodology

This integrated framework includes two distinct stages with case studies followed by surveys. The goal of this methodology is to achieve both depth and breadth to the data and findings within available resources. When studying new areas or phenomena, Eisenhardt (1989) suggests that periods of data collection and analysis overlap so that adjustments to data collection efforts for improved effectiveness. This recommendation supports the use of multiple data collection stages in the research design wherein later data collection activities (i.e. surveys) are influenced by the data collected in the earlier stage (i.e. interviews). The use of multiple sources of information also allows for triangulation of information to increase the validity of the results (Yin, 2009).

3.5.1 Case Study Approach

The first stage consists of case studies of programs executed under the new acquisition process guidelines. Case studies provide an advanced understanding of the subjects under investigation because their findings are grounded in reality and captured in

empirical data (Flyvbjerg, 2006). Case studies should be used when the research question addresses the "how's" and "why's" of the topic of interest; the researcher is not able to conduct controlled experiments; the goal of the research is to explore current events and outcomes; and the context of the research is application-oriented as opposed to theoretical. The case study methodology is specifically cited as appropriate approach for investigating the outcomes and drivers for government programs (Yin, 2009). The case study methodology has been successfully applied to systems engineering and management aspects of defense acquisition projects (Friedman and Sage, 2003).

In this research design, two cases of defense acquisition programs executed under the new process are examined at multiple levels through review of program documentation and interviews of several members of each program team. This stage provides a significant level of depth to the research as it examines each case individually from multiple perspectives using multiple data sources. Relevant program documentation is reviewed to examine the prominence of the constructs and determine the prevalence of the hypothesized relationships. The document reviews are completed prior to the interviews to ensure that the researcher has a thorough understanding of the context of each case. Interviews are then conducted to assess hypotheses and gain a deeper understanding of the case elements than is possible with review of static documents.

Interviews allow for targeted focus on specific topics and provide causal inferences by subjects (Yin, 2009). Niazi, Wilson, and Zowghi (2005) raised the concern that

previous "Critical Success Factor" research has been dominated by multiple-choice questionnaire survey methodology. The restriction of response options may lead to bias due to the limitation of responses to those factors that have been already identified in the literature or which the researchers find to be important. Therefore, the use of interviews that allow the subjects to identify the crucial elements that shape the programs' knowledge and risk position is appropriate for this application. The primary purpose of the interviews is to develop a framework to facilitate understanding of the organizational interactions (Cunningham, 1993) and to support development of the survey research instruments.

Individual case analyses are performed to determine both the prominence of the constructs and the relationships among them. Cross-case analysis is also performed to identify patterns and differences between the two cases with regard to the factors identified in the single-case analyses. The study of multiple programs provides a small but significant amount of breadth to the research by limiting the effect of idiosyncratic elements of either case on the theory to be developed.

The research design incorporates a feedback loop wherein the results of the case studies are compared to the research model and hypotheses to determine whether they should be revised. This approach is flexible and allows for what Eisenhardt (1998) defines as "controlled opportunism" which is especially important when the goal of the research is the establishment of theory through the exploration of new topics or phenomena. If necessary, the survey instrument is also modified as a result of discoveries that occur during case analysis.

3.5.2 Survey Approach

The second stage consists of a questionnaire-based survey of a population selected from a pool of participants in Evolutionary Acquisition programs as well as subject-matter experts in relevant fields. The survey is structured such that the questions identify the prevalence of the constructs on the programs and the impacts of the independent constructs on the program's execution and subsequent risk position.

In contrast to case studies, survey research seeks to identify the prevalence of constructs within a larger cross-section of the population. The use of surveys to gather more information regarding topics and issues discovered during interviews is suggested by Cunningham (1993). The larger sample size allows for generalization of concepts across groups (Babbie, 1990), providing substantial breadth to the study by incorporating a wider variety of viewpoints based on diverse experiences. The use of a survey instrument adds a set of quantitative data collected from a broad population to the narrow, but rich set of empirical data collected during the case study portion. The quantitative data obtained from the survey is used to statistically test the hypotheses.

3.5.3 Case Studies and Surveys as Complementary Methods

When dealing with complex, dynamic situations, qualitative and quantitative methods applied in conjunction often provide the most effective insight into the problem under review (Flyvbjerg, 2006). Interviews and surveys, in particular, are complementary instruments, providing breadth and depth, respectively (Elm, 2008; Flyvbjerg, 2006), while the document reviews provide objective context of the cases being studied.

Analysis of qualitative data is difficult and complex, requiring a solid understanding of the data's context and social setting (Marshall and Rossman, 1989). Case study methods provide deep understanding of the nuanced and dynamic environment of the programs, allowing for the identification of factors that might not be captured by a questionnaire instrument (Woodside and Wilson, 2003), whereas surveys are useful for discovering the prevalence of factors and determining their effect on a large number of situations in a relatively short period of time (Yin, 2009).

Previous case studies of multiple concurrent development projects using interview and survey data have been successfully completed, yielding insight into organizational processes. For example, Purser, Pasmore, Tenkasi (1992) utilized multiple data collection methods including 55 structured interviews and a survey of 130 practitioners focused on two projects executed by the same organization. Similarly, the research methodology presented here includes the gathering of data from multiple programs within a common organization using interviews and surveys. Based on the resulting research design, data collection and analysis procedures are developed and pre-tested.

3.5.4 Pilot Study Approach

Piloting of a research study incorporates the middle components of a Deming cycle (i.e., "Plan, Do, Check, Act") to improve the outcome of the main study by testing the methods prior to full implementation. Pilot studies can be particularly effective for the refinement of data collection plans and lines of questioning (Yin, 2009). Research instruments, hypotheses, and analysis techniques may be improved or replaced based

on the outcome of these activities. Pilot study activities provide an opportunity for the researcher to practice the data collection and analysis skills necessary for the effective execution of studies. They also allow for third-party review of results to identify improvements to the data collection and analysis process prior to the initiation of the data collection phase of the study (Marshall and Rossman, 1989).

The execution of full pilot case studies is not feasible in the context of this research due to the small number of relevant cases available. However, in order to take advantage of the benefits of the piloting process, the interview and survey instruments are tested prior to full implementation. As the nature of documentation is static and allows for repeated analysis, reviews of these artifacts are not piloted. The focus of pilot activity for this research is refinement of the research and data analysis techniques. The survey instrument employed by this research is examined by academic experts prior to survey execution.

The data from these pilot activities is processed according to the research plan to ensure that the data obtained can be analyzed using the proposed techniques. The analysis encompasses all steps of the processing from data verification through hypothesis testing. The examination of pilot data serves to ensure that the data from the surveys is compatible with the procedures and tools used to process it. The results from this analysis are reviewed with colleagues and the respondents to assess the validity of the results obtained. The purpose of this piloting process is to assess whether the mechanics of the process are correctly specified. The results of any analysis during the piloting activity are not used to validate constructs or hypotheses.

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If found to be advantageous, the interview format, survey instrument, or data analysis process may be modified to ensure that subject responses are able to be properly transformed from raw data to usable results. The output of the pilot activities are captured in the research database, but are not included in the published results.

3.5.5 Quality of Research Methodology

The quality of the research is crucial due to the fact that research that lacks validity provides questionable results that are more likely to be improperly applied in the field (Valerdi and Davidz, 2009). In furtherance of demonstrating the quality of the research methodology, the following tests of construct validity, internal validity, external validity, and reliability identified by Yin (2009) are used. Additionally, potential sources of bias are identified and addressed

3.5.5.1 *Construct Validity*

Construct validity is the degree to which the concepts identified by the research actually exist and correct operational metrics are used to assess the effects of identified concepts and the hypothesized relationships among them. Construct validity in Systems Engineering research is especially challenging due to the lack of consistent definition of systems engineering terms and practices across organizations (Valerdi and Davidz, 2009). Therefore, conducting studies on different projects executed within a commercial organization provides for increased construct validity due to the common context for the concepts measured by the research instruments. Additionally, the use of a two-phase data collection strategy that incorporates a feed-back loop and

review of the instruments by third parties allows for the verification that the constructs identified are being properly measured. The results of theory-building research methods based on real-world situations such as case studies have a high likelihood of empirical validity because the construct and theory development process is so closely intertwined with the data collection efforts (Eisenhardt, 1989). As the constructs measured by the survey instrument are derived from the case study results, the research has a high level of construct validity. To demonstrate the construct validity of the research design, Confirmatory Factor Analysis (CFA) is performed on the survey data. CFA provides analysis of the internal structure of operationalized measures and the constructs to identify the degree of correspondence between them (Pedhazur and Schmelkin, 1991).

3.5.5.2 *Internal Validity*

Internal validity relies on the establishment of causal relationships among the constructs. Internal validity is bolstered through the development of logic models to better understand and communicate relationships (Yin, 2009). The use of the logic model presented in Section 2.4 as the basis for the construct model and hypothesized relationships improves the internal validity of the research design. The in-depth study of multiple cases and the survey covering a larger number of programs allows for pattern matching and triangulation (Yin, 2009), also known as Convergent Validity (Valerdi and Davidz, 2009). Triangulation also increases the internal validity of the research when multiple lines of questioning and methods (e.g., interviews and document reviews) for gathering data within each case study yield similar results. The

existence of convergence increases the likelihood that the observed effects are real and not an artifact of the data collection instruments or methods. The use of cross-case analysis as well as the collection of data from respondents with varying perspectives and responsibility levels within each case increases the likelihood of triangulation when the constructs under investigation are supportable by the data (Yin, 2009).

3.5.5.3 *External Validity*

External validity is a measure of the applicability of the study results to the defined domain (Yin, 2009). A high level of external validity is critical for successful application of the theory developed to other programs. If the generalizability of the results is low, implementation of suggestions forwarded by this research could conceivably hinder rather than improve the knowledge and risk position of a program (Valerdi and Davidz, 2009).

A challenge to the external validity of the research is posed by the number of programs to be included in the first phase of the study. The small number of cases available is due to the fact that the few programs that have been executed under the new DoD acquisition process have reached a point where results are evident. While there is relatively small number of active programs currently being executed under this new process, the external validity is likely to improve over time as older programs end and new programs incorporate the elements of Evolutionary Acquisition as specified by DoD regulations. The fact that the programs under review represent emerging phenomena that will become more prevalent in the future qualifies these cases as "revelatory", and therefore important for investigation (Yin, 2009).

Although a large population is usually preferred to increase the likelihood that the research is generalizable, small-sample case studies are acceptable for theory building as long as depth is acquired (Eisenhardt, 1989). The review of program documentation and interviews with multiple participants per program provide the requisite depth. To account for the relatively small sample size, the constructs under study in this research have a strong grounding in the literature on defense acquisition and product development. The external validity of research is improved when variables are based on literature reviews because the literature incorporates results from a large number of diverse scenarios (Gable, 1994).

As the primary goal of this effort is to build theory to be tested by future research, the results may be tested across a greater number and variety of programs as part of future research when more data becomes available. The future extension of the study is supported by a documented research protocol contained in the Data Collection and Analysis section. The documentation facilitates reliable replication of the research in other contexts and supports other studies to verify the results. Additionally, the use of surveys administered to practitioners to determine the prevalence and impacts of the identified constructs in other contexts adds significant breadth to make results more generalizable.

Another specific challenge to the chosen research methodology and the programs selected is that it does not seek to draw responses from a diverse set of cases. The programs studied are selected purposively rather than randomly, which is preferable for research oriented to developing theory and identifying constructs (Eisenhardt,

1989). The selection of cases that incorporate the newly modified acquisition principles is highly relevant to future acquisition programs and improves the external validity of the research inside of an important emerging context.

On the surface, the limitation of scope to DoD programs may make the theories and constructs generated difficult to extend to other areas. Even though acquisition programs conducted by NASA, Homeland Security (including Coast Guard), other federal agencies, or private firms are not directly included in the study, those domains share many characteristics with defense acquisitions. Future studies may be executed based on the documented methodology to investigate the prevalence and impact of the identified factors in those specific domains.

Due to the opportunity for access to interview subjects and detailed programmatic data, the case studies are limited to contractor organizations that execute programs. The fact that both programs drew data from contractors and involved similar levels of complexity serve to reduce the number of factors involved in the evaluation, but potentially reduces the external validity of the results. The concentration of studies on a single organization is not unprecedented. Previous studies in related areas have been conducted with phases of data collection focused on a single organization. The Corning Systems Engineering Directorate (2009) measured the effectiveness of systems engineering techniques using a literature review and interviews with 19 systems engineers and project managers at Corning, Inc. Kludze (2003) conducted a study of systems engineering effectiveness by interviewing a population limited to NASA program personnel. Purser, Pasmore, and Ramkrishnan (1992) conducted case

studies of two concurrent product development projects within a single division of a company. The Purser and Kludze case studies were also complemented with questionnaires administered to a larger population to increase the generalizability of the results. These examples bolster the view that the challenges to generalizability, while significant, do not invalidate the value of the research.

3.5.5.4 *Reliability*

The term "reliability" in this context refers to the repeatability of results using the identified protocol. Reliability is principally enhanced through development of a database and rigorous documentation of the study execution (Yin, 2009). A threat to the reliability of the research is that a single individual was responsible for collection and analysis of all research data. The use of a single researcher could not be avoided due to the resources available to support the research. This fact is mitigated by the existence of field notes taken during the investigation and the rigorous methodology applied during data collection. Well-defined case study protocols significantly increase the reliability of the research by reducing variation in execution (Yin, 2009).

Though the data presented is masked, protection of the confidentiality of the data is not identified as a major impediment to the research, as the researcher has knowledge of the identities of the respondents. The reproducibility could be questioned, however if another researcher wishes to follow up on the conducted research proper assurance of information non-disclosure could be the major impediment. The fact that the interviewees perceptions and experiences color the responses may also be a challenge

to reliability, but the open nature of the questions reduce the effect of interviewer bias (Cunningham, 1993).

When using a questionnaire to gather quantitative data, it is important to test the results to assure that the instrument is reliable. The reliability of the questionnaire is critical to the overall validity of the findings as well as the ability to extend the research in future work to encompass adjacent topics or populations. Unfortunately, as the reliability of a measurement is dependent on the population being measured, the reliability of the questionnaire cannot be determined prior to employment (Pedhazur and Schmelkin, 1991).

To quantitatively assess the reliability of the survey instrument, the results of questions grouped by associated operationalized measures and Cronbach's Alpha is calculated for each group. If reliability scores are low for a particular item, then it is considered for removal as an appropriate measure of the construct. At that time, it is decided if the question is invalid, if it is closely related to another construct, or if it measures a factor that is likely to vary independently of the other questions while still representing the construct.

3.5.5.5 *Potential Sources of Bias*

All research is susceptible to bias, therefore, it is critical to recognize and account for it during the research planning stage and acknowledge it in research reports (Leedy, 1989). The following sources of bias have been identified and action has been taken to decrease the influence of these sources as described below.

Due to available resources, one individual is responsible for collection and analysis of all data. Yin (2009) identifies researcher preconceptions as a significant source of bias in case study research. To address this source of bias, a rigorous process is documented and followed during collection and analysis of the data. The overlap of data collection and analysis that results from the two-stage process provides the opportunity to revise the constructs of the research if they are not supported by the data. Eisenhardt (1989) suggests that the closeness of the researcher to the data when using case study methods actually reduces bias in the results. A research database is maintained so that others can examine the evidence and preliminary findings are discussed with colleagues to gather multiple points of view.

The methods used to extract the data are a potential source of bias because the respondents may be influenced by the way that questions are asked. Connotations of terms may influence the respondent to try to give the "correct" answer. Additionally, it should not be assumed that everyone has the same understanding of context-specific terms. Interviewees are likely to answer the questions in response to the meaning that any ambiguous terms have to them (Pedhazur and Schmelkin, 1991). To ensure clarity of purpose, interviews are conducted using open-ended questions that avoid the use of jargon and ambiguous phrasing. The terms used in the survey questions are based on Government sources that are not program-specific. Both the interview and surveys questions are reviewed by third parties to ensure that all terms used are clear and do not imply positive or negative connotations. The interview process and the survey

instrument are piloted to further identify questions that may influence the respondent's answers.

Data collected from interviews is particularly susceptible to the effects of memory and retrospective reasoning (Woodside and Wilson, 2003). An effective strategy to account for bias in interview data is the collection the use of multiple subjects to provide diverse perspectives because it is unlikely that their individual biases converge (Eisenhardt and Graebner, 2007). Self-presentation, that is the tendency of interview respondents to make a particular impression (Pedhazur and Schmelkin, 1991), may be a significant in the interview phase. Collecting data from program documentation and Government assessments provides independent verification of the risk position of each program.

The affect of sample selection may also be significant due to the small number of cases being studied and the theoretical sampling approach (Eisenhardt, 1989) used to increase the relevance of the data to the research question. The programs to be studied are revelatory cases for the new process; therefore there are few cases available. The focus of the case studies on an organization with a consistent, well-established culture is driven by the researcher's opportunity access to a large amount of rich data. The researcher has an extensive understanding of the organizational culture and the impact of cultural effects is included in the set of rival explanations considered. The use of a questionnaire instrument to test the findings of the cases studies provides for testing of the hypotheses on a larger sample population.

3.6 <u>Data Collection and Analysis Process</u>

The purpose of the data collection and analysis phase is to gather information regarding the specified constructs and measures that is used to determine the validity of the constructs and their hypothesized relationships. This phase of research includes the selection of cases, the development of the research instruments, and the collection and analysis of the individual data sets. The documentation reviews, interviews, and surveys are used as data-gathering tools to obtain diverse perspectives on the problems facing defense acquisition programs. Table 3.6-1 identifies the subjects addressed and the objectives sought through use of each type of research instrument.

Table 3.6-1: Overview of Data Collection Methods

Data Collection Method	Data Source	Objective
Program Documentation Review	Program requirements, review material, and program plans	Determine program context and execution effectiveness
Interviews	Twenty practitioners involved in two Evolutionary Acquisition programs	Develop insight into impacts of process changes on program execution and identify new barriers and enablers to effective execution
Surveys	Thirty practitioners involved in Evolutionary Acquisition programs	Measure the prevalence and impact of identified constructs and test relationships among them

This section describes how the data is collected, analyzed, and documented during the research process.

3.6.1 Case Selection Process

The case-selection process identifies "what" is to be studied. Factors that affect case selection include access to sources of information, data collection methods being used,

applicability to the research question, and type of data sought. Selection of the cases to be studied requires determining the unit or units of analysis to define the boundaries of a case in the context of the study, be it an individual, a project, a company, or even an entire country (Yin, 2009). This research defines a case as the Technology Development phase of a Major Defense Acquisition Program.

This research employs purposive sampling to ensure that valid cases are studied, increasing the probability that the results yield data useful to the specific problem. When employing a case-study methodology to develop theory, it is preferable to select cases that are germane to the theory domain rather than employing random sampling. Purposive selection of cases can also serve to control for variation of unmeasured factors in the case (Eisenhardt, 1989).

To ensure selection of appropriate cases, the objectives of the study are enumerated along with the resultant constraints on the available cases. These constraints are identified and mitigation measures are implemented within the research plan to lessen their impact. The objectives, constraints, and mitigation related to case selection are presented in Table 3.6-2.

Table 3.6-2: Case Selection Objectives, Constraints, and Mitigation

Objective	Constraint	Mitigation
Study impacts of DoD 5000.02 changes on projects at or after Milestone B	Defense programs initiated between 2008 and 2010	• Literature review to establish validity of constructs; • Significant depth of inquiry
Control for Program Complexity	Limited to Major Defense Acquisition Programs	• Multiple hypotheses linked to individual construct relationships
Complete Study within Time & Resources	Maximum of two cases; Excludes very-large-scale and multi-national programs	• Identify future work; • Use survey to check external validity
Access Sufficient Data Detail	Protection of proprietary and competition-sensitive data Issues	• Store sensitive data on organization's computers; • Mask and Aggregate Published Data

3.6.2 Program Documentation Review Process

Program documentation is reviewed to obtain evidence that demonstrates the presence and level of emphasis placed on the identified constructs during planning and execution of the Technology Development phase of the program. Organizational information, such as that contained in program documentation, is useful for developing the context of the case (Cunningham, 1993). The benefits of using program documentation as a source of information for case studies are that they are stable, unobtrusive, and allow for examination of longer time spans which facilitates establishment of the case's history (Yin, 2009).

3.6.2.1 *Documentation Selection*

Program documentation artifacts are chosen for the review based on their applicability to the research constructs within each program and their availability for both cases. The documents selected for review are identified in Table 3.6-3.

Table 3.6-3: Documents Reviewed for Case Studies

Document	Source	Description	Information Sought
Systems Engineering Management Plan (SEMP)	Contractor	Documents contractor's process and planned activities for technical effort of contract.	• Review execution and focus • Open systems approach • Prototype and system development process • Requirements management approach
Statement of Work (SOW)	Government	Defines Scope of work for contract to include reviews, assessments, and test activities.	Programmatic requirements for: • Systems engineering execution • Prototype development • MOSA implementation
System Specifications	Government & Contractor	Specifies performance requirements and design solution	• Technology and manufacturing scope and challenges • Technologies and solutions applied to program • Maturity of requirement baselines
Preliminary Design Review (PDR) Material	Government & Contractor	Snapshot of program and system development progress prior to Milestone B. Addresses cost and schedule, and technical factors.	• MOSA Implementation • Prototype results • Review focus and content • Risk assessments

Additionally, these documents are relatively consistent in format and required content and provide multiple perspectives of the programs. After selection of the documents, they are obtained from each program and stored in a secure on-site research database.

3.6.2.2 *Documentation Analysis Process*

Each document is initially reviewed individually to provide an understanding of the structure and overall themes. Using the document review analysis instrument (see Appendix A), each construct is rated using a scale that is adapted from the Government-developed MOSA Program Assessment and Rating Tool (MOSA PART, 2004). The scale is applied to four questions for each measure as to the extent that it is present on the program. The four-point rating scheme is described in Table 3.6-4.

Table 3.6-4: Document Rating Scale Adapted for Documentation Reviews

Extent Present	Description
1 – None	No evidence that the subject has been adequately addressed
2 – Little	Minimal evidence that subject has been adequately addressed
3 – Moderate	Significant evidence that subject has been adequately addressed
4 – Large	Very high level of evidence that subject has been adequately addressed

In addition to the rating of construct applicability to the program, the document review provides general insight into the execution of the program and allows for the tailoring of interview questions to align with program-specific terms.

3.6.3 Interview Process

Semi-structured interviews with practitioners involved in defense acquisition programs executed under the new guidelines are conducted to identify characteristics of evolutionary acquisition implementation on the selected programs. The interview questions, particularly the terms used to describe the constructs, are shaped by the context provided by the literature review and the examination of program documentation. These questions focus on the relationships among the constructs identified in the research model.

3.6.3.1 *Interview Question Development*

Interview questions are developed to measure the constructs as well as to gather demographic data about the interview subjects. These questions are developed in part based on the review of case documentation to align them with the organizational

situation and properly reflect the context of the organization. The questions included

in the survey instrument are presented in Table 3.6-5.

Table 3.6-5: Interview Questions for Case Study Participants

#	Question	Construct	Objective
1	How would you characterize your role on the TD program?	Demo-graphic	Determine perspective of interview subject. Provides context for responses.
2	How long have you been working in the field of national defense and what roles have you performed?	Demo-graphic	Determine experience base from which conclusions and assessment are drawn.
3	How did the new TD/EMD structure affect the planning and execution of the program?	General	Assess positive or negative impressions of the affect of the process modifications. May identify bias regarding the new paradigm and barriers to effective implementation.
4	How did the scope of the TD program impact the knowledge and risk position of the Government with regard to completing the acquisition of this system on-time and within budget?	General	Assess the opinion of the respondent as to whether the new structure as implemented on the program is beneficial to the Government.
5	How did completion of systems engineering reviews (e.g., PDR) during the TD phase impact the risk position of the program for EMD and later phases?	H_1	Assess the perceived impact of early systems engineering activities on the risk level of completing the program.
6	How did prototype development and testing during the TD phase impact the risk position of the program for EMD and later phases?	H_2	Assess the perceived impact of prototype development and demonstration activities on the maturity of the proposed system solution.
7	How did the execution of Modular Open Systems scope during the TD phase impact the risk position of the program for EMD and later phases?	H_3	Assess the perceived impact of open systems requirements and assessment activities on the system sustainment and upgrade risk level of the program.
8	What additional actions could the Government have taken during the TD phase to improve the risk position of the program for EMD and later phases?	Barriers / Enablers	Identify Government-controlled enablers and barriers to implementation of the new process.
9	What additional actions could the Government have taken during the TD phase to improve the risk position of the program for EMD and later phases?	Barriers / Enablers	Identify contractor-controlled barriers and enablers to implementation of the new process.

The first two items are demographic questions posed to establish background, experience base, and potential biases of the interview subject. The third and forth questions are posed to the subject to assess their opinion regarding barriers and enablers to the success of the new process. Questions 5, 6, and 7 pertain to the impact of each of the independent constructs on the results of the Technology Development program. The purpose of the three independent-construct questions is to evaluate the validity of the dependent constructs and the hypothesized relationships. The final two questions are asked regarding the overall impact of the transition to a two-phase program structure to gather general impressions regarding the acquisition process changes that may affect the responses to other questions. Significant themes across responses to the final two questions are used to develop new survey questions to measure the impact of these barriers and enablers on a larger sample of programs.

The interview contains many "discovery" characteristics which allow the interviewee to describe concepts and experiences through responses to generalized, open-ended questions. Discovery interviews are particularly useful during the beginning stages of studies and are helpful in the development of valid research instruments (Cunningham 1993). They also allow for deeper understanding than highly structured questions and present opportunities to probe the subject using follow-up questions.

While it is more difficult to analyze the responses to open-ended questions than closed-ended inquiries, this approach may decrease the effect of bias due to question phrasing. They also significantly improve the researcher's understanding of the response context (Cunningham, 1993). As it is critical to recognize the respondent's

reference frame when executing empirical research, this reference is important because it allows for the examination of motives and methods that are internal to the organization, not just assigning cause-and-effect relationships based on external factors (Valerdi and Davidz, 2009). In addition, the depth of understanding gained by the researcher through the review of program documentation related to the constructs prior to the interviews is expected to facilitate analysis of the data.

3.6.3.2 *Interview Population Selection Process*

The target subjects of the interviews are practitioners in the field of military system development that have significant experience on one of the programs selected as a case study. Involvement of practitioners in the research process is critical because members of organizations are most capable of defining their problems and potential solutions (Cunningham, 1993). A diverse set of program roles is identified for inclusion in the study including program managers, technical managers, logisticians, and systems, software, and hardware engineers. The roles of intended interview subjects and their anticipated perspectives are identified in Figure 3.6-1.
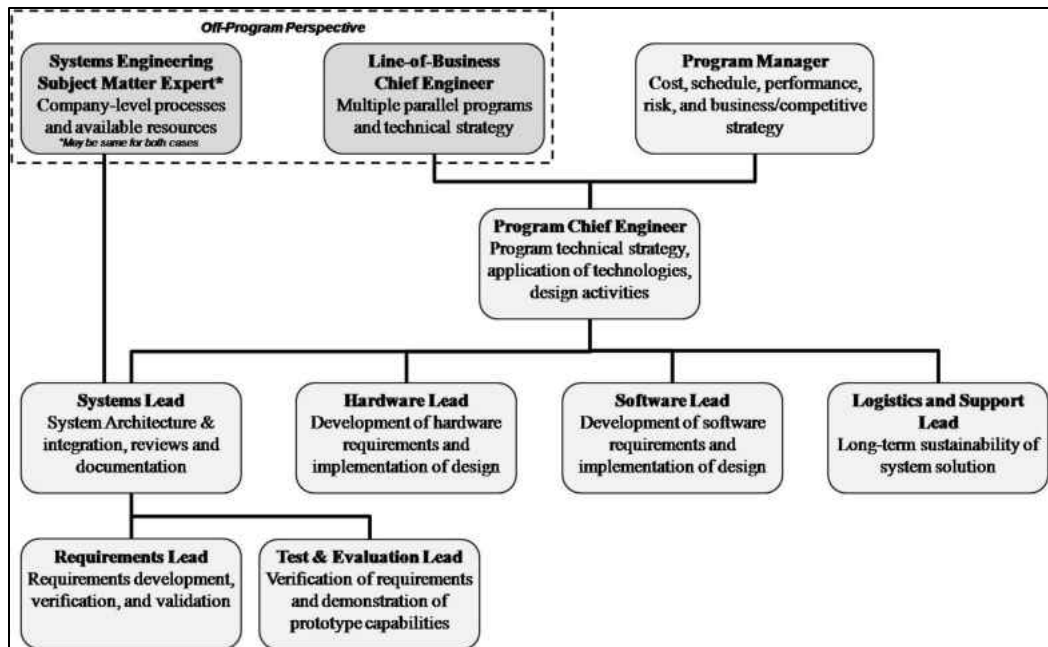
Figure 3.6-1: Interview Subjects and Associated Perspectives

Candidates for inclusion in the interview population are identified during the document review. Sources of information regarding the appropriate interview population include document signatory pages, review presentations, and organization charts.

3.6.3.3 *Pilot Interview Execution*

Pilot interviews are executed primarily to ensure that the meanings of the questions are clear, the inquiries elicit the correct type of information, and the interviews can be executed in an appropriate amount of time. This pilot activity consists of interviewing subjects in positions similar to potential subjects, but who are not required candidates for inclusion in the main study due to their level of involvement in the cases under review. In order to increase the effectiveness of the interview pretest, the pilot interviews are conducted in the same manner and in the same setting as the later data

collection stage. Feedback is solicited from the subject after the event with regard to the interview pace, context, and question phrasing. If necessary, the interview questions and process are modified as a result of issues found during the pilot interviews. If the interview process or questions are not significantly modified after the pilot interview, the data collected is included in the research sample.

3.6.3.4 *Interview Administration Process*

The top-level questions are written out before the interview stage begins. The phrasing of the questions are carefully developed and documented to ensure that the questions are capable of eliciting the proper information from the respondent. The questions are to be posed to the interviewee exactly as written. This consistency decreases bias that may be caused by variations in the question phrasing that introduces measurement variation (Babbie, 1990).

The interviews are conducted one-on-one with individuals. The goal is to conduct all interviews in person to take advantage of the tone and body-language information that can be obtained by observing the subject (Pedhazur and Schmelkin, 1991), though some interviews may be performed by telephone if necessary. The interview administration process is depicted in Figure 3.6-2.
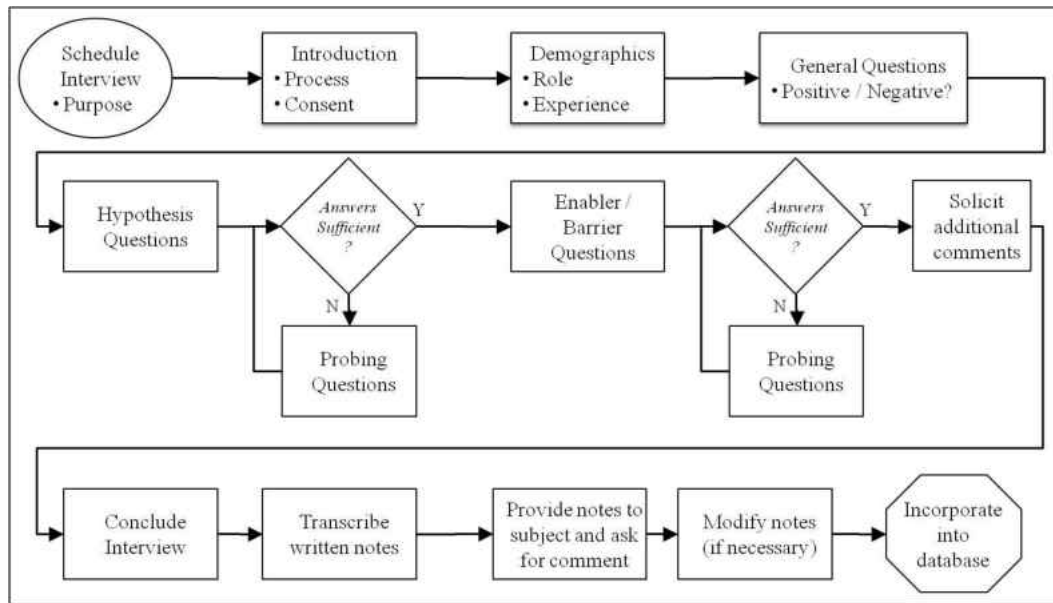
Figure 3.6-2: Interview Administration Process

Each potential subject is contacted by phone or in person and asked to participate in the study. If the subject agrees, the interview is scheduled. The day before the interview, a reminder of the time and location is sent to the subject. Each interview begins with a statement by the interviewer to explain the purpose of the interview to frame the context of the discussion. The interview questions are then posed to the subject and responses are recorded. If answers to any particular question are insufficient, probing questions are asked to clarify the response. As audio recordings are not allowed at the facility where interviews are conducted, notes from interviews are documented on specially prepared interview data collection sheets. A study of Systems Engineering effectiveness conducted at the Corning Corporation that included interviews also used no recording devices in favor of handwritten notes (Corning Systems Engineering Directorate, 2009).

During the interview, care is taken to ensure that the notes record the responses reflect the answers as they are given. Additionally, marginal comments are recorded with regard to the interviewee's tone and body language. After conclusion of each interview, the researcher records initial impressions of the responses. These responses are recorded separately from the subject responses.

Raw data from interviews is converted from the hand-written notes into an electronic format via typing or scanning and stored on computer systems internal to the organization where data is collected to limit the risk that proprietary data is revealed to unauthorized persons. The notes are then provided to the subject for comment and updated if necessary. The output of the interview process is retained in an online data storage site to permit access from multiple locations.

3.6.3.5 *Interview Data Analysis Process*

The data collected through the interview process is analyzed to gain further insight into the cases and the validity of the constructs and hypotheses. The demographic questions are used to obtain background information for the subject and context for the information received from the other questions. This data is also employed to qualitatively identify any relationship between the subject's background and perspective on the processes. The responses to the general questions regarding the changes to the acquisition process are used to identify program-level implications of the changes and are analyzed to determine if there is an impact to the models and hypotheses. The data from the general questions is also used to determine if a bias

exists against the process changes that may color the responses to the remaining question.

For the questions relating to the hypotheses, the individual interview responses are coded for the presence of the relevant dependent construct as well as the polarity of the hypothesized relationship. Constructs and themes among responses that are not related to the identified constructs are analyzed with particular attention paid to similar phrasing among responses. Responses to the two questions relating to potential improvements that could be made by the Government and contractors during execution of programs are examined to determine if any additional barriers and enablers to a successful acquisition exist and should be studied by future research.

After all of the interviews have been conducted for a case, notes among interview events are compared with the intent of identifying the prevalence of the constructs and the hypothesized relationships within the case. If new themes emerge through the interview process, they are added to list of potential constructs for assessment. Once the interview stage of each case study is complete and the final list of themes and trends is identified, the data from each interview is examined for the presence of dissenting or contradictory evidence. Yin (1989) identifies the addressing of rival theories as critical to the validity of research findings, therefore responses to the interview questions are analyzed to identify preliminary conclusions that are used to revise the conceptual model, research model, hypotheses, and survey instrument if necessary. It is critical to identify contradictory trends in data as they may serve to

identify challenges to the resulting hypotheses that may need to be explored during theory testing (Marshall and Rossman, 1989).

Upon completion of the interview data analysis, descriptive statistics are generated with regard to demographics and correlated responses. A percentage of responses that corroborate the dependent constructs and hypotheses are presented along with significant rival explanations present in the data. Themes within the barriers and enablers identified by the subjects are also analyzed and described. Significant quotes are included in the report to increase the understanding of the data. This data is combined with the document review results to support case-level analysis.

3.6.4 Single and Cross-Case Analysis Process

Both single and cross-case analyses are performed to assess the presence and impacts of the constructs on the programs under review. The process for analysis of the case study data is depicted in Figure 3.6-3.
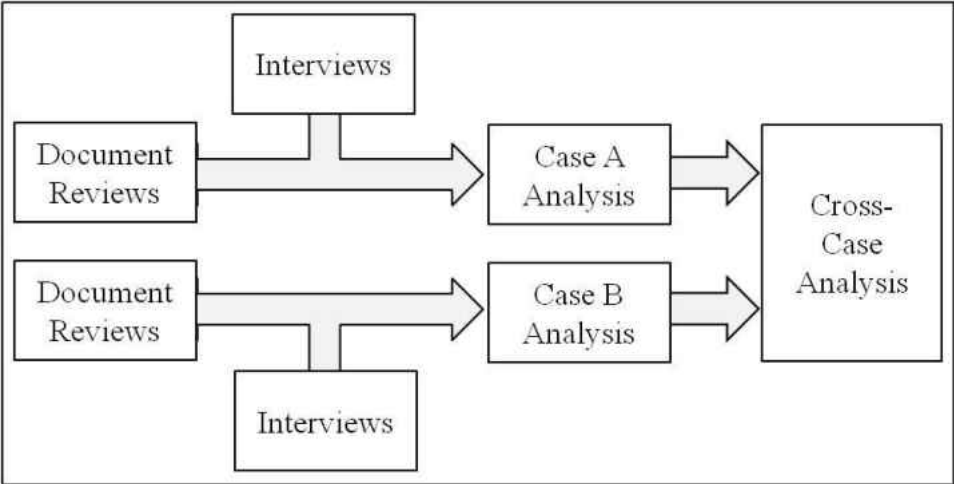
Figure 3.6-3: Single and Cross-Case Analysis Process

At the conclusion of the interview phase for each case, documentation is again reviewed as necessary to corroborate interview responses and investigate responses that seem contradictory with other information. Factual responses to interview questions should be corroborated with information from other sources, such as case documents, whereas opinions need not be supported by other sources (Yin, 2009). The document review results are then compared with the interview responses to determine if they converge. These results provide insight into the internal and construct validity of the research. A description of the characteristics of each case is constructed wherein the general level of agreement between the sources is noted and particular areas of convergence or divergence are analyzed and described.

After both case studies are complete, cross-case analysis is conducted by comparing the profiles. They are examined with regard to their agreement on the validity of the constructs and hypotheses and the identification of new themes. The degree of convergence between the two cases provides strong evidence as to the validity of the constructs and hypotheses. If necessary, the conceptual model, hypotheses, and survey instrument are modified based on this analysis.

3.6.5 Survey Process

After conclusion of the case studies, a survey is administered in order to obtain data from a wider range of programs. The data gathered is used to determine the generalizability of the case study findings and statistically evaluated to test the hypotheses. Self-reporting instruments, such as written surveys, are a common and effective tool for gathering data on organizational and process studies because they

support a large number of samples and can be analyzed quantitatively (Cunningham, 1993). The development of the survey instrument and administration process was executed using the following sequential steps:

1. Review relevant examples of survey studies
2. Select the population to be surveyed
3. Develop the survey instrument
4. Pilot the survey and incorporate findings
5. Administer the survey
6. Analyze the survey responses
7. Test hypotheses

These steps were adopted based on the relevant examples identified during the literature review (Elm, 2008; Kludze, 2003).

3.6.5.1 Review of Relevant Survey Examples

Two example survey studies in the area of Systems Engineering were analyzed to aid in development of the survey for this research. The survey instruments, target populations, and analysis techniques were examined to determine the desirable characteristics of the research methods and processes. Additionally, the results of the surveys and issues identified during the development and execution of them were analyzed to determine lessons learned that could be incorporated into this research.

A cooperative study (Elm, et al, 2008) between the Software Engineering Institute and the National Defense Industry Association sought to identify the association between the systems engineering practices and project performance using multiple choice, forced-Likert-scale, and free-response questions. The study used a questionnaire to

determine the amount of systems engineering content of a program by measuring the creation and use of systems-engineering-related work products. The questionnaire employed quantitative financial and technical measures to assess project performance.

A study by Kludze (2003) included a survey to determine the value of systems engineering on complex projects. The intended survey population was systems engineers and project managers at NASA as well as members of the International Council on Systems Engineering (INCOSE).

3.6.5.2 *Survey Population Selection*

A knowledgeable target population with relevant experience on programs executed under the new acquisition process is identified to provide insight into the constructs and hypotheses from a wider perspective. The survey questions are primarily related to the perception of impacts, therefore a knowledgeable population is vital to the validity of the survey. Programs identified during the case selection process that are not included in the case study phase are incorporated into the survey phase along with the previously studied programs. The roles of the respondents align with those interviewed during the case study and include program managers, technical managers, logisticians, and systems, software, and hardware engineers.

3.6.5.3 *Survey Instrument Development*

The survey instrument is designed to obtain relevant information regarding the respondent's background, program experience, and opinions regarding the dependent

and independent variables as identified in the Research Model. The inputs and objectives used to determine the survey questions are depicted in Figure 3.6-4.
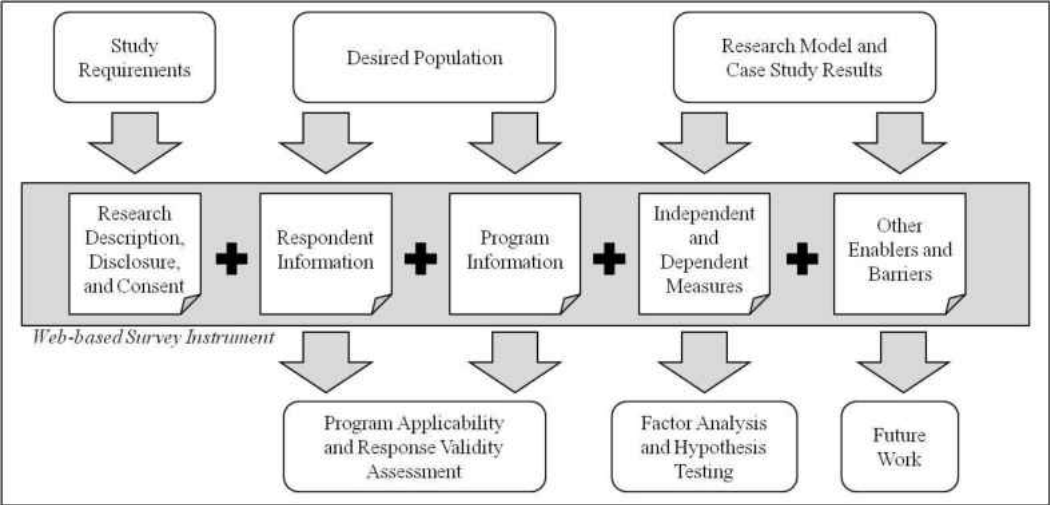
Figure 3.6-4: Drivers and Results of the Survey Development Process

The survey contains a page that includes description of the study, disclosure of relevant information, and documentation of consent as required. Data is collected on the background of the respondents, their overall opinion of the impact of the new acquisition process structure, and the characteristics of the program that is being assessed. The survey contains questions about the relevant program to determine if the respondent is qualified to answer the survey. It also requests data from the respondents regarding their professional experience and details of the program including years experience, place of employment, and role within the program. This data is used to determine if both the respondent and program are within the desired population.

Substantive questions relating to the measures identified in the research model are posed to assess the prevalence of the constructs and their relationships. The survey instrument includes four questions to assess each of the measures related to the

constructs. The substantive survey items are structured as 4-point, Likert-type questions. Likert-type questions are used because the questions relate to the presence and impact of the constructs as perceived by the respondent. The respondent is asked to characterize the extent to which the statement given applies to the program according to the following scale: "None", "Little", "Moderate", and "Large". The description for the scale is contained in Table 3.6-6.

Table 3.6-6: Rating Scale for Survey Items

Extent Present	Description
1 – None	No inclusion of the activity or characteristic on the program
2 – Little	Minimal or nominal inclusion of the activity or characteristic on the program
3 – Moderate	Significant inclusion of the activity or characteristic on the program
4 – Large	Extensive inclusion of the activity or characteristic on the program

The scale is based on Government sources and is similar to the scale used during the document reviews. Additionally, two free-response questions are included to gather suggestions of tactics that may be employed in the future to improve acquisition outcomes. Responses to these questions are used to support the development of suggestions for future research. A paper version of the survey instrument is contained in Appendix D. The data collection model that associates questions with measures and hypotheses is presented in
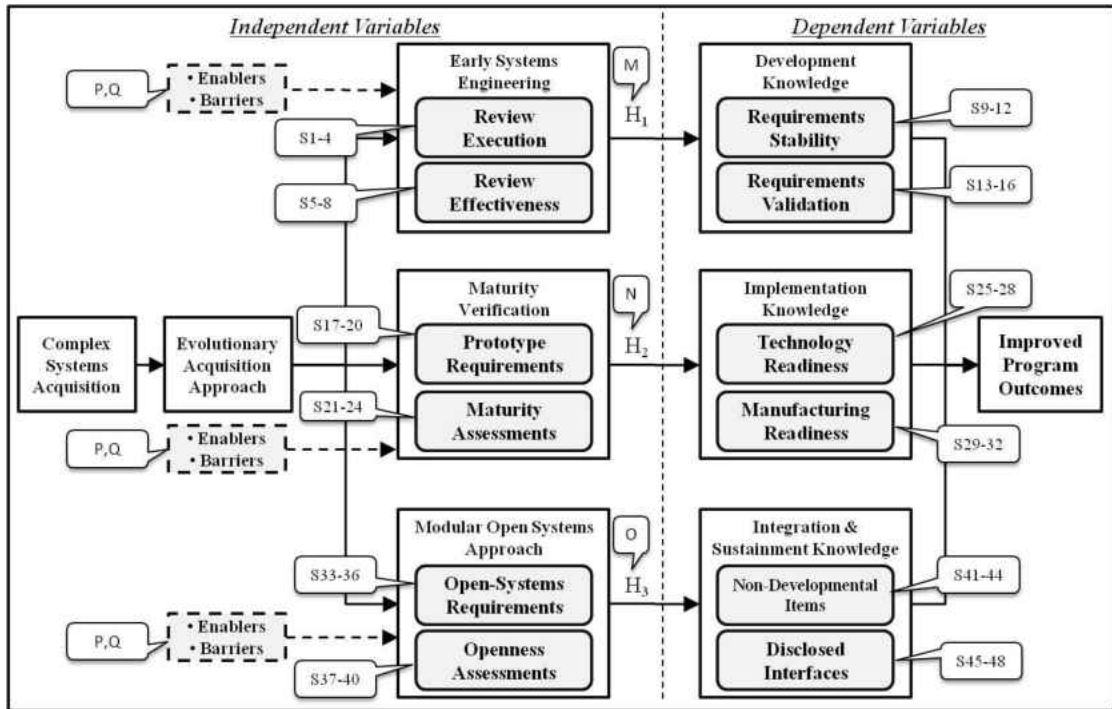
Figure 3.6-5: Survey Data Collection Model

3.6.5.4 _Pilot Survey Execution_

Piloting of questionnaires is particularly important when the research design calls for a single round of data collection. The pilot survey allows for modification of the instrument prior to implementation based on the identification of missing or unclear questions (Babbie, 1990). In order to ensure that the survey can be self-administered by the respondent and completed within the allotted time, the questionnaire instrument is reviewed by knowledgeable personnel who are not required for inclusion in the full study sample. Use of these perspectives allows for effective testing of the data collection techniques without contaminating the relatively small pool of available subjects. Feedback is solicited from the reviews to obtain their opinions regarding question clarity, survey organization, and other characteristics of the instrument. The

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piloting activity identifies problematic questions and verifies the mechanics of the survey process.

3.6.5.5 *Survey Administration Protocol*

This research uses web-based survey data collection methods. As this mode of delivery provides convenience to the respondent, use of the internet to execute the survey is expected to provide an increased response rate over paper surveys. Additionally, the time it takes to complete the survey can have an impact on the response rate. The researchers in the Elm (2008) study expressed that if the response took more than an hour, response rate would decline; therefore the target amount of time for the completion of this survey is less than one hour.

A survey response request is sent to each potential respondent and is accompanied by a cover letter that assures the respondent that the data collected would be used only for the survey and would not be attributed to individuals. In order to increase the response rate, the administration process employs methods to electronically contact non-responsive participants periodically to encourage completion of the survey.

3.6.5.6 *Survey Data Analysis*

A multi-stage process is required to process, analyze, and manage the survey data. This process includes response verification, question reliability evaluation, descriptive statistics generation, confirmatory factor analysis (CFA), and hypothesis testing. The overall survey data analysis process is depicted in Figure 3.6-6.
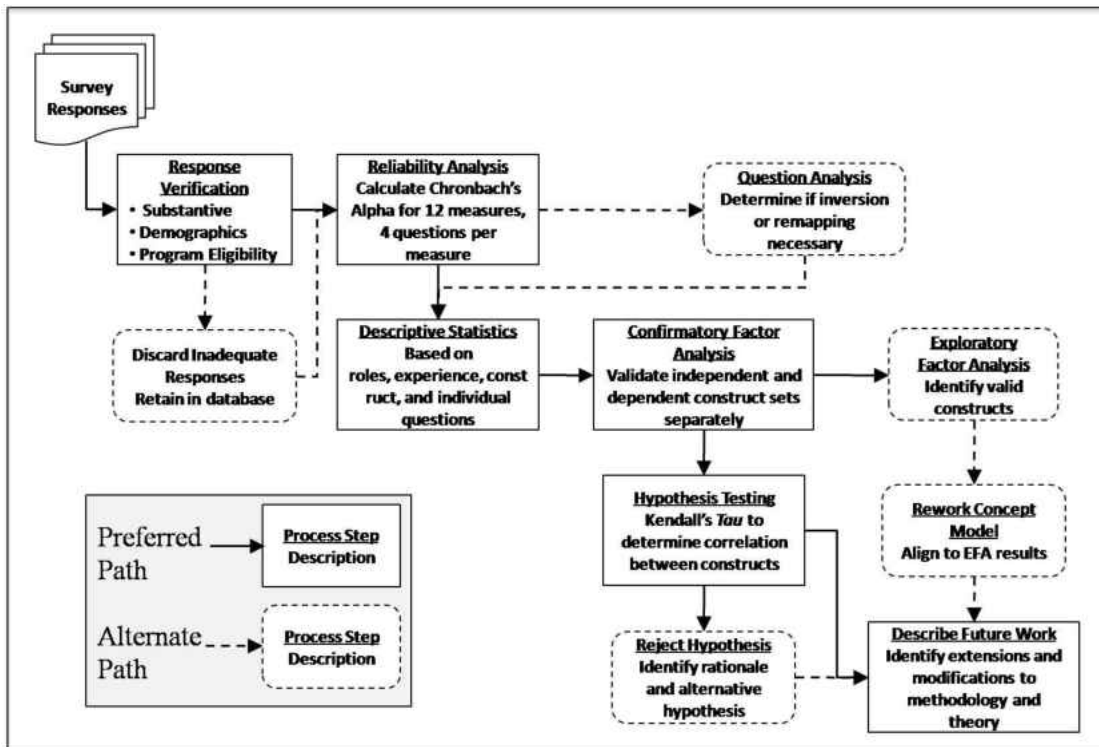
Figure 3.6-6: Survey Data Analysis Process

After collection of the data, it is transferred to a spreadsheet to facilitate analysis with
the R statistical software package (R Core Development Team, 2011). The survey
responses that do not contain sufficient information or are completed by respondents
that are not part of the targeted population are removed from the data set. A response
is considered invalid and discarded if it meets one of the following criteria:

- Missing critical demographic or program information
- More than one non-response for questions related to an operational measure
- Characteristics of program do not qualify it for inclusion in the study

The discarded responses are stored in the research database to provide assurance that
the sample is not shaped to influence the results.

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To quantitatively assess the reliability of the instrument, a statistical test of reliability, Cronbach's Alpha, is applied to the data obtained from the questionnaire. For this type of research, which relies primarily on the opinion and perception of the subjects, the results of questions grouped by associated measure and Cronbach's Alpha is calculated for each variable. If reliability scores are low for a particular question, then it is considered for removal as an appropriate measure of the construct. At that time, it is decided if the question is invalid, or if it is closely related to another construct.

Descriptive statistics are generated from the valid response set to include demographic profiles, program descriptions, and response distributions for each question. As part of the descriptive statistic development, the responses to the questions related to the dependent constructs are analyzed to determine if programs are implementing the new processes as specified in accordance with the regulations and applicable guidelines.

In order to verify the validity of the constructs in the theoretical conceptual model, CFA is performed on the survey data. CFA examines the construct validity of the research by estimating the correlation of measures related to the factors with the correlations observed in the sample population. By using maximum likelihood techniques, estimation is performed for the population as a whole and not solely for the sample (Thompson, 2004). If the response sample is large enough to account for the all twenty four questions (N ~ 60), then CFA is performed on the collective set of independent variables to ensure that the data collected supports them and the same process is executed for the dependent variables. If the sample size is too small to provide sufficient degrees of freedom to estimate the variability due to each question

and associated errors, then confirmatory factor analysis is performed on each construct individually.

As part of the confirmatory factor analysis, multiple fit statistics are used to evaluate the fit of the model to the collected data. If the analysis does not confirm the presence of the constructs and the sample size is sufficient, then exploratory factor analysis is performed to identify the constructs that are present in the data. If necessary, these constructs are included in an updated conceptual model and hypotheses to be presented in Chapter V. If the analysis is successful, then the survey data is used to support hypothesis testing.

A critical output of the confirmatory factor analysis process is the set of factor scores that are used during hypothesis testing. These scores are derived for each construct from the responses provided to the survey data. To prepare the survey data for testing, the responses to the substantive questions that are mapped to each construct are reduced to yield a factor loading. The Structural Equation Model package for R is used to perform confirmatory factor analysis and determine the loading for each factor. This loading matrix is multiplied by the response set to yield the data used in hypothesis testing.

3.6.5.7 *Hypothesis Testing*

The three hypotheses are tested using statistical analysis of the responses to the substantive survey questions (i.e. the questions related to the constructs). As the data collected using Likert-type questions is non-parametric and ordinal in nature,

Kendall's *tau* test (Kendall, 1938) is used to assess the hypotheses with regard to the research data. The *tau* test calculates the rank correlation between two sets of data. *Tau* is calculated using Equation 3.6-1.

Equation 3.6-1: Kendall's *tau*

$$\tau = \frac{(\text{number of concordant pairs}) - (\text{number of discordant pairs})}{\frac{1}{2}n(n-1)}.$$

Tau is expressed as a number between -1 and 1. A negative value indicates negative correlation and a positive value indicates a positive correlation between the two variables. The absolute value of tau indicates the strength of the association between the two factors. The levels of association for each tau value range as designated for this study are presented in Table 3.6-7.

Table 3.6-7: Thresholds for Correlation Evaluation

tau Value Range	Strength of Association
tau > 0.35	Very Strong
0.35 > tau ≥ 0.3	Strong
0.3 > tau ≥ 0.25	Moderate
0.25 > tau ≥ 0.2	Weak
tau < 0.2	Insignificant

3.7 Conclusion and Recommendation Development

For research to have value to anyone other than the researcher, the results must be communicated to others in a way that properly conveys the implications of the findings. The documented conclusions contain a summary of the hypothesis testing as

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well as recommendations for effective implementation of the revised acquisition process on future programs. Suggestions for expansion of research to increase generalizability are provided along with an updated research model and hypotheses to support future research. Additionally, anecdotal evidence from the interview data and review of program documentation is presented to suggest future research topics and identify lessons learned from the execution of the programs.

The conclusion and recommendation section includes a determination as to whether the individual hypotheses are supported by the survey data collected. In the case that a hypothesis is not supported, a rationale is presented for the discrepancy between the relationship suggested by the literature and the survey data. If necessary, the conceptual model and hypotheses are updated and presented with explanation. Finally, suggestions for future work based on barriers and enablers discovered as well as potential extensions of the research design to new populations are documented in the conclusion and recommendation section in Chapter V. The conclusions and recommendations are based primarily on the data analysis results, which are presented in Chapter IV.

CHAPTER IV: RESULTS AND ANALYSIS

4.1 <u>Introduction</u>

This chapter presents the case study and survey findings. Results of survey data verification, reliability, and confirmatory factor analysis are also included to demonstrate the validity of the research design and the data obtained. Finally, the results of nonparametric rank-correlation hypotheses testing are provided to determine whether the collected data supported the theories under development.

4.2 <u>Program Selection</u>

A candidate pool of programs was designated with the goal of selecting viable cases for in-depth analysis of the research constructs and their relationships. Programs were initially identified and assessed for the applicability and availability of data. The results of the case evaluation process are presented in Table 4.2-1.

Table 4.2-1: Assessment of Candidate Programs

Program Designation	TD Start Date	Life-cycle Phase	Interview Availability	Study Inclusion
Program A	2009	Milestone B	High	Case A and Survey
Program B	2008	Milestone B	High	Case B and Survey
Program C	2008	Milestone B	Medium	Survey
Program D	2010	Milestone B	Low	Survey
Program E	2010	TD Execution	Low	Survey
Program F	2010	TD Execution	Low	Declined to Participate

The programs are identified using codenames to protect the anonymity of the participants and to avoid the exposure of potentially sensitive information. The identified life-cycle phase for each case indicates the status of the program at the start of case selection. All programs were invited to participate in the survey stage of the study and only one declined. Programs A and B were chosen as the subjects of in-depth case studies primarily because they were at the proper phase for inclusion in the study and provided a high level of availability to the researcher. Additionally, Programs A and B were intended to produce disparate products for different branches of the armed services, therefore they differ enough to provide acceptable validity for any identified convergence.

4.3 <u>Study Pilot Activity Results</u>

A pilot interview was conducted with a member of the engineering staff assigned to Case A. This individual was a systems engineer responsible for the development of interface specifications for the product. As the individual was not a lead member of the team, piloting of the interview did not contaminate or reduce the pool of potential interview subjects. The pilot interview identified minor improvements to the phrasing of interview questions that improved the subject's understanding of the question context. No questions were deleted nor were the intent of any of the questions modified. The original questions, updated questions, and reasons for change are described in Table 4.3-1.

Table 4.3-1: Modifications to Interview Questions

Question #	Original Question	Updated Question	Reason
2	How long have you been working in the field of national defense?	How long have you been working in the field of national defense and what roles have you performed?	Allows for better understanding of subject background.
5	How did completion of systems engineering reviews (e.g., PDR) prior to full development commitment impact program risk?	How did completion of systems engineering reviews (e.g., PDR) during the TD phase impact the risk position of the program for EMD and later phases?	Provides more specific context for question. Pilot interview response to original question was in terms of TD risk and performance.
6	How did prototype development and testing impact the risk position of the program?	How did prototype development and testing during the TD phase impact the risk position of the program for EMD and later phases?	Clarifies the intent of the question to ensure that impact provided is with regard to the EMD phase, not the TD phase.
7	How did the Modular Open Systems scope impact the risk position of the program risk?	How did the execution of Modular Open Systems scope during the TD phase impact the risk position of the program for EMD and later phases?	Clarifies the intent of the question to ensure that impact provided is with regard to the EMD phase, not the TD phase.
8	How could the Government have improved the risk position of the program?	What additional actions could the Government have taken during the TD phase to improve the risk position of the program for EMD and later phases?	Clarifies the intent of the question to ensure that impact provided is with regard to the EMD phase, not the TD phase.
9	How could the Government have improved the risk position of the program?	What additional actions could the Government have taken during the TD phase to improve the risk position of the program for EMD and later phases?	Clarifies the intent of the question to ensure that impact provided is with regard to the EMD phase, not the TD phase.

These changes are intended to improve the subject's understanding of the data sought by the question. In all but one case, the clarification attempts to ensure that the information provided relates to action that occurred during the Technology Development phase and the effect on the Engineering & Manufacturing Development phase and subsequent program stages. After the pilot interview was completed, the data was processed in accordance with the procedure described in Chapter III. No

modifications to the data processing procedures were made as a result of the pilot interview. Due to the changes made to the interview questions, data from the pilot interview was not included in the research sample for Case A.

The survey instrument was provided to multiple individuals in the academic and industry community prior to the beginning of the survey period to determine the quality of the instrument and support evaluation of the data analysis procedures. All of these individuals are knowledgeable about systems engineering and the defense acquisition process and none were used in the survey population. The piloting process activity identified no major changes to the instrument or survey analysis procedure, but did identify minor changes to the survey instructions and background explanations. Piloting the instrument also provided useful information regarding the time required to complete the survey.

4.4 <u>Case Study Results</u>

Case studies were performed on two programs executed under the new process. The studies were executed individually and followed by cross-case analysis to determine the level of convergence between the programs regarding validity of the constructs, hypotheses, and previously unidentified enablers and barriers.

4.4.1 Case Study A

The Technology Development phase of Program A was established in 2009 with the objectives of developing a system design resulting in a Preliminary Design Review and testing of a prototype system containing all critical technology elements in a

relevant environment. Two vendors were selected to participate in this phase and complete the tasks in parallel. At the end of the Technology Development phase, a single contractor was selected to complete the system design and qualification under an Engineering & Manufacturing Development contract. This case study examined one of the vendors involved in the Technology Development phase for Program A.

4.4.1.1 *Case A Document Review Results*

The program was rated for each subfactor based on evidence contained in the documentation that addressed the questions posed in the Documentation Analysis Sheet. The program was assessed with 48 questions to identify the degree to which the operational measures were present on the program according to the scale presented in Table 4.4-1. Details about the development of the scale are provided in section 3.6.2.2.

Table 4.4-1: Document Rating Scale Adapted for Documentation Reviews.

Extent Present	Description
1 – None	No evidence that the subject has been adequately addressed
2 – Little	Minimal evidence that subject has been adequately addressed
3 – Moderate	Significant evidence that subject has been adequately addressed
4 – Large	Very high level of evidence that subject has been adequately addressed

The rating for each operationalized measure was calculated by averaging the ratings for each of the questions associated with that measure. The results for individual questions are contained in Appendix A. The ratings at the level of operationalized measures are provided in Table 4.4-2.

Table 4.4-2: Case A Document Review Results

Construct	Operationalized Measure	Rating (1-4)	Analysis
Early Systems Engineering	Review Execution	2.750	Appropriate reviews held with focus on requirements. Certification of system for advancement not sufficiently tied to overall budget, schedule, or risks.
	Review Effectiveness	2.250	Reviews well-attended, but did not identify new risks, address open requirements, or establish cost and schedule baselines prior to Milestone B.
Development Knowledge	Requirements Stability	1.750	Major changes to functional and performance requirements between phases threaten to invalidate architecture and technology assessment. Requirements likely to change after in EMD to address open issues.
	Requirements Validation	2.250	Requirement set not complete or consistent due to open requirement issues. Budget and schedule impacts not assessed. Architecture validated via modeling and prototype, but may not support new requirements.
Maturity Verification	Prototype Requirements	2.000	Prototype requirements focus on functionality and performance. No size, weight, power, or manufacturing requirements and these aspects are not addressed by prototype demonstration scenarios.
	Maturity Assessment	3.250	Prototype testing assessed critical technologies, but equally focused on previously proven applications. Prototype requirements formally verified by contractor with Government involvement. Multiple technology and manufacturing maturity assessments conducted.
Implementation Knowledge	Technology Readiness	3.250	Technology demonstrated during prototype testing and high-fidelity modeling and simulation. Critical technology previously used for related purpose. High level of design reuse and COTS components.
	Manufacturing Readiness	4.000	Sourcing for all system components identified. Prototype manufactured on pilot production lines with significant design reuse and incorporation of commercial components.
Modular Open Systems Approach	Open-Systems Requirements	3.250	Program requires use of a modular open systems approach, discourages use of proprietary interfaces, and leveraging of commercial hardware and software, however many MOSA-related requirements are ambiguous and unverifiable.
	Openness Assessments	3.750	Extensive use of Government standard tools for formal evaluation of MOSA progress as well as meeting, plans, and analysis documents related to openness of system.
Integration and Sustainment Knowledge	Non-Developmental Items	3.500	Commercial processing resources and software used where feasible, including open-source software elements. Application-specific components re-used from other programs and proven systems.
	Disclosed Interfaces	3.750	Extensive use of widely used commercial and open standard interfaces coupled with partitioning of potentially volatile components from the rest of the system.

While reviews were held on Program A as required, they did not sufficiently identify new risks or close existing ones. Additionally, requirements issues were left open within the established technical baselines. This negatively affected the quality of the baselines which suggests that the appropriate level of Development Knowledge was not obtained by the program. This condition is exacerbated by the fact that the Government implemented significant system requirements changes after the conclusion of the Preliminary Design Review. The lack of requirement issue closure introduced substantial risk with regard to technical, cost, and schedule factors because the changes were not incorporated into the technical baselines and the effects are on the design, cost and producibility of the system were unknown.

The prototype requirements levied by the Government focused on performance factors necessary to demonstrate the maturity of the technologies used and the ability of the system architecture to support the desired capabilities without regard to the form factor or producibility. Using the prototypes and previously developed systems as a basis, multiple technology and manufacturing readiness assessments were performed jointly by the contractor and the Government. These evaluations led to the conclusion on the program that the system as proposed had the requisite maturity of both technology application and manufacturing processes.

Case A contained a significant amount of MOSA-related scope including technical requirements, and statement of work tasks such as generation of planning documents, execution of assessments using Government-developed tools, and performance of market surveys to identify potential subcomponent vendors. The resulting system

incorporated a high percentage of non-developmental hardware and software components including open-source operating environments for software applications and commercial processing resources. The design also leveraged commercial or open standards in every interface that was not required to integrate with legacy external systems. The application of this design philosophy provided for multiple sources of supply for system components and facilitates upgrade and sustainment throughout the system lifecycle.

4.4.1.2 *Case A Interview Results*

The interviews for Case A were conducted after completion of the document reviews. The documents for Case A did not indicate that the nature or wording of the questions in the interview should be changed due to ambiguity or uncommon usage. A total of 10 interviews were conducted for Case A with a population consisting of two program managers, two technical managers, three systems engineers, one software engineer, one hardware engineer, and one logistics/reliability engineer. The population covered all of the desired areas of expertise and the respondent pool had an average of approximately 27 years of experience in defense and aerospace, which is more than sufficient to consider them to be authoritative with regard to system development programs.

The overall opinions of the program participants with regard to the revised acquisition process was mixed but skewed towards the negative. While it was acknowledged that the process had the potential to provide the Government with increased insight into the system under development, significant issues with regard to communication between

the Government and the contractor, simultaneous development of a design and a prototype, an unfunded gap between the Technology Development and Engineering & Manufacturing Development phase, and lack of information regarding Technology Development scope and objectives were noted by the interview subjects.

There was heavy focus in every interview on the prototype development, even in answers to questions that did not reference the prototype. This indicates that the program itself was heavily focused on the prototype during planning and execution of the Technology Development phase. Competitive effects were also prevalent throughout the interviews for Case A and appeared to have a significant impact on the behavior and strategy of both the contractor and the Government teams.

Elements of the dependent constructs were largely cited in response to questions regarding the effects of the independent constructs. This supports the validity of the dependent constructs and relationships between the constructs for this case. Overall, the data collected displays a high degree of convergence both within the interview data set and with the document reviews regarding both the general impressions of the program structure and content, the identified research constructs, and barriers to program success.

4.4.1.2.1 Early Systems Engineering and Development Knowledge

A slight majority (six out of ten) of the subjects interviewed stated that the execution of System Engineering Reviews prior to Milestone B and the Engineering & Manufacturing Development phase source selection reduced the overall risk level for

the program. The reviews were seen as a good method for providing insight to the Government; however, they were ineffective at establishing stable baselines. This finding regarding the execution and effectiveness of System Engineering Reviews for Case A aligns with the documentation analysis assessment regarding Early Systems Engineering and Development Knowledge.

The instability of requirements is largely seen as an effect of the lack of communication on the part of the Government and the inability to make requirements changes during the Technology Development phase due to competitive factors. One systems engineer stated that "we could not negotiate adjustments in requirements, so the requirements needed adjustments after PDR." The adjustments to which this individual referred were significant changes to the technical requirements made by the Government between the end of the Technology Development phase and Milestone B outside of the baselining and review process. These requirement changes added functionality and increased the complexity of the system. This potentially invalidated the baselines established during the Technology Development phase and drove a requirement in the Engineering & Manufacturing Development phase to repeat a major review in order to reestablish the feasibility and effectiveness of the proposed solution when including the modified requirements.

The need to continue system-level requirements development after Milestone B indicates an ineffectiveness of the required System Engineering Reviews to establish the necessary levels of Development Knowledge. In this case, the lack of requirement completeness at the Preliminary Design Review was caused by a failure to identify all

stakeholder requirements prior to or during the Technology Development phase. Discovery of these new requirements during the Technology Development phase drove changes to the system-level specification after the Preliminary Design Review because the Government was reluctant to make changes to the system-level specification during the Technology Development phase for reasons related to the procurement schedule and competition for the Engineering & Manufacturing Development phase.

4.4.1.2.2 Maturity Verification and Implementation Knowledge

The development and test of prototypes during the Technology Development phase was predominately cited in interviews for this case as an effective activity for the improvement of System Implementation Knowledge and reduction of risk early in the program. The referenced benefits of the company's prototyping strategy included both the knowledge gained with regard to the integration of the system components and, to a lesser extent, the maturity of the manufacturing environment and processes. However, the evaluation of critical technology elements, which is the driving requirement for execution of prototype scope in the Technology Development phase, was not mentioned in any of the interviews for Case A.

It should be noted that the contractor developed a prototype that far exceeded the Government requirements and was highly representative of the intended production system configuration. The implementation and test of a high-fidelity prototype was an effort to reduce production and performance risk for the Engineering & Manufacturing Development phase and was intended to improve the company's competitive position.

The level of fidelity was not driven by the requirements of the prototype specification as evidenced by repeated references to the comparatively low level of maturity with regard to form factor and functionality displayed by the competing contractor's prototype offering. This finding aligns with the document review finding that the system design had a high level of maturity despite the moderate level of prototype requirements levied by the Government.

4.4.1.2.3 Modular Open Systems Approach and Integration & Sustainment Knowledge

Elements related to the construct of Integration and Sustainment Knowledge were identified through the interview process to be valid for this case. The assessments of system and program openness as part of the independent construct of a Modular Open Systems Approach, though required by the statement of work and presented at system engineering reviews, were not mentioned by any of the interview subjects. The documentation review resulted in a high level of both MOSA application and Integration & Sustainment Knowledge for Case A, which is supported by multiple interview responses.

The inclusion of MOSA-related system requirements was cited by multiple interview subjects as having a positive effect on the life-cycle cost and sustainment risk of the system by increasing the sources of supply for system components and allowing for increased competition, thus reducing the cost and effort required to upgrade or replace system components throughout the lifecycle. Despite the ambiguity of the requirements, the contractor embraced MOSA and worked to understand the concepts and incorporate them into the system design.

As with other requirements on the program, there was a lack of effective communication regarding Government expectations for the open-systems requirements. The primary issue identified by the interview subjects with regard to MOSA was the ambiguity of the requirements language and the lack of associated objective verification criteria. The resulting opinions were of increased risk with regard to development of the system due to the potential for issues to arise during verification because the requirements were not well defined. Despite the performance of openness assessments, significant questions remained as to, in the words of a systems engineer, "How modular? How open was the architecture?"

4.4.1.2.4 Barriers to Success of Program A

Multiple factors not included in the Conceptual Model were identified during the interviews for Case A as having significant impacts on the execution of the program and the resulting risk position at the end of the Technology Development phase. The most-cited barrier to success of the Technology Development phase for Case A was a lack of communication with the Government. The predominant complaint was that the Government did not communicate openly with the contractor, however it was also suggested that the contractor might not have been as open as it could have been regarding potential issues due to the pending competition for the next program phase. The reason most often provided for the Government's unwillingness to provide information was the pending competition and the fear of the losing contractor protesting the award of the Engineering & Manufacturing Development contract. This caused the Government to withhold information from the contractor regarding critical

program questions as fundamental as identification of the Government's evaluation criteria for successful prototype testing. In the words of a member of the program management team: "We came into TD with an idea of how we would be evaluated and the Government would neither confirm nor deny whether we were correct."

Perhaps the most critical impact of this lack of communication was the inability to modify system requirements during the Technology Development phase. Multiple interview subjects noted that there were errors in the Government's top-level specification and that many requirements were ambiguous and unverifiable. Even though the Government team acknowledged these deficiencies, very few changes to the system-level performance specifications were approved during the Technology Development phase. Instead, the requirements set was addressed by both contractors during the systems engineering process and modified at the end of the Technology Development phase by the Government. The Government's unwillingness to negotiate requirements changes during the Technology Development phase caused significant issues with regard to the contractor's ability to trade system requirements in order to reduce risk. The inflexibility of the contractual requirements set paired with the lack of feedback from the Government in response to contractor interpretations of requirements limited the capability for the program to develop a best-value solution. The significant modifications to system requirements made unilaterally by the Government after the Preliminary Design Review added risk to the program by reducing the validity of development knowledge gained during the Technology Development phase.

Competitive factors hindered the ability of the program to resolve issues during the Technology Development phase; however competition was also cited by multiple subjects as having a beneficial impact to the Government. In this case, the contractor focused more intently on the cost and schedule performance of the Technology Development phase than is normal for a cost-type contract. The contractor is also incentivized to invest in the program prior to contract award, particularly with regard to prototype hardware, and focus on the direct comparisons that the Government can perform based cost and schedule performance during the Technology Development phase and on the performance of the prototypes. The potential downside is that because the Technology Development phase is seen as an audition to demonstrate business performance for the Engineering & Manufacturing Development phase. In one interview it was stated that the contractor didn't perform additional risk reduction activities because adding more resources during the Technology Development phase might be detrimental during the competition for the next phase.

The prototype developed by the contractor was highly production-representative and sought to incorporate many of the features of the final system configuration that were not required per the Government's prototype requirements specification. The development of the prototype in this manner limited the amount of resources available to be spent on the production system design. The development and testing of the prototype concurrently with the development of the production system design put stress on the contractor's team. The Government's evaluation of the prototype was

believed by the contractor to be a significant factor in the Engineering &
Manufacturing Development source selection process.

The resulting emphasis placed on the prototype impeded the development of the
production system design and many decisions were deferred until they could be
resolved in a non-competitive environment during the Engineering & Manufacturing
Development phase. A contributing factor to the level of effort necessary to develop
the prototype that was cited in the interviews is the misalignment between company
procedures and the Government's revised acquisition process which increased the
time spent on the prototype.

Staffing of the Government team was seen as a barrier to success by some of the
interview population. The Government team did not have the manpower to manage
multiple contractors and was unable to appropriately provide experts in relevant areas
to both teams. Additionally, the teams were charged with evaluating the contractors'
proposals for the Engineering & Manufacturing Development phase, further
increasing the workload of the Government team.

The existence of a gap between the end of the phases was not sufficiently addressed
by the program prior to its occurrence and jeopardized the progress made by the
program team. Though not prevalent in the interviews with the technical personnel,
the issue of the gap between the phases was cited as a serious issue by a member of
the program management team. The gap added risk to the program by disrupting
continuity between the phases and required additional Government and contractor

funding to maintain the contractor team between phases. This funding was necessary to ensure that the contractor team would be available at the beginning of the next contract in order to reduce the schedule risk for the remainder of the program.

4.4.1.3 *Summary of Case Study A*

A summary of the case study results for Program A is presented in Table 4.4-3.

Table 4.4-3: Case Study A Results Summary

Case Study Topic	Case A Results
Overall Impact of TD Phase	Slightly negative overall
Early Systems Engineering	• Improved system knowledge • Requirements unstable after PDR
Maturity Verification	• Increased design maturity • Prototype driven by competition
Modular Open Systems Approach (MOSA)	• High level of MOSA emphasis; • Significant openness in design
Barriers to Program Success	• Lack of communication • Competitive environment • Inflexible requirements • Requirements changes after PDR • Excessive focus on prototype • Gap between program phases • Misaligned Government and Contractor processes

The end result of Program A's Technology Development phase was a significant increase in Implementation and Integration & Sustainment Knowledge over the levels present at contract award. Levels of risk for the program outcome are elevated by misalignment between the Government and contractor teams. The misalignment stemmed primarily from the inhibition of communication due to the competitive environment. The lack of information flow caused confusion about the role and importance of the prototype and prevented the teams from establishing complete and

stable technical baselines. These results were compared with the results from Case Study B to determine if convergence between the programs was present.

4.4.2 Case Study B

The Technology Development phase of Case B was established with the objective of developing a system design, holding a Preliminary Design Review, and demonstrating a prototype containing all critical technology elements in a relevant environment. Two vendors were selected to participate in and execute the Technology Development phase in parallel. In addition to the Government-funded prototype activity, both contractors committed significant internal resources to demonstrate the maturity of their solutions. The program included a nominal amount of MOSA scope. At the end of the Technology Development phase, a single contractor was to be selected to complete the system design and qualification under an Engineering & Manufacturing Development contract. This case study examined one of the two vendors that participated in the Technology Development phase for Program B.

4.4.2.1 Case B Document Review Results

The program was rated for each subfactor based on evidence contained in the documentation that addressed the questions posed in the Documentation Analysis Sheet. The results for individual questions are contained in Appendix B. The rating for each operationalized measure was calculated by averaging the ratings for each of the questions associated with that measure. The average ratings at the operationalized measure level are provided in Table 4.4-4.

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Table 4.4-4: Case B Document Review Results

Construct	Operationalized Measure	Rating (1-4)	Analysis
Early Systems Engineering	Review Execution	2.750	Reviews held at system and subsystem levels and focused on requirements. Program budget and schedule not adequately addressed
	Review Effectiveness	3.500	Extensive involvement of stakeholders and SME's. Risks not identified during reviews. Requirements issues and resolution paths addressed.
Development Knowledge	Requirements Stability	3.250	No unresolved Government requirements at the end of the TD. A few contractor requirements were TBD, but closure plans in place. Design-driving requirements and functionality reduced between PDR and Milestone B.
	Requirements Validation	3.000	Program lacks necessary budget/schedule information to ensure that system compatible with constraints. Requirements set complete and verification in place. Architecture validated via modeling, simulation, and a highly representative prototype.
Maturity Verification	Prototype Requirements	1.750	Direct prototype requirements not identified, however size, weight, power, and performance driven by demonstration requirements. No manufacturing requirements identified by the Government.
	Maturity Assessment	3.250	Critical technology central to system core functionality. Verification tests and demonstrations ensure prototype meets requirements. Technology and manufacturing assessments conducted.
Implementation Knowledge	Technology Readiness	3.500	Technologies integrated into prototype that is highly representative of final system configuration and successfully demonstrated in relevant environments and operational scenarios.
	Manufacturing Readiness	4.000	Sources for all components identified. Prototype manufactured on representative production lines. Extensive component reuse from previous programs.
Modular Open Systems Approach	Open-Systems Requirements	3.000	MOSA and use of open standards for growth interfaces required, but requirements are vague and no details or products for requirement verification are present.
	Openness Assessments	1.000	No formal evaluation tools, business case analyses, or market surveys of open systems to provide understanding of potential issues, commercial sources, growth capabilities, or obsolescence risks.
Integration and Sustainment Knowledge	Non-Developmental Items	3.250	System solution uses commercial processing resources and software operating environments. Significant reuse of hardware and software components from other programs.
	Disclosed Interfaces	1.750	Openness of external communication and form factors are limited by legacy interfaces. Internal interfaces use few standards and have little growth capacity.

System engineering reviews were held at multiple levels with extensive involvement of stakeholders and domain experts. The reviews sufficiently focused on requirements issues and adequately linked design features to driving requirements. The result was a complete, consistent requirements set. There was a significant requirement change between the Preliminary Design Review and Milestone B which reduced the operational capability of the system. This change did not invalidate the knowledge position of the program with regard to development, but may have changed the risk/reward ratio of the selected technology and architecture.

While direct technical specifications for the prototype were not provided by the Government as part of the Program B requirements, operationally relevant scenarios under which the prototype would be tested were identified in the Technology Development statement of work. These scenarios identified the environments and capabilities which were to be demonstrated in the Technology Development phase. These scenarios drove many of the characteristics of the delivered prototype, but requirements as to the production environment for the prototypes were not imposed. Demonstration of the critical technologies proposed for use in the system was the focus of the prototype tests, which had the desired effect of establishing Technology Readiness Levels of 6 or higher for the critical technology elements. Additionally, integration procedures and suppliers for the system were exercised and evaluated during prototype development leading to sufficiently high Manufacturing Readiness Levels to support the finalization of the production environment and procedures during the Engineering & Manufacturing Development phase.

The Government specification and statement of work contained requirements for the use of MOSA on the program, but it did not specify assessments to be completed or verification criteria for MOSA-related requirements. Despite the lack of focus on how MOSA requirements would be verified, and because of the history associated with the design, the system incorporated a significant number of non-developmental hardware and software items. The growth capability of external system interfaces was limited by requirements to integrate with legacy components and platforms. Internal interfaces were largely based on commercial or open standards, but the protocols selected did not provide significant bandwidth growth capacity for future capability extension.

4.4.2.2 *Case B Interview Results*

The interviews for Case B were conducted after completion of the document review. The documents did not indicate that the nature or wording of the questions in the interview should be changed due to ambiguity or uncommon usage. A total of 10 interviews with individuals assigned to Program B were conducted with a population consisting of two program managers, two technical managers, three systems engineers, one hardware engineer, and one logistics/reliability engineer. The population covered all of the desired areas of expertise and the respondent pool had an average of approximately 26 years of experience in defense and aerospace, which is sufficient to consider them to be authorities on system development programs.

The overall response of the program participants to the revised acquisition process was both positive and negative. Of those that were opposed to the changes opinions seemed to be very strong as exemplified by statements such as "Overall, TD was a

colossal waste of time and money." While the incorporation of design and test scope to reduce risk and the inclusion of competition were cited as elements that improved the general risk position of the program, issues with regard to communication, requirements management, and the alignment of scope with schedule were cited as negative aspects.

4.4.2.2.1 Early Systems Engineering and Development Knowledge

The majority of the interview subjects expressed the opinion that execution of System Engineering Reviews during the Technology Development phase decreased risk and multiple subjects directly referenced the increased level of knowledge available to support the Government's selection of a single contractor due to the scope of the Technology Development phase. This data suggests a positive relationship between execution of Systems Engineering Reviews prior to Milestone B and the level of Development Knowledge available to support a procurement decision. This finding is consistent with the results of the document review that high ratings for both Early Systems Engineering and Development Knowledge.

The Government did not consistently identify new risks at the reviews or provide sufficient feedback regarding the design because of restrictions on the Government's team with regard to communication. While there was little to no change in the requirements specification during the Technology Development phase, the requirements set had some stability issues between the Preliminary Design Review and the Engineering & Manufacturing Development phase. The Government removed a driving system capability to ensure a level competition for the Engineering &

Manufacturing Development phase. While this reduction in capability did not directly introduce technical risk into the program, it drove the solutions developed during Technology Development to use more complex technology than was necessary to provide the newly defined base capabilities. There is a potential for additional risk in the Engineering & Manufacturing Development phase if the design were changed to use less advanced technology, but reviews were not held to assess the new design.

4.4.2.2.2 Maturity Verification and Implementation Knowledge

The consensus of the team members for Program B was that development and test of prototypes during the Technology Development phase improved the maturity of the design and reduced the risk to further development and implementation. Only two of the ten interviewed team members mentioned technology readiness or selection in any of their answers, though some did refer to elements of manufacturing readiness such as production process definition and identification of suppliers for system components. This finding agrees with the document review of a high level of Product Maturity coupled with a moderate level of prototype requirements.

The contractor team developed and tested a prototype that was highly representative of the intended production design. There were still significant differences between the prototype and the intended production design, which was a source of frustration among the technical team members due to the fact that there was "dead-end engineering that does not help the next phase" which was seen as a waste of resources. However, most interview subjects stated that the testing of the system during the

Technology Development phase identified design changes that would be implemented during Engineering & Manufacturing Development to correct errors and reduced risk.

4.4.2.2.3 Modular Open Systems Approach and Integration & Sustainment Knowledge

Inclusion of Government-mandated MOSA-related scope such as requirements and assessments was seen to have only a minimal impact on the design of the system. It was repeatedly acknowledged in interviews that use of MOSA principles facilitates upgrades to and sustainment of the system throughout the lifecycle. However, the Government's requirements in this area were poorly defined and not emphasized during the program. A software engineer stated that "there was no pressure on this requirement from the Government."

Despite the Government's indifference, the system incorporated significant levels of modularity and design reuse due to a legacy program and the company's standard procedures for system development. In one interview, it was stated that "we were driven by best practices, not the Government requirements." This assessment aligns with the document review findings of a high level of Non-Developmental Item use coupled with a low level of interface disclosure and robustness.

4.4.2.2.4 Barriers to the Success of Program B

Open communication between the Government and the contractor was impaired on program due to competitive factors. An engineer from Case B said the "there was mostly one-way communication [from the contractor to the Government] despite the fact that there were two Government teams, one for each contractor and no cross-

pollination between the Government teams." Members of both the technical and program management teams attributed the root cause of the lack of communication to the Government's fear of a protest by the vendor that is not awarded the Engineering & Manufacturing Development contract. These issues inhibited the "free flow of information" in the words of one of the technical managers and prevented the Government and contractor from working as a team.

Another effect of the competitive environment that was identified through the interviews was the inability of the contractor to change system-level requirements during the Technology Development phase. As a result, trade-offs among capability, reliability, environments, physical attributes, and cost of the system were unable to be made. After the Preliminary Design Review, however, the Government removed significant requirements from the system level specification, which was seen by program personnel as an effort to ensure a competition between technically equivalent offerings for the Engineering & Manufacturing Development phase.

Multiple respondents stated that there was not enough time in the Technology Development phase to properly develop both a prototype for test and a system design to support production in parallel. The contractor tested a prototype that was intended to be representative of the tactical system, which increased the complexity and required development of multiple components on a short timeline. As a result of this hardware focus, the depth of analysis regarding requirements, software, and algorithms as part of the tactical system design process was less than is normal for development efforts of this size. According to a member of the engineering team,

"problems resulted from a near-term view that may affect the program into EMD" because of this focus on the technology-demonstration hardware and software.

Multiple interview subjects identified the gap between the Technology Development and Engineering & Manufacturing Development phases as a risk to the completion of the program due to issues with maintaining technical teams. One technical manager stated that "the delay between TD and EMD causes a loss of organizational inertia." The same individual also said that "initial operating capability may be delayed because you step back in the learning curve and open up supplier issues." Both of these factors are sources of significant schedule risk to the program because of the aggressive timelines of the Engineering & Manufacturing Development phase.

4.4.2.3 *Summary of Case Study B*

A summary of the case study results for Program B is presented in Table 4.4-5.

Table 4.4-5: Case Study B Results Summary

Case Study Topic	Case B Results
Overall Impact of TD Phase	Mixed with strongly negative opinions
Early Systems Engineering	• Improved system & requirements knowledge • Requirements unstable after PDR
Maturity Verification	• Increased design maturity • Not driven by Government requirements
Modular Open Systems Approach (MOSA)	• Low level of MOSA emphasis • Openness driven by design practices
Barriers to Program Success	• Lack of open communication • Requirements inflexibility • Modification of requirements after PDR • Excessive focus on prototype • Gap between program phases

The end result of Program B's Technology Development phase was a significant increase in both Development and Implementation Knowledge over that available at contract award. The ultimate success of the program is at risk, however, due to the inability of the Government and contractor teams to communicate and work together to stabilize requirement baselines for the eventual production system and the gap between program phases.

4.4.3 Cross-Case Analysis Results

The results of the two case studies were compared to determine areas of convergence and divergence in approach and outcomes. The results of the document reviews, findings from the individual case interviews, and data from the cross-case expert interviews are analyzed to determine the degree to which the results of the case studies support the hypotheses and to identify convergent evidence of barriers to success.

4.4.3.1 *Document Review Comparison*

The ratings for the factors derived from the document reviews were compared to determine if the hypothesized correlation among the constructs was supported by this small data set. The hypothesized relationships were defined as follows:

H$_1$: *Execution of systems engineering activities prior to full implementation commitment increases development knowledge.*

H$_2$: *Verification of product maturity prior to system detailed design increases implementation knowledge.*

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H₃: *Application of a Modular Open Systems Approach during development increases integration & sustainment knowledge.*

The hypotheses assert that a positive relationship exists between the independent and dependent variables. If the hypotheses are supported, a high level of the independent constructs would be associated with a high level of the dependent constructs. If the constructs display negative relationships when comparing the two cases, or there is no discernible difference, the data would not indicate support for the hypotheses. A graphical representation of the document review results comparison across the two cases with regard to the hypotheses is presented in Figure 4.4-1.
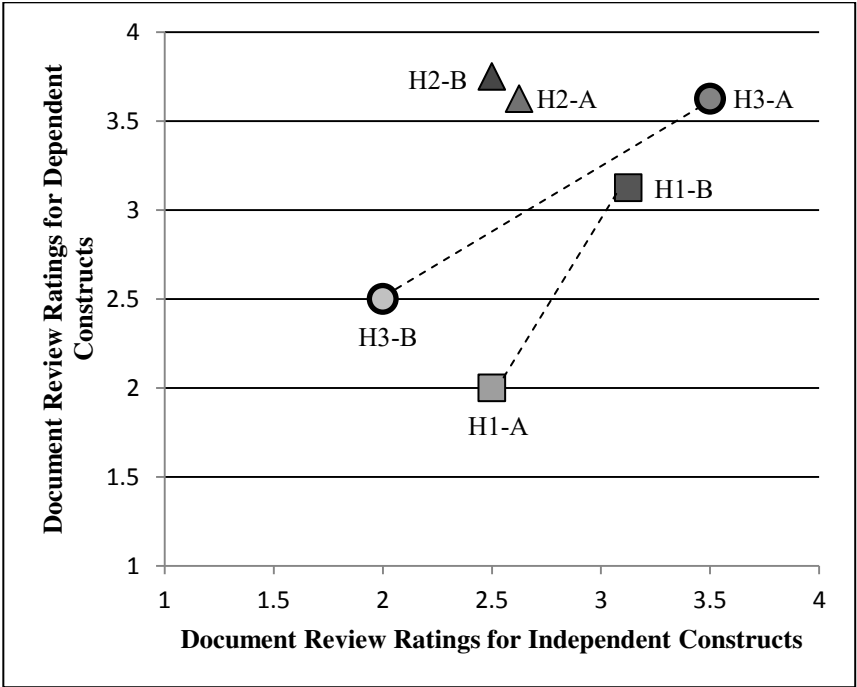
Figure 4.4-1: Comparison of Document Review Results

For Hypotheses 1 and 3, the case with the higher rating for the independent construct (Case B and A, respectively) also had the higher rating for the dependent construct.

This relationship indicates support for the first and third hypotheses. For Hypothesis 2, both cases are similarly rated with regard to the independent and dependent construct, leading to a finding that the validity of Hypothesis 2 is not discernible from comparison of the document review results. The very high levels of the Implementation Knowledge ratings are explained by the Government's strategy of providing flexibility to the contractor by only specifying key aspects of the prototype coupled with the contractor's strategy of developing prototype units that are representative of the system's intended production configuration. This analysis is qualitative in nature and based on a minimal data set, however it suggests that there is not enough evidence to reject any of the hypotheses based on the document reviews.

4.4.3.2 *Interviews with Cross-Case Experts*

In addition to interviews with dedicated program personnel, two off-program technical experts that had insight into both cases were interviewed to obtain an independent perspective of the program outcomes. These experts have a combined 72 years of experience in the defense and aerospace industry. They were charged with the review of both programs before and during the Technology Development phases.

The experts concurred that systems engineering activities executed earlier in the program increases the knowledge available to support decisions and estimates. Similarly to the individuals interviewed for the case studies, the experts' responses were heavily centered on the prototype portion of the Technology Development phase and noted that the testing of the prototypes significantly improved the maturity of the design and identifies improvement to be made in later phases. Unlike the majority of

the case study interviews, one of the experts tied advancement of technology readiness levels to the execution of the prototype testing. Both experts identified MOSA as an enabler for upgrade and sustainment of the system in the long term and agreed with the individual case results that the driver of open systems characteristics on one of the programs was the company's procedures rather than Government requirements.

One of the experts noted a severe misalignment between contractor internal procedures and the Government's revised acquisition process. The difficulty in executing system design and prototype test efforts in parallel was stated by both experts. They also identified the lack of open communication from Government to the contractor to be a significant source of risk for programs. The inability to make trade-offs related to requirements was also cited by both individuals as a problem for the development of the system. One of the experts pointed out that the requirements for different competitors are not allowed to diverge because it makes Government's evaluation of the Engineering & Manufacturing Development phase proposals more difficult. This restriction on flexibility limits the contractor's ability to be creative and provide a best-value offering with regard to cost and capability.

4.4.3.3 *Systemic Barriers to Program Success*

The interviews contained questions that solicited the impact of the process modifications as well as actions that could have been taken by the Government and contractor to improve the program's risk position at Milestone B. From responses to these questions, barriers to the successful implementation of the acquisition process were identified that were common between the two programs. From the commonality

it is inferred that the potential root causes of the barriers are systemic effects of the process itself rather than an artifacts of program execution.

Both cases displayed a clear lack of open communication between the contractor and the Government due to the competitive environment and the possibility of a protest after award of the Engineering & Manufacturing Development contract. This impacted the alignment of purpose, the identification of risks, and the understanding of requirements between the contractor and Government teams.

In both cases, the Government would not allow flexibility of requirements during the Technology Development phase. This prevented the contractor from resolving conflicts in the specification and trading less critical requirements for improved capability, higher producibility, and reduced procurement and lifecycle cost. Requirements were changed by the Government outside of the systems engineering process after the Preliminary Design Review via new specifications delivered with the Engineering & Manufacturing Development Requests for Proposals. In neither case were these requirements changes or their effects on the existing design formally reviewed with the contractor. These changes negatively impacted the value of the Development Knowledge gained from the Technology Development phase and increased the risk of completing the development of the system on time and budget.

Additionally, the gap that existed for both programs between Technology Development and Engineering & Manufacturing Development phases impeded the team's momentum and endangered the contractor's ability to maintain the execution

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team. Due to lack of Government funding, the contractor was forced to disperse some team members to other efforts. The result was that the team would have to reform at the beginning of the Engineering & Manufacturing Development phase and new personnel might need to be brought on to fill the roles of those that are no longer available to the program which impacts learning curve.

In general, focus on prototype at the expense of the system design and Engineering & Manufacturing Development program was a factor on both cases as well. Given the relatively small level of funding for Technology Development programs due to the limited scope and the focus on cost and schedule performance, less resources were available for depth of analysis of the production system. The desire on the part of the contractor to make the prototype representative of a production system forced key design and architectural decisions to be made too early without sufficient supporting analysis or understanding of requirements. The desire for similarity between the prototype and production systems drives architecture and technology selection decisions too early if prototype is considered baseline for system and significantly increases the complexity and effort required to develop a non-tactical system. Additionally, the prototype focus causes some work to be deferred until the Engineering & Manufacturing Development phase that should have been addressed earlier in the program.

Misalignment between the Government's new acquisition process and the contractor's standard development process was cited in the interviews for Case Study A and one of the cross-case expert interviews as an obstacle that had to be overcome by the

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program. This misalignment made it difficult for the contractor team to develop a prototype and production design in parallel due to the amount of analysis and work products required for the release of the prototype.

4.4.4 Case Study Results Summary

Hypotheses 1 and 3 were supported by the comparison of the case study results. Support for Hypothesis 2 was undetermined due to the high levels of Implementation Knowledge displayed by both cases. Additionally, all of the independent and dependent constructs were validated and the following barriers were identified by the case study phase:

- *Lack of open communication between the Government and contractor*
- *Requirements mismanagement during the Technology Development phase*
- *Focus on the prototype at expense of production system design*
- *Gap between Government funding of TD and EMD program phases*
- *Misalignment of Government and Contractor development processes*

A summary of the individual case study results and identification of patterns resulting from cross-case analysis is presented in Table 4.4-6.

Table 4.4-6: Cross-Case Analysis Results Summary

Case Study Topic	Case A Results	Case B Results	Cross-Case Findings
Overall Impact of TD Phase	Slightly negative overall	Mixed with strongly negative opinions	Participants are unsure of new process, but negative opinions are strongly so.
Early Systems Engineering	• Improved system knowledge • Requirements unstable after PDR	• Improved system & requirements knowledge • Requirements unstable after PDR	Reviews Improved Development Knowledge, but baselines not stable
Maturity Verification	• Increased design maturity • Prototype driven by competition	• Increased design maturity • Not driven by Government requirements	Very high Implementation Knowledge resulting from competition
Modular Open Systems Approach (MOSA)	• High level of MOSA emphasis; • Significant openness in design	• Low level of MOSA emphasis • Openness driven by design practices	Integration & Sustainment Knowledge depends on Government emphasis
Barriers to Program Success	• Lack of communication • Competitive environment • Inflexible requirements • Requirements changes after PDR • Excessive focus on prototype • Gap between program phases • Misaligned Government and Contractor processes	• Lack of open communication • Requirements inflexibility • Modification of requirements after PDR • Excessive focus on prototype • Gap between program phases	• Lack of Communication • Requirements Mismanagement • Prototype Focus • Program Gaps • Misaligned Processes

In response to the findings of the case studies, the research model was revised to incorporate the newly discovered barriers. The independent construct, dependent constructs, operationalized measures, and hypotheses were unchanged. The revised research model is depicted in Figure 4.4-2.

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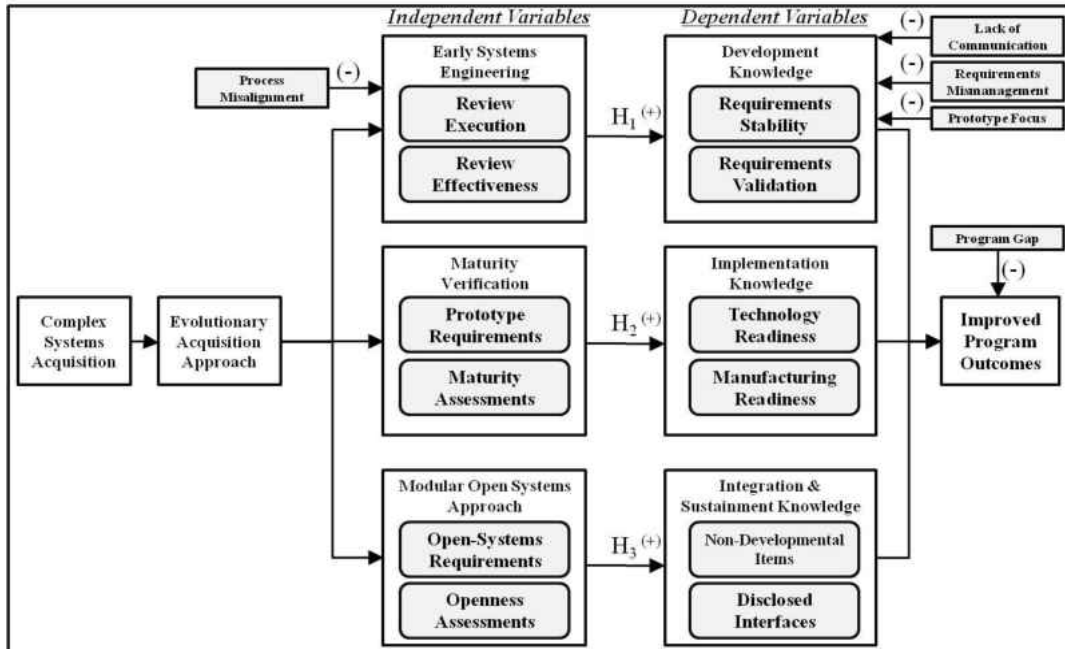
Figure 4.4-2: Revised Research Model as a Result of the Case Study Findings

The survey instrument incorporated the case study findings to improve measurement of the identified enablers and barriers on a larger set of programs.

4.5 Impacts of Case Study Results on Survey

No modifications to the survey questions regarding the constructs and hypothesized relationships were made as a result of the case study findings; however additional questions regarding the specific barriers that were present on the programs were added to the questionnaire. Items regarding these factors were added to the general impressions section of the questionnaire to sequester them from the questions used to test the hypotheses. These questions are provided in Table 4.5-1.

Table 4.5-1: Survey Questions to Assess Barriers on Programs

Question	Associated Barrier
62. To what degree was effective communication from the Government to the contractor adversely affected by the competitive environment during the Technology Development program phase?	Lack of Open Communication
63. To what degree was effective communication from the contractor to the Government adversely affected by the competitive environment during the Technology Development program phase?	Lack of Open Communication
64. To what degree did the development and test of a prototype system during the Technology Development phase of the program adversely affect the focus on the design to be presented at the Preliminary Design Review?	Focus on Prototype
65. To what degree was the prototype developed and tested during the Technology Development phase of the program representative of the intended production system design?	Focus on Prototype
66. To what degree were the internal company processes aligned with the Government's current acquisition process?	Process Misalignment
67. To what degree were proposed changes to the Government's system specification incorporated during the Technology Development phase of the program?	Requirements Mismanagement
68. To what degree did the gap between the end of the TD phase and the beginning of the EMD phase add risk to the program?	Program Gap

For each question, response options are identical to the substantive items used to assess the hypotheses (i.e., "None", "Little", "Moderate", or "Large"). Both programs exhibited the characteristic of significant changes to the system-level requirements by the Government between the Preliminary Design Review and Milestone B, however the addition of a new question to the survey instrument is not necessary because this topic is already addressed by a question related to the "Requirements Stability" measure. To assess whether the perceived purpose of prototype development and testing as implemented on the programs under investigation aligns with the Government's primary goal of identifying immature technology in proposed systems prior Milestone B, the following question was added to the Respondent and Program Background section of the questionnaire:

What was the __primary__ purpose of the prototype development and test efforts on the program?

- o *Evaluation of the maturity of critical technologies*
- o *Evaluation of system performance to support EMD proposal evaluation*
- o *Evaluation of manufacturing capabilities*
- o *Evaluation of integrated production representative components*
- o *There was no prototyping during the TD phase*

The answers to these newly added questions are used to determine if the barriers had a significant impact on programs being surveyed. For barriers that were prevalent on the surveyed program population, suggestions are provided in Chapter V to enable future programs to overcome similar obstacles to success.

4.6 <u>Survey Analysis Results</u>

The survey was deployed to 97 contractor personnel in roles that mirrored those of the case study interviewees. Each respondent was involved in one of five recent Major Defense Acquisition Programs that were executed at multiple contractor sites. Each of the military services (i.e., Air Force, Army, and Navy) were represented by at least one program. As the programs were all subject to the revised acquisition process, each included a Technology Development phase with a Preliminary Design Review, competitive prototyping among multiple contractors, and some level of MOSA scope.

Examination of organizational charts provided by program management representatives identified potential respondents. Each of the organizational charts was the version presented at the programs' Preliminary Design Review. The survey was open for three months for Programs A, B, and C. The survey for programs C and D was open for two months due to delays in acquiring the organizational charts.

4.6.1 Survey Data Validation

Before analysis of the survey results with regard to the constructs, hypotheses, and barriers, the results were validated to ensure that the data collected was complete, from acceptable sources, reliable, and fit the proposed research model.

4.6.1.1 Response Verification Results

Four survey responses were discarded and not included in the analyzed sample. Three were from Program A and one was from Program B. One of these responses indicated that the data provided pertained to a program other than the one being profiled. All other discarded responses were only partially completed.

4.6.1.2 Descriptive Statistics

Statistics about the survey data were generated to provide insight into the sampled population. The goal was to ensure that programs participated, that the respondents had sufficient experience, and that an appropriate mix of roles was represented by the participants. Table 4.6-1 presents the response characteristics for the survey sample.

Table 4.6-1: Response Characteristics for the Survey Sample

Program	Invitations	Valid Responses	Response Rate	Proportion of Total Sample
A	24	11	46%	32%
B	16	6	38%	18%
C	16	5	31%	15%
D	19	2	11%	5%
E	22	10	45%	29%
TOTAL	**97**	**34**	**35%**	**100%**

The low response rate was possibly due to concerns over providing potentially sensitive information. This rationale is supported by the decision of a candidate

program (Program F) to withdraw from the study for reasons related to the competition for an Engineering & Manufacturing Development phase contract. Additionally, since the companies involved in the research did not provide financial support to the survey, time taken to respond was not compensated. Though the response rate for Program D was particularly low, the shortened survey period did not appear to be the cause as the Program E survey was open for the same period of time.

Small sample sizes were anticipated as this study was uncompensated academic research being performed in an industrial setting. A low number of total survey invitations were distributed due to the small number of programs available. The anticipation of small sample sizes was part of the rationale for selection of multi-method research process that drew data from several sources. The goal of obtaining a sample that consisted of individuals that held lead positions on the programs, of which there is a small number, further limited the number of responses.

4.6.1.2.1 Roles of Participants

The pursuit of input from program leaders influenced the roles represented in the survey sample and limited the number of candidates eligible for study participation. Figure 4.6-1 presents proportions of the respondent roles in the survey sample.
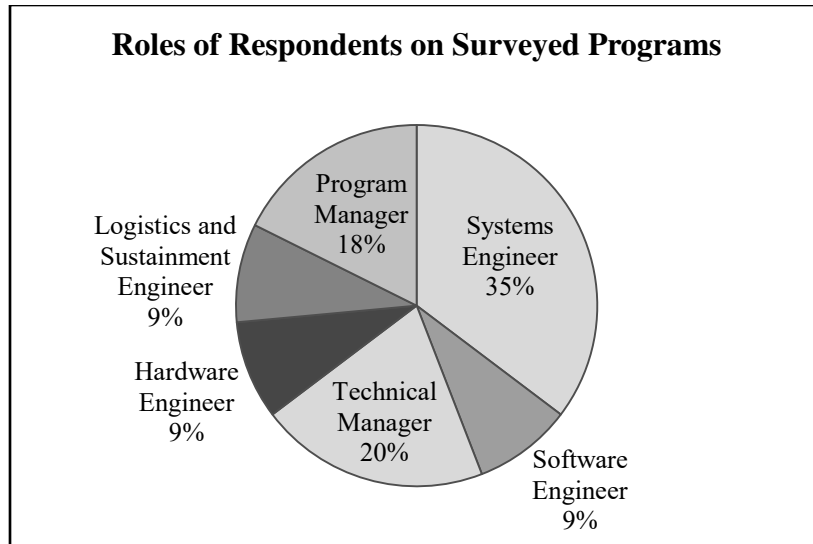
Figure 4.6-1: Distribution of Program Roles within the Respondent Population

The organizational charts indicated that the primary holders of leadership roles on the programs were concentrated in the roles of Program Manager, Technical Manager, and Systems Engineer. Since the objective of the research was to examine the high-level program impacts of the new acquisition process and environment, the predominance of these roles in the sample population for this study is valid, as the individuals likely had perspectives and responsibilities that spanned the program.

4.6.1.2.2 Experience Levels of Respondents

Previous experience is another important factor to the validity of the population sample. Because there was no control group and no absolute measure of program knowledge and risk, the study relied on comparison with past program execution. To assess the level of experience, the survey contained a question to determine how many years of experience that the respondents had in the area of national defense. The results from the question are presented in Figure 4.6-2. The figure shows the high, low, and average number of years of experience for respondents on each program.

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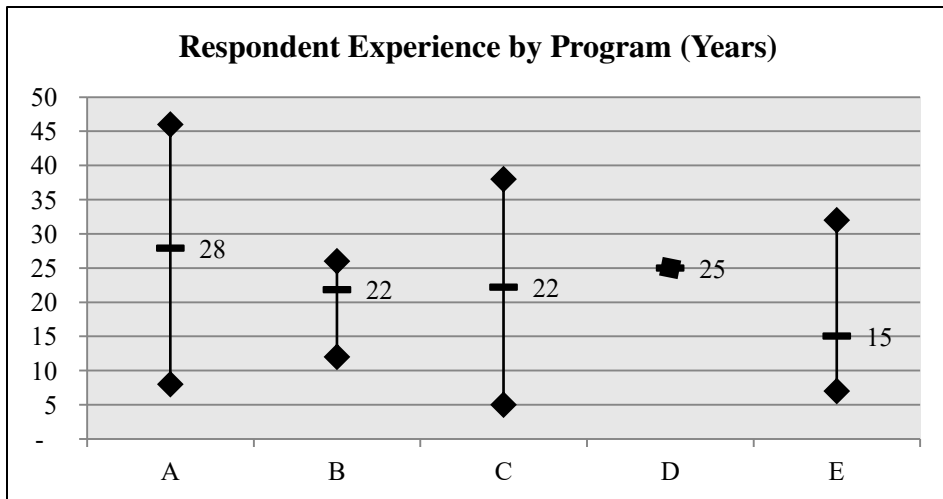
Figure 4.6-2: Respondent Experience Statistics for Program Survey Samples

The level of experience contained within the survey sample was sufficient to have

confidence that the respondents are capable of comparing the execution of the

surveyed programs with past efforts. The very high level of experience of the sampled

population is not surprising as the survey targeted senior roles on programs.

4.6.1.3 *Reliability Analysis Results*

Cronbach's alpha test was applied to the survey questionnaire responses to determine

the reliability of the instrument with regard to assessment of the operationalized

measures. An online calculator built on the R statistics language was used to perform

the analysis (Wessa, 2012). The threshold for inclusion of a measure in the study was

an alpha value of 0.6. While this minimum rating is considered less than optimal, it is

acknowledged that this is exploratory research and that the instruments may require

refinement after applications to more data sets. The results of the analysis are

presented in Table 4.6-2.

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Table 4.6-2: Cronbach's α Analysis Results for the Survey Instrument

Construct	Operationalized Measure	Excluded Items	Cronbach α
Early Systems Engineering	Review Execution	-	0.64
	Review Effectiveness	14	0.73
Developmental Knowledge	Requirement Stability	-	0.62
	Requirement Validation	-	0.77
Maturity Verification	Prototype Requirements	-	0.62
	Maturity Assessments	-	0.61
Implementation Knowledge	Technology Readiness	-	0.71
	Manufacturing Readiness	-	0.85
Modular Open Systems Approach	Open System Requirements	44	0.61
	Openness Assessments	-	0.62
Integration and Sustainment Knowledge	Non-developmental Items	53	0.62
	Disclosed Interfaces	-	0.80

The reliability analysis indicates a mixed level of quality for the survey instrument with regard to this data sample. The questions relating to Technology Readiness, Manufacturing Readiness, and Disclosed Interfaces display a high level of reliability without the removal of questions. The adaptation of these questions from existing Government assessment instruments likely contributed to their high level of reliability. The questions that assessed Requirements Validation were adapted from Bahill and Dean (2009) and were also rated as more reliable than those for most of the other measures.

In order to increase the reliability of the data set gathered from this sample, three questions were excluded from the confirmatory factor analysis and hypothesis testing. The questions that were removed were Question #1 for the Review Effectiveness measure, Question #3 for the Open System Requirements Measure, and Question #4 for the Non-Developmental Items measure. Removal of the first noted question greatly improved the reliability of the measurement, while removal of the other two

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questions merely made the measurement acceptable. Details regarding the removed

questions and potential causes for their negative impact on reliability are described in

Table 4.6-3.

Table 4.6-3: Questions Removed from Survey Analysis with Rationale

Construct	Operationalized Measure	Removed Question Text	Reliability Rationale
Early Systems Engineering	Review Effectiveness	14. Systems Engineering Review identified and documented risks to be addressed during system development.	Risk documentation is also accomplished in separate dedicated meetings.
Modular Open Systems Approach	Open System Requirements	44. The system is required to employ non-developmental items and/or commercial off-the-shelf components for non-application-specific functions."	Use of NDI and COTS driven by system environmental considerations. Specific requirement may not have been levied or may have been included independently of MOSA.
Integration and Sustainment Knowledge	Non-developmental Items	53. The system design incorporates reuse of hardware component designs developed on previous programs.	Reuse depends on other product lines that company offers more than requirement of each program.

After the identified questions were removed from the sample the fit of the construct

model to the data was evaluated using Confirmatory Factor Analysis.

4.6.1.4 *Confirmatory Factor Analysis Results*

Confirmatory Factor Analysis was initially performed on the survey responses at the

construct level to determine the presence of the latent variables in the data set. Due to

the small sample size, each construct was analyzed independently.

4.6.1.4.1 Confirmatory Factor Analysis of Initial Model

The model was constructed using the R statistics language and analyzed using the Structural Equation Model package. Figure 4.6-3 contains the initial model relating the observed variables to the latent constructs.
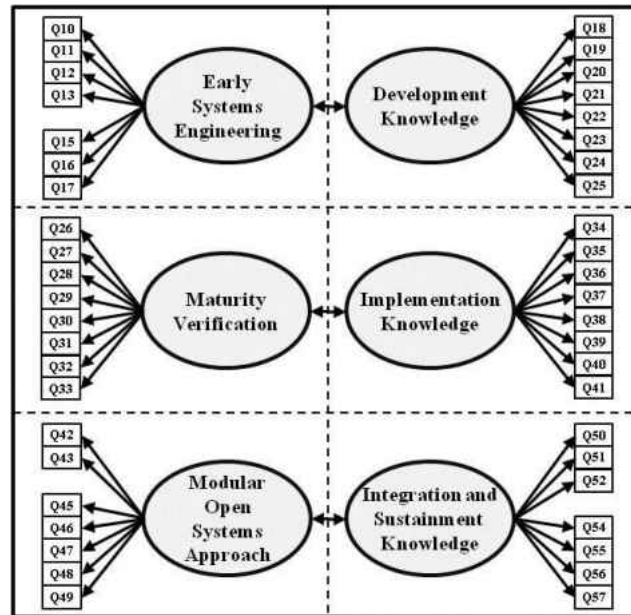
Figure 4.6-3: CFA Model at Construct Level

Five fit statistics were used to assess the model: Goodness of Fit Index (GFI), Bentler-Bonett Index or Normed Fit Index (BB NFI), Bentler Comparative Fit Index (CFI), Tucker-Lewis Index (TLI), and Standardized Root Mean Square Residual (SRMR). Table 4.6-4 contains the results of fit analysis at the construct level.

Table 4.6-4: CFA Fit Statistics for the Research Constructs

Measure of Fit (Threshold)	GFI (≥ 0.90)	BB NFI (≥ 0.90)	Bentler CFI (≥ 0.90)	TLI (≥ 0.90)	SRMR (≤ 0.08)
Early Systems Engineering	0.815	0.623	0.741	0.612	0.123
Developmental Knowledge	0.757	0.595	0.731	0.623	0.135
Maturity Verification	0.843	0.608	0.927	0.898	0.105
Implementation Knowledge	0.726	0.648	0.748	0.647	0.154
Modular Open Systems Approach	0.803	0.641	0.728	0.592	0.122
Integration and Sustainment Knowledge	0.754	0.603	0.701	0.551	0.134

The confirmatory factor analysis results showed that the constructs as identified in the Conceptual Model were not well represented in the sample. With the exception of the Bentler Comparative Fit Index for the Maturity Verification construct, all fit measures for all of the constructs were below the acceptability thresholds. This result indicated that the model required significant revision.

4.6.1.4.2 Confirmatory Factor Analysis of Revised Model

To assess whether the lack of fit was a function of the defined operationalized measures or their groupings, a new model was developed to separate the observed variables from each other. In this new model each operational measure was mapped to the questions that measured them directly. Additionally, the model contained interactions among the independent and dependent variables. The revised model is presented in Figure 4.6-4.
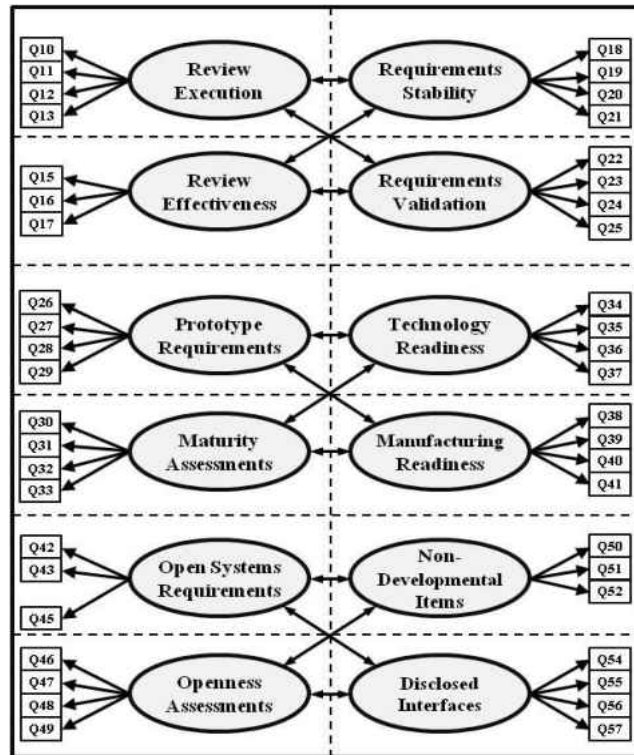
Figure 4.6-4: CFA Model at Operationalized Measure Level

The fit of the collected survey data to the model at the operationalized measure level was assessed using Confirmatory Factor Analysis. Statistics describing the fit for individual questions resulting from the analysis at the operationalized measure level were calculated and compared to thresholds. Statistics could not be calculated for the Review Effectiveness, Open-Systems Requirements, and Non-Developmental Items measures because their correlation matrices do not contain enough elements. Removal of questions from the model as a result of reliability analysis caused this lack of matrix size. Because these measures were deemed to be reliable by the Cronbach's alpha test, they remained in the model. However, conclusions related to relationship assessment for these measures carry a caveat that the validity of these factor measures were not completely understood. The fit statistics are presented in Table 4.6-5.

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Table 4.6-5: CFA Fit Statistics for the Operationalized Measures

Measure of Fit (Threshold)	GFI ($\geq$ 0.95)	BB NFI ($\geq$ 0.90)	Bentler CFI ($\geq$ 0.90)	TLI ($\geq$ 0.90)	SRMR ($\leq$ 0.08)
Review Execution	0.992	0.978	1.000	1.263	0.034
Review Effectiveness	1*	-	-	-	-
Requirements Stability	0.940	0.824	0.880	0.641	0.100
Requirements Validation	0.985	0.975	1.000	1.135	0.037
Prototype Requirements	0.997	0.988	1.000	1.593	0.022
Maturity Assessments	0.954	0.810	0.893	0.680	0.075
Technology Readiness	0.989	0.976	1.000	1.169	0.032
Manufacturing Readiness	0.989	0.990	1.000	1.056	0.021
Open-Systems Requirements	1*	-	-	-	-
Openness Assessments	0.991	0.988	1.000	1.114	0.028
Non-Developmental Items	1*	-	-	-	-
Interface Disclosure	0.974	0.961	1.000	1.032	0.040

The statistics indicated that the lower level model provided a substantial improvement over the fit of the original conceptual model. The calculated fit statistics were at or very near thresholds with two exceptions. The Requirements Stability and Maturity Assessment operationalized measures were well below threshold for the Tucker-Lewis index. This perceived deficiency was likely a result of the low number of degrees of freedom present in the model. The other fit statistics were near thresholds for the Requirements Stability and Maturity Assessment operationalized measures, therefore these measures remained in the model.

4.6.2 Evaluation of Relationships among Variables

The confirmatory factor analysis resulted in an assessment of the contribution of each question to the variability in the sample. The contributions of each question to the

factor score were represented by the loadings for the questions. The loadings for the questions are presented in Table 4.6-6.

Table 4.6-6: Confirmatory Factor Analysis Loadings for the Survey Questions

Operationalized Measure	Q1 Loading	Q2 Loading	Q3 Loading	Q4 Loading
Review Execution	0.613	1.005	0.270	0.394
Review Effectiveness	0	0.695	0.787	0.627
Requirements Stability	1.154	0.245	0.383	0.490
Requirements Validation	0.486	0.736	0.567	0.926
Prototype Requirements	0.347	0.997	0.490	0.333
Maturity Assessments	0.422	0.781	0.457	0.513
Technology Readiness	0.823	0.269	0.749	0.641
Manufacturing Readiness	0.511	0.883	0.840	0.922
Open-Systems Requirements	0.648	0.689	0	0.429
Openness Assessments	0.502	0.659	1.034	0.665
Non-Developmental Items	0.087	2.980	0.194	0
Disclosed Interfaces	0.538	0.643	0.857	0.840

Cells that contain "0" indicate questions that were removed from the data set as a result of reliability analysis. The scores were included as the weighting coefficients in a weighted average that represents the value of the variables for each respondent. Because relationships were tested using pair-wise comparisons of ranks within each measure, the comparative magnitude of the loadings across measures does not influence the outcome of the correlations analysis.

The relationships among the independent and dependent constructs were evaluated by applying Kendall's *tau* rank correlation test to the survey results to determine the levels of correlation between the independent factors and the dependent factors. Association thresholds of *tau* values ranges for this study are presented in Table 3.6-7.

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Table 4.6-7: Thresholds for Correlation Evaluation

tau Value Range	Strength of Association
tau > 0.35	Very Strong
0.35 > *tau* ≥ 0.3	Strong
0.3 > *tau* ≥ 0.25	Moderate
0.25 > *tau* ≥ 0.2	Weak
tau < 0.2	Insignificant

In addition to the questions that assessed the operationalized measures, direct questions were asked of the respondents with regard to program elements and their impact on program risk levels. The results from these questions are presented with the hypotheses to compare the perceived level of knowledge and risk improvement resulting from the respective program elements with the observed data.

4.6.2.1 *Early Systems Engineering and Development Knowledge (H_1)*

The results of the quantitative relationship evaluation indicated that the evidence supported H_1.The *tau* rank correlation results for the operationalized measures associated with H_1 are presented in Table 4.6-8.

Table 4.6-8: Tau Rank Correlation Matrix for Hypothesis 1

	Review Execution	Review Effectiveness
Requirements Stability	0.242	0.375
Requirements Validation	0.356	0.435

The associations between Review Effectiveness and both Requirements Stability and Validation were very strong. Additionally, a very strong positive relationship was observed between Review Execution and Requirements Validation. Though the *tau*

value for the relationship between Review Execution and Requirements Stability was not greater than 0.3, a value of 0.242 indicated a weak correlation. These findings suggested that completion of the reviews prior to the Preliminary Design Review had the intended effect of increasing program knowledge prior to Milestone B.

The respondents were asked a direct question regarding the magnitude of the positive impact on program risk resulting from the execution of a Preliminary Design Review prior to approving implementation of the system design. The direct question regarding completion of a Preliminary Design Review prior to Milestone B supported the assessment of H_1 is illustrated by the graph in Figure 4.6-5. In all of the graphs presented in this chapter, each program accounts for 20% of the response, regardless of the number of responses from each case. The options presented to the respondents were on a scale similar to the items related to the operationalized measures. The responses to these questions as presented are normalized on a per-case basis to ensure that Programs A and E did not skew the results and that Program D was adequately represented. The normalization caused each program to represent one fifth of the total sample.
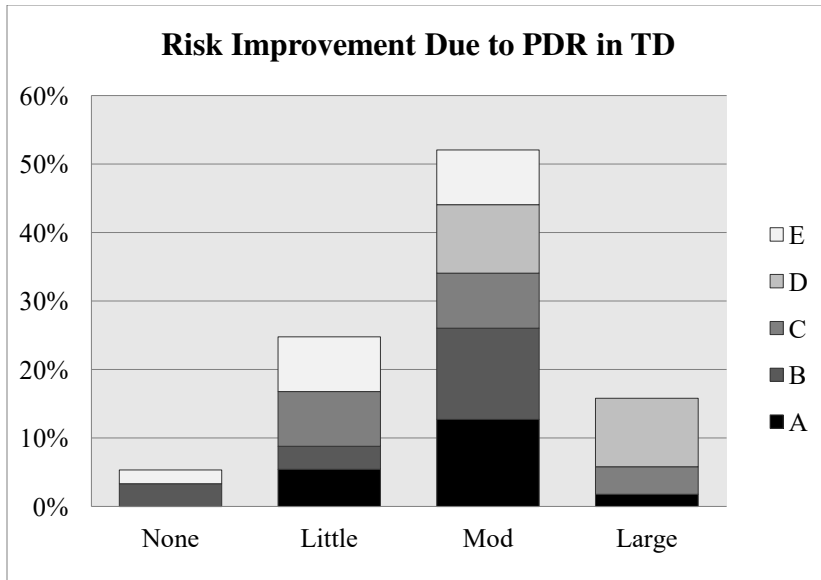
Figure 4.6-5. Impact of PDR prior to Implementation Approval on Program Risk

Almost all respondents across the programs expressed that holding a Preliminary Design Review prior to funding system implementation improved the risk position of the program to some degree, though they disagreed as to the magnitude of the benefit. The majority (68%) of the overall sample expressed that there was at least a moderate improvement in program risk due to holding a Preliminary Design Review prior to Milestone B. A majority of each of the program samples except for Program E concurred with the assessment that the Preliminary Design Review reduced risk at least moderately.

4.6.2.2 *Maturity Verification and Implementation Risk (H₂)*

The results of the hypothesis testing did not fully support H_2. The correlation results for the operationalized measures associated with H_2 are presented in Table 4.6-9.

Table 4.6-9: Tau Rank Correlation Matrix for Hypothesis 2

	Prototype Requirements	Maturity Assessments
Technology Readiness	0.262	0.264
Manufacturing Readiness	0.395	0.288

The *tau* score of 0.395 between Prototype Requirements and Manufacturing Readiness indicated a very strong association, but the other correlations did not exceed the threshold of 0.3. However, the *tau* values among the independent and dependent variables were all above 0.25, which indicated a moderate positive correlation between the respective variables.

The respondents were asked a direct question regarding the magnitude of the positive impact on program risk resulting from the development and test of a system prototype during the Technology Development phase. The response to the direct question regarding the prototype's impact on program risk is presented in Figure 4.6-6.
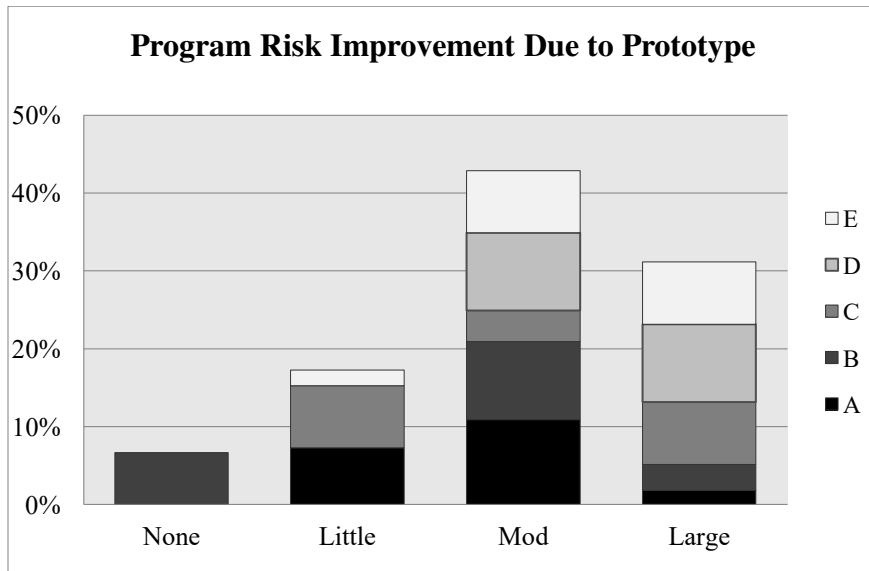
Figure 4.6-6. Improvement of Program Risk Due to Prototype

Over 70% of the sample expressed that the prototype had a "Moderate" or "Large" positive impact on program risk levels. Only Program B expressed that the impact of the prototype development and test during the Technology Development phase was less than positive, and the majority of that case still indicated that there was a "Moderate" or "Large" improvement. Interestingly, no member of Program B answered that there was "Little" positive impact of the prototype, indicating that there is a split opinion as to the value of prototyping on that program.

The results of this question were not consistent with the lack of support for H_2 during relationship evaluation. Two potential explanations are offered for this misalignment. First, the respondents may not understand the extent or nature of the impact of prototyping on program risk levels. Alternately, the reduced risk on the program might have manifested in variables other than Technology and Manufacturing Readiness as measured. The second explanation is supported by the strong correlation between the Maturity Verification construct and the measure of Requirements Validation.

The case studies found that the characteristics of the prototypes on Programs A and B were driven more by competition than by Government-levied requirements, which might have been true of the other programs as well. If competition was the primary factor in prototype development, the independent Prototype Requirements measure would not necessarily be strongly correlated with the dependent measures of Manufacturing and Technology Readiness. In fact, no independent measure was strongly correlated with Technology Readiness; however the Review Execution, Prototype Requirements, and Maturity Assessment independent variables displayed

moderately positive correlations. This pattern suggests that both Maturity Verification and Early Systems Engineering positively influenced Technology Readiness, but neither ensured technology maturity of the solution in isolation.

4.6.2.3 *MOSA and Integration & Sustainment Risk (H₃)*

The results of the hypothesis testing supported H_3. The tau rank correlation results for the operationalized measures associated with H_3 are presented in Table 4.6-10.

Table 4.6-10: Tau Rank Correlation Matrix for Hypothesis 3

	Open-Systems Requirements	Openness Assessments
Non-Developmental Items	0.084	0.418
Disclosed Interfaces	0.333	0.442

The tau values for the correlations between Openness Assessments and both Non-Developmental Items and Disclosed Interfaces indicated that there was a very strong correlation among these variables. There was also a strong association between Open Systems Requirements and Disclosed Interfaces. This finding suggested that assessing programs' use of Non-Developmental Items and Disclosed Interfaces positively influenced the inclusion of these elements in the product design. However the correlation between Open Systems Requirements and the use of Non-Developmental Items was negligible. The explanation for this lack of correlation may be that the use of Non-Developmental Items such as commercial off-the-shelf components and components used on other programs had more to do with the availability of such items than Government requirements. Data was collected using a question to directly gauge

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the respondents' impression of the impact of MOSA on program risk. Figure 4.10-3

contains the normalized results from this question.
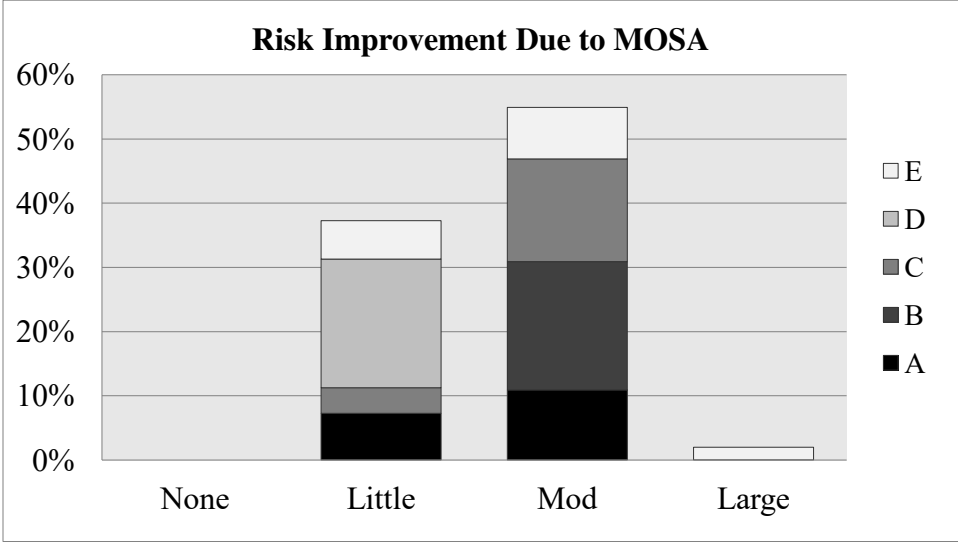
Figure 4.6-7. Improvement in Program Risk as a Results of MOSA Scope

The figure shows that all respondents perceived some level of improvement from the

application of MOSA and that a slight majority (57%) described the improvement as

"Moderate" or "Large". This finding further supports the validity of H_3. A potential

explanation for the dearth of "Large" or "None" responses is that because the effects

of MOSA on the programs are not necessarily immediately evident, the measurement

of this construct was more prone to Central Tendency Bias.

4.6.2.4 *Additional Relationships*

In addition to the hypothesized relationships, correlation analysis revealed

unanticipated relationships between other factors in the data. The correlation matrix

for the factors is presented in Table 4.6-11.

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Table 4.6-11: Tau Rank Correlation Matrix for the Operationalized Measures

	Review Execution	Review Effectiveness	Prototype Requirements	Maturity Assessments	Open-Systems Requirements	Openness Assessments
Requirements Stability	0.242	**0.375**	0.269	0.19	-0.272	0.046
Requirements Validation	**0.356**	**0.435**	**0.606**	**0.471**	0.196	**0.384**
Technology Readiness	0.262	0.217	0.262	0.264	0.018	0.135
Manufacturing Readiness	**0.317**	0.188	**0.395**	0.288	0.064	**0.495**
Non-Developmental Items	0.102	-0.016	0.225	0.099	0.084	**0.418**
Disclosed Interfaces	**0.361**	0.011	0.123	0.158	**0.333**	**0.442**

Shaded cells in the table signify the relationships that were hypothesized prior to data collection. Bold type indicates strong correlations ($\tau \geq 0.3$) in respondent ranking related to the independent and dependent variables. The potential relationships with strong correlation were examined to determine the validity of the research hypotheses and to understand possible causes and implications for unanticipated relationships.

The dependent Requirements Validation measure was significantly correlated with both of the measures of the independent Maturity Verification construct. The Prototype Requirements operationalized measure, with a correlation value of 0.606, was more strongly correlated with Requirements Validation than either of the systems engineering review measures. The connection between these aspects is logical given that the value of prototypes development and evaluation include validation of the system design and refinement of requirements (Drezner and Huang, 2010).

The relationship between Maturity Assessments and Requirements Validation is less clear. The use and nature of assessments was observed to impact validation to a much

greater degree than Technology or Manufacturing Readiness. Examination of the correlations on a question-by-question basis identified the driving factors for the relationship at a deeper level. Firstly, the completion of technology readiness assessments requires documentation of the system architecture which increases the score for the Requirements Validation measure. Secondly, formal verification of prototype requirements with Government involvement during the Technology Demonstration phase establishes an initial set of verification criteria for some system-level requirements. If these criteria were deemed as inappropriate after the prototype testing, they would be more likely to be changed than verification requirements that had yet to be validated. Finally, execution of Maturity Assessment activities, especially with regard to high-risk areas and critical technologies likely gave the team confidence that the program could be completed on budget and schedule.

Examination of the correlation between Openness Assessments and Requirements Validation identified that programs with a documented system architecture and with established verification criteria for system-level requirements were much more likely to have performed market surveys. No further explanation was found in the data for this correlation. The relationship between Disclosure of Interfaces and Review Execution was also examined and found to have no logical rationale for the correlation at the individual question level.

The observed relationship between Openness Assessments and Manufacturing readiness is likely a second-order effect. Openness Assessments were also strongly correlated with the use of Non-Developmental Items. Because Non-Developmental

Items, including both commercial products and components used on other programs have already been produced, they have an inherently higher level of maturity and it is logical that processes equipment for producing them would be better understood. One might expect a commensurate increase in the Technology Readiness measure with use of Non-Developmental Items, but the questions related to Technology Readiness focus only on unproven technology elements. The Manufacturing Readiness questions addressed the system as a whole to include lower-risk components such as processor cards and physical structures.

4.6.3 Potential Barriers to Program Success

The survey instrument included direct questions to evaluate the prevalence of the potential barriers to successful program execution identified during the case study phase. All charts containing response data presented within this section are normalized such that each program constitutes twenty percent of the sample, regardless of the number of responses from each program.

4.6.3.1 *Communication in a Competitive Environment*

Lack of communication between Government and contractor personnel was indicated to be a major issue during the case studies of Programs A and B. To assess the impact to the additional programs, two questions were asked of respondents regarding communication on programs executed under the new acquisition process. Figure 4.11-1 presents normalized response data for the first question regarding Government-to-contractor communication.

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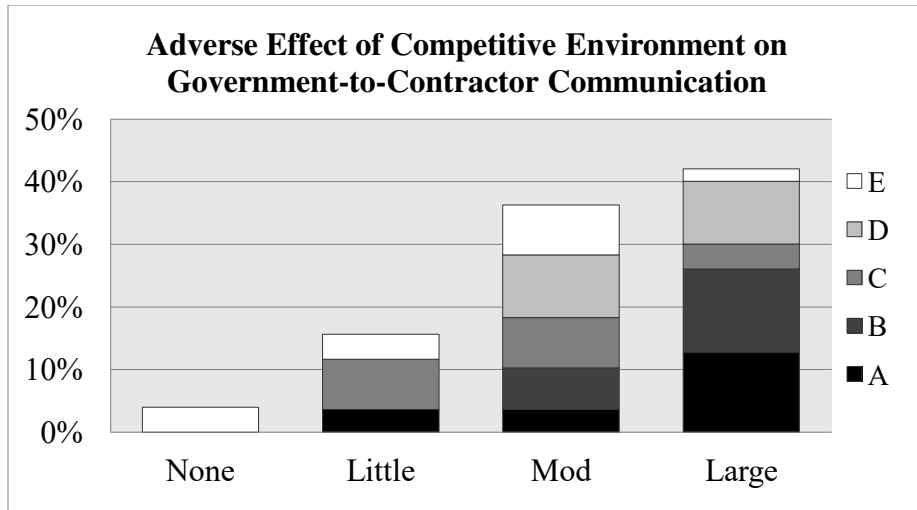
Figure 4.6-8. Adverse Effect of Competition on Government-to-Contractor Communication.
Almost all respondents expressed that there was some level of adverse effect with over 75% of the sample and the majority of each program characterizing the impact as "Moderate" or "Large". These results suggest that the new program structure negatively impacted communication from the Government to the contractor.

Figure 4.6-9 contains the normalized response data for the second question regarding the level of adverse effect that the competitive environment had on communication from the contractor to the Government.
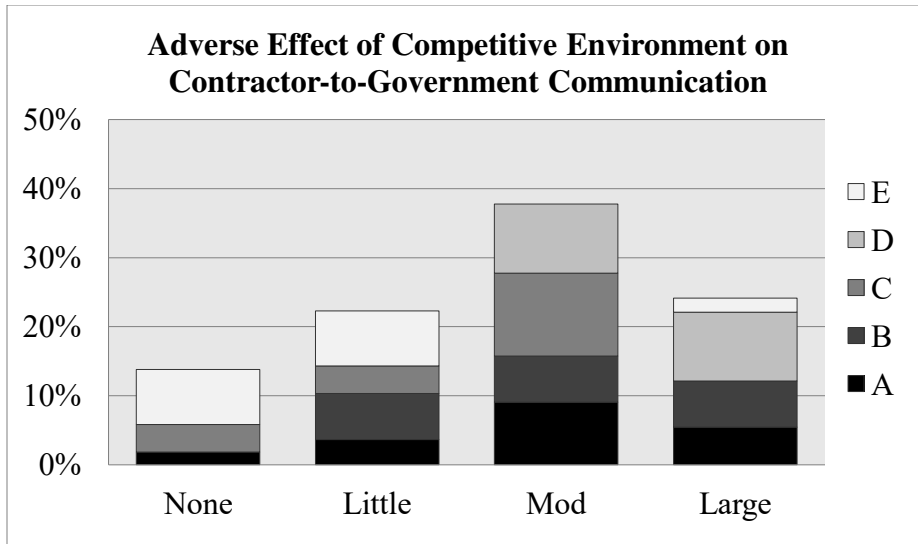
Figure 4.6-9. Adverse Effect of Competition on Contractor-to-Government Communication.

The results of the direct question suggested that the new program structure also

negatively impacted communication from the contractor to the Government, though to

a smaller degree. The majority of Case E expressed that the effect on contractor-to-

Government communication was "Little" to "None".

4.6.3.2 *Requirements Mismanagement during the TD Phase*

The case studies indicated that requirements were inflexible during the Technology

Development phase, but changed significantly after the Preliminary Design Review.

As one of the goals of the Technology Development phase is to refine requirements by

incorporating contractor inputs, a question was asked of the respondents regarding

Government acceptance of changes to the system requirements that were proposed by

the contractor. The response data for that question is presented in Figure 4.6-10.
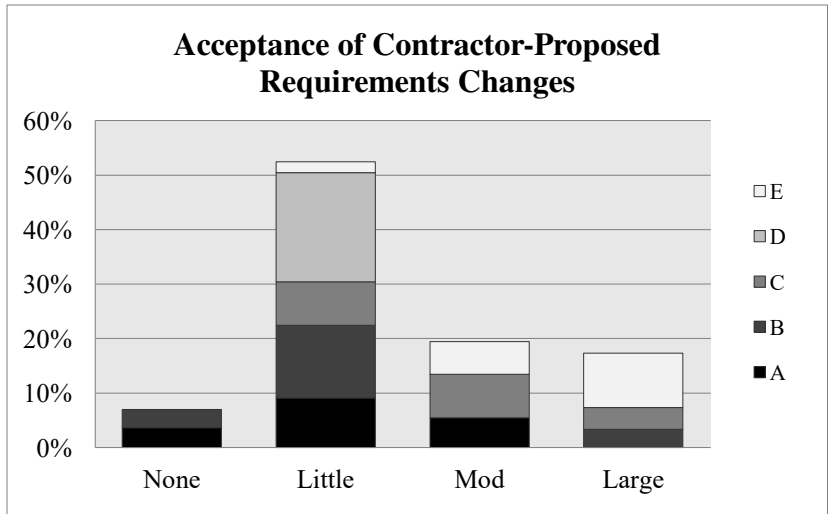
Figure 4.6-10. Acceptance of Contractor-proposed Requirements Changes during Technology Development Phase.

The majority of the samples from Programs A, B, and D expressed that there was little to no acceptance of contractor-proposed specification changes during the Technology Development phase. A small majority of the overall sample also shared this view. A question was also asked related to the stability of requirements after the establishment of the allocated baseline upon completion of the Preliminary Design Review. Figure 4.6-11 presents the results from this question.
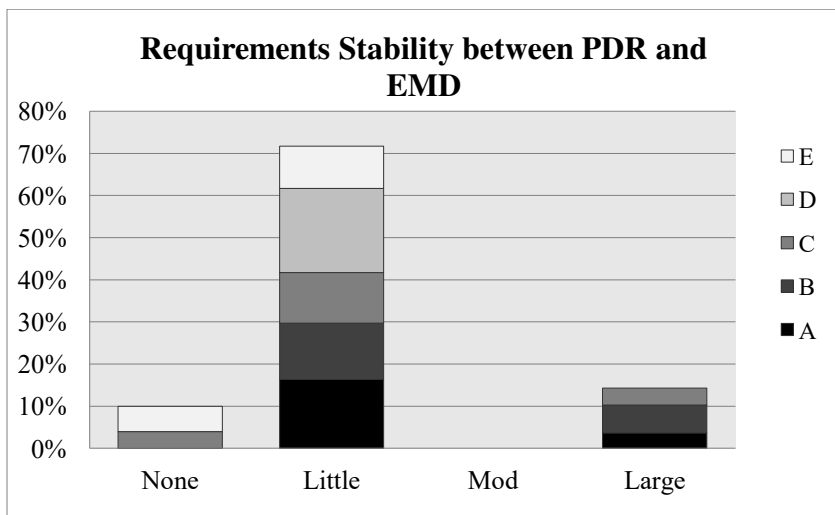
Figure 4.6-11. Requirements Stability after PDR.

The majority of each program agreed that the system-level requirements were significantly changed after the execution of the Preliminary Design Review, but before the beginning of the Engineering & Manufacturing Development phase. The combination of these results suggests that the finding of the case studies related to the mismanagement of requirements is systemic and not isolated to Programs A and B.

4.6.3.3 *Excessive Focus on Prototypes*

The case study interviews signaled a disproportionate focus on the prototyping activity compared to the refinement of requirements and development of the preliminary design. In response to this finding of the case studies, multiple items were included in the survey instrument regarding the prototyping activity on the programs. The first question sought to determine the purpose of the prototypes on each program as perceived by the contractor personnel. The unmodified response data for this question is presented in Table 4.6-12.

Table 4.6-12. Perceived Purpose of Prototype

Program	Evaluation of the maturity of critical technologies	Evaluation of system performance to support the EMD source selection evaluation	Evaluation of integrated production-representative components
A	1	8	2
B	3	3	-
C	4	1	-
D	1	-	-
E	9	-	1
TOTAL	**18**	**12**	**3**

The responses indicated that there was significant confusion on Programs A and B regarding the purpose of the prototype. If the goals of prototyping scope on each program were clearly communicated, each case should have provided consistent

responses to the question. In both cases, a significant number of respondents signified

that the purpose of the prototype was primarily to support source selection. This

finding is corroborated by the case study interviews wherein it was indicated by a

significant number of subjects that prototype performance was a major factor in the

competition for the next phase.

Another question intended to gather information regarding prototype focus on the

programs asked the respondent to rate the degree to which the prototype represented

the production design under development throughout the Technology Development

phase. Figure 4.6-12 provides the normalized response data for this question.
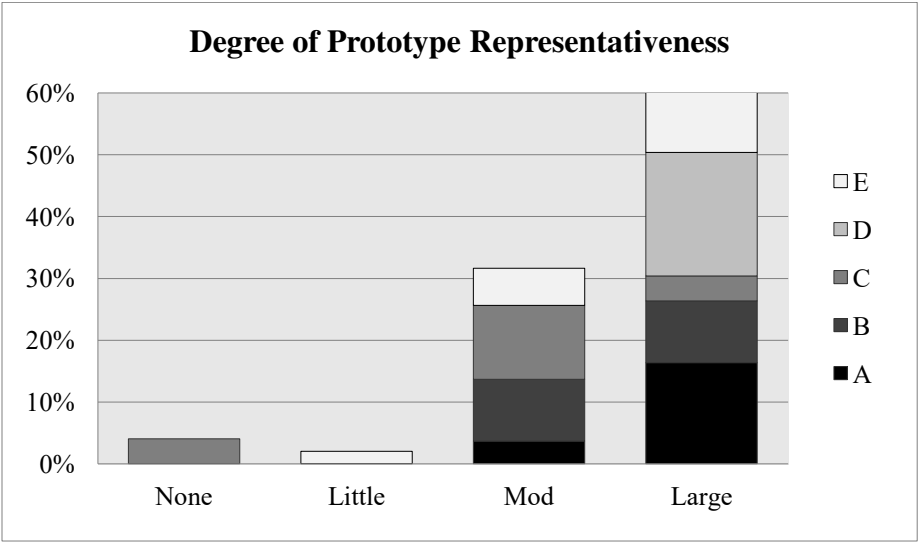
Figure 4.6-12. Degree that the Prototypes Represent Intended Production Design.

The programs overwhelmingly stated that the prototypes were at least moderately

representative of the intended production design in each case, with 60% of the sample

characterizing the degree of representativeness as "Large." This finding indicated that

a significant amount of focus was placed on the design, manufacture, and demonstration of the prototype systems during the Technology Development phase.

A third question asked the respondent to characterize the degree to which the development and test of a prototype adversely affected the focus of the program team on the system design to be presented at the Preliminary Design Review. Figure 4.6-13 contains the normalized response data for the question.
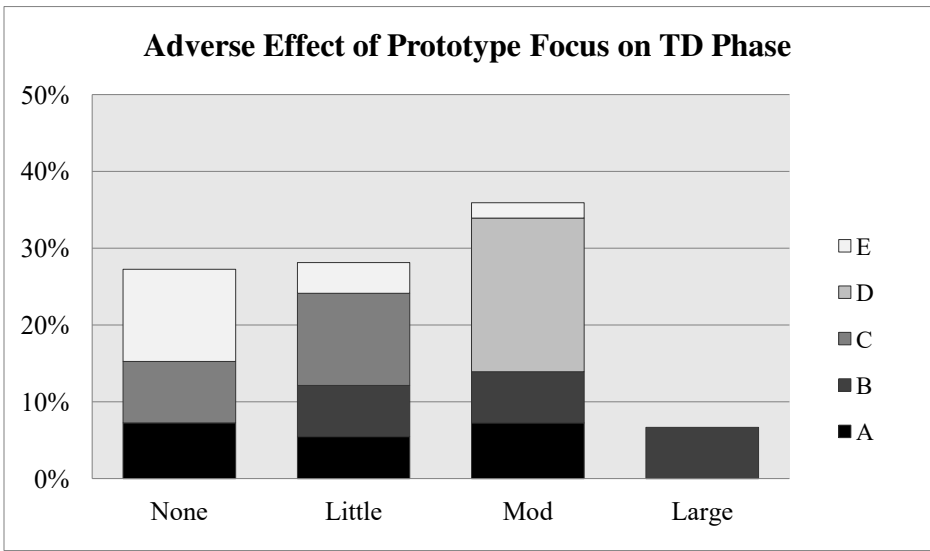
Figure 4.6-13. Degree of Adverse Effect Due to Prototype Focus.

A significant majority (73%) of the population expressed that the prototype interfered with execution of the system design, however 59% of the sample stated that there was little to no adverse effect. All of the programs except for D split responses over multiple categories, indicating that there was not a strong consensus within the programs. Programs C and E felt little to no adverse effect from the prototype scope, both of which displayed a firm understanding of the prototype purpose. Program D is difficult to characterize based on the small sample size, but it appears that the

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prototype scope had a moderate negative effect on the program. The responses from Programs A and B were more varied. This variance might be related to the lack of cohesion among the program teams regarding the purpose of the prototypes. In contrast to the evidence from the case study interviews, the majority of Program A stated that the negative effect was "Little" or "None". A previous question found that almost all of the respondents for Program A felt that the primary purpose of the Technology Development phase was to support the source selection for the next phase through prototyping. The combination of these data points suggests that Program A did not assess that prototyping had a negative impact because it was thought to be the most important aspect of that phase.

4.6.3.4 *Gaps between Program Phases*

The case study interviews indicated that significant risk to Engineering and Manufacturing Development was introduced by splitting the program into two distinct segments. In response, a question was included in the survey to determine the amount of risk introduced to the program by the transition between program phases. Figure 4.6-14 contains the normalized data resulting from this question.

Risk Due to TD/EMD Transition
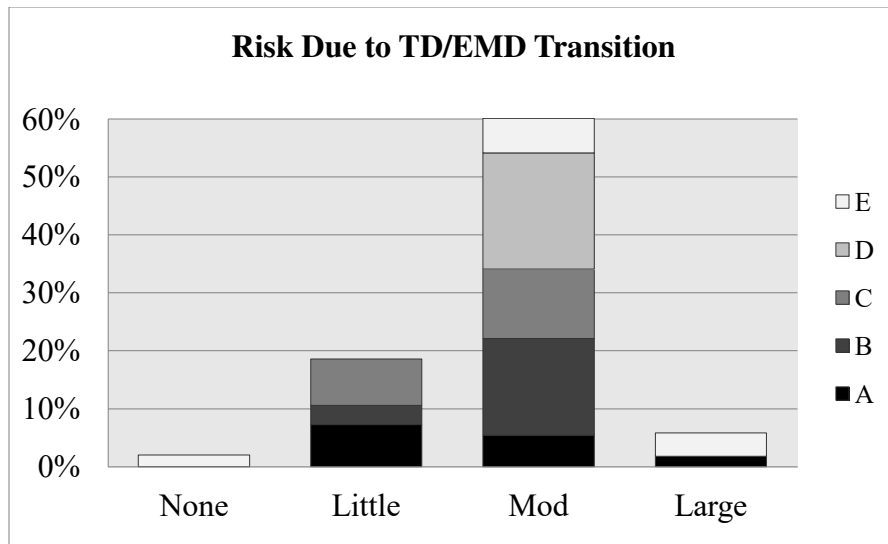
Figure 4.6-14. Program Risk Due to Transition between Program Phases

Almost all respondents (98%) asserted that there was some level of additional risk due to the transition and 66% of the normalized sample stated that there was at least a "Moderate" negative effect. The data from this question confirmed that disruption of the program due to the transition to a new contract after the execution of the Preliminary Design Review was experienced by programs other than those included in the case study phase.

4.6.3.5 *Contractor / Government Process Alignment*

The case-study interviews with cross-case experts in Systems Engineering identified a potential misalignment between contractor and Government system development processes. To assess this potential barrier, a question was included in the survey to determine the degree to which the processes of the organizations are aligned. Figure 4.6-15 presents the results of this question.
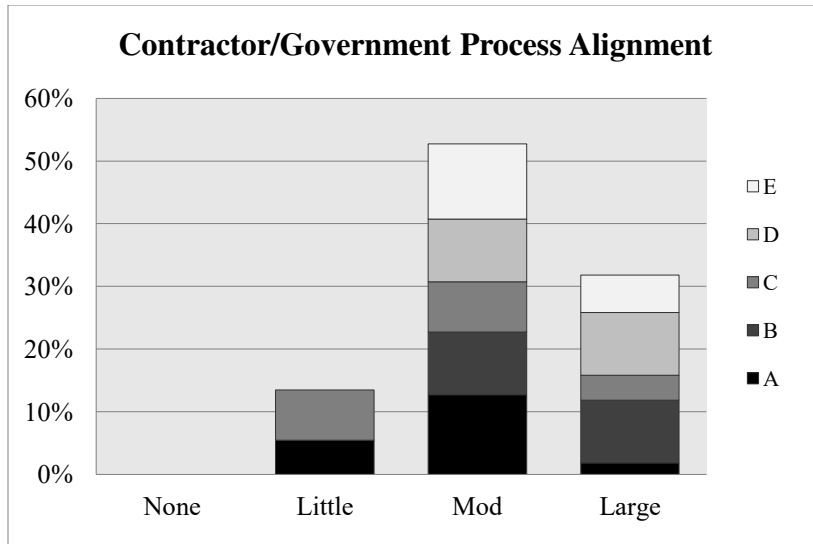
Figure 4.6-15. Government and Contractor Development Processes Alignment

The results of the question indicate that there was not a large degree of misalignment between the Government and contractor processes on these programs. While there were responses from Programs A and C that the respective processes are not synchronized, over 80% of the population stated that the processes are aligned to at least a moderate degree, indicated that the programs were not severely impacted by any misalignment.

4.6.4 General Impressions of TD/EMD Program Structure

To provide context for assessment of individual program elements, a question was posed to determine the overall perceived effect of the TD/EMD program structure. The results of the overall TD/EMD effectiveness question are presented in Figure 4.6-16.
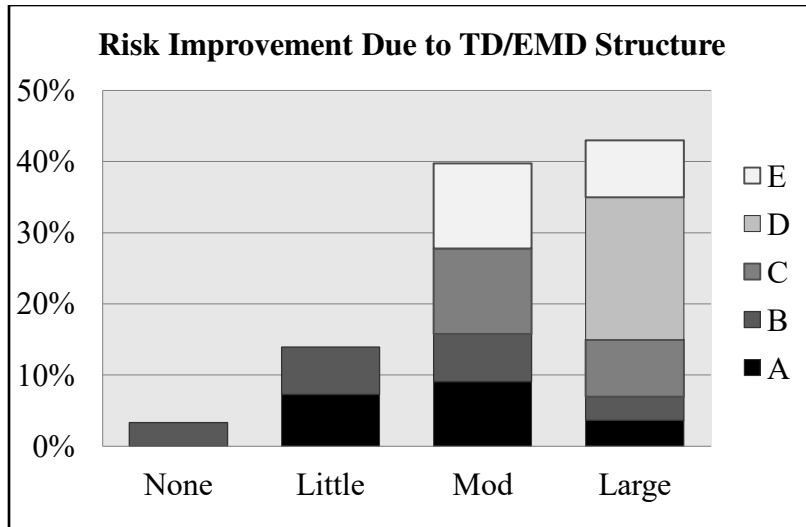
Figure 4.6-16: Overall Program Risk Improvement due to TD/EMD Structure

A strong majority of the surveyed population expressed that the new structure provided a moderate (40%) or large (42%) degree of risk improvement for their programs. This result provided perspective when examining the impact of each program element and barriers to program success introduced by the new process. Though the remainder of the survey data indicated that multiple factors contribute to risk in both positive and negative ways, the overall opinion among contractor participants was that the changes benefited these programs to a substantial degree.

4.6.5 Survey Results Summary

H_1 and H_3 were supported by at strong correlations among the related independent and dependent variables. H_2 was moderately supported. The proposed barriers to success were all supported by the survey results with the exception of Process Misalignment. A summary of the survey findings are presented in Table 4.6-13.

Table 4.6-13. Summary of Survey Findings

Measured Factor	Survey Result
Early Systems Engineering	• Strongly correlated with Development Knowledge • Perceived to have positive impact on risk
Maturity Verification	• Very strongly correlated to Requirements Validation • Moderately correlated to Implementation Knowledge
Modular Open Systems Approach	• Strong correlation with Integration & Sustainment Knowledge • Indirectly improved Manufacturing Readiness
Lack of Communication	• Government-to-Contractor communication significantly reduced by competitive environment • Contractor-to-Government communication also affected
Prototype Focus	• Purpose of prototype not clear on all programs • All prototypes highly representative of final design • Majority of sample cited some adverse effect
Requirements Mismanagement	• Requirements not refined with contractor • Requirements not stable between PDR and next phase
Program Gap	• Significant risk added by gaps in program • Some impact felt by all programs
Process Misaligned	• Processes not significantly misaligned • Results relatively consistent across all programs

4.7 Results and Analysis Summary

This chapter presented data from case studies and surveys. It communicated the results of hypothesis testing, examined potential barriers to program success, and identified potential relationships among elements of the acquisition process. Chapter V contains an integrated summary of the findings from multiple research methods and conclusions regarding the proposed enablers and barriers. Chapter V also explores the implications of the study results and provides recommendations for Government and industry to improve program outcomes and suggestions for expansion of this research.

CHAPTER V: CONCLUSIONS AND RECOMMENDATIONS

5.1 <u>Introduction</u>

This chapter provides conclusions based on the research findings and updates to the previously identified constructs and hypotheses based on the study results. This chapter also presents recommended applications of the research and suggestions for future work to expand the research and explore newly identified aspects of the problem.

5.2 <u>Integrated Summary of Findings</u>

Table 5.2-1 presents an integrated summary of the findings from the case studies and the survey data. The table compares the output of the document analyses, interviews, and the qualitative survey questions. The marks in the table cells are interpreted as follows:

- Checkmark (✓): The data source supports the hypothesis or barrier
- Ex-out (✗): The data source does not support the hypothesis or barrier
- Question Mark (?): The data source's support for the hypothesis or barrier is undetermined
- Dash (-): The data source did not address the hypothesis or barrier

The assessment of each of the survey findings represents an analysis of whether the related qualitative question responses were predominately "None"/"Little" or "Moderate"/"Large".

Table 5.2-1. Integrated Findings of the Research Study

Method / Theory	Documents A	Documents B	Interviews A	Interviews B	Interviews Experts	Surveys A	Surveys B	Surveys C	Surveys D	Surveys E	Conclusions	Recommendations
Hypothesized Enablers												
Enabler: Early Systems Engineering	✓	✓	✓	✓	✓	✓	✓	✓	✓	✗	**Accept** as enabler for Development Knowledge	Maintain requirement for reviews prior to Milestone B.
Enabler: Maturity Verification	?	?	✓	✓	✓	✓	?	✓	✓	✓	**Accept** as enabler for Development Knowledge Implementation Knowledge	• Focus prototype on technology and requirements validation. • Establish prototype purpose early.
Enabler: MOSA	✓	✓	✓	✓	✓	✓	✓	✓	✗	✓	**Accept** as enabler for Integration & Sustainment Knowledge	Emphasize MOSA on programs and establish verification criteria.
Potential Barriers												
Barrier: Lack of Communication	-	-	✓	✓	✓	✓	✓	✓	✓	✗	**Accept** as barrier to Development Knowledge	Implement processes for effective communication at program start.
Barrier: Prototype Focus	-	-	✓	✓	✓	✓	✓	✗	✓	✗	**Accept** as barrier to Development Knowledge	• Align effort to technology risk. • Limit use of performance test results in source selection decisions.
Barrier: Requirements Mismanagement	-	-	✓	✓	✓	✓	✓	✓	✓	✓	**Accept** as barrier to Development Knowledge	• Refine requirements during Technology Development • Maintain stable baselines after PDR
Barrier: Program Gap	-	-	✓	✓	✓	✓	✓	✓	✓	✓	**Accept** as barrier to Program Schedule	Identify value-added scope to sustain teams during transition
Barrier: Process Misalignment	-	-	✓	✗	✓	✗	✗	✗	✗	✗	**Reject** as barrier	Drop barrier from future studies.

The case studies were unable to determine the impact of the Maturity Verification efforts because the prototypes developed during the Technology Development phase were driven by competitive factors rather than Government requirements. The responses to the qualitative question regarding the impact of prototyping on Program B were sufficiently diffuse as to preclude determination of the effect of Maturity Verification as an enabler on that program.

Program A was determined to have been impacted adversely by prototype focus despite the lack of responses to the direct question in the "Moderate" or "Large" categories, because most of the respondents misunderstood or were improperly informed of the purpose of the prototyping scope in the Technology Demonstration phase.

While the interviews for Program A suggested a negative impact due to Process Misalignment, the primary source of information that supported the existence of that potential barrier was the cross-case experts. Misalignment of the Government and contractors was not identified as a significant impediment to program success by any other sources, including the survey responses from Program A.

The alignment of the survey data from Programs A and B with the case study data indicate that the instruments were properly developed to find convergent evidence among sources. Though there is natural variation among the programs with regard to the concepts under investigation, Program E appears to diverge from the remainder of the program set. This difference could be a result of the nature of the system under

development, the Government program team, the culture of the business unit, or a combination of these factors which were not included in the research scope.

The primary data supporting the decision to reject or not reject the research hypotheses were measured correlations among the associated measures. A summary of the quantitative hypothesis testing results is presented in Table 5.2-2.

Table 5.2-2. Correlations among Operationalized Measures Related to Hypotheses

Hypothesis	Strong Correlations ($\tau \geq 0.30$)	Moderate Correlations ($0.30 > \tau \geq 0.25$)	Weak Correlations ($0.25 > \tau \geq 0.20$)	Insignificant Correlations ($\tau < 0.20$)
H_1	3	0	1	0
H_2	1	3	0	0
H_3	3	0	0	1

H_1 and H_3 were each supported by three strong positive correlations among the associated operationalized measures. H_2 was only supported by a single strong correlation between variables related to the hypothesis (Prototype Requirements and Manufacturing Readiness), however the remaining three correlations were all moderately positive. Only one correlation (Open Systems Requirements and Non-Developmental Items) was found to be insignificant. The following sections present the conclusions and recommendations resulting from these findings.

5.3 <u>Conclusions</u>

This section presents the research conclusions regarding the three hypotheses and the five potential barriers to program success identified by the case studies.

5.3.1 Conclusions Regarding Hypotheses

The hypotheses were evaluated based primarily on the levels of correlations among the associated operationalized measures. A majority of the correlations had to be strongly positive to be considered as sufficiently supporting the hypothesis as tested.

5.3.1.1 Hypothesis 1 (Supported)

The hypothesis that application of Early Systems Engineering would improve the levels of Development Knowledge on defense acquisition programs was supported by the study evidence. This decision was derived from the case study results and the fact that three out of the four correlations among the independent and dependent variables were strongly positive. Additionally, the remaining correlation (Review Execution and Requirements Stability) was found to be weakly positive. These relationships indicate that execution of systems engineering reviews prior to Milestone B reduces the risk to the program during implementation of the system design. This conclusion is supported by the qualitative assessment of program personnel that holding a Preliminary Design Review during the Technology Development phase improved the risk position of the program at Milestone B.

5.3.1.2 Hypothesis 2 (Not Sufficiently Supported)

The hypothesis that verification of design maturity through prototyping and maturity assessments would improve Implementation Knowledge regarding the system design was not supported by sufficient evidence. This conclusion was a result of the ambiguity of the case study results with regard to this relationship and because only

one of the potential correlations among the associated independent and dependent

operationalized measures (Prototype Requirements and Manufacturing Readiness) was

found to be strongly positive. However, the three other relationships among the

variable were found to be moderately positive, suggesting that there was likely a

similar relationship among the constructs that could be determined by a modified

research process. Despite the insufficient level of support for H_2, Maturity Verification

is accepted as an enabler to program success. The conclusion that there is a valid

relationship between Maturity Verification and risk to the implementation of the

design is supported by the qualitative assessment of program respondents that

prototyping provided a "Moderate" to "Large" improvement in the level of risk after

Milestone B.

5.3.1.3 *Hypothesis 3 (Supported)*

The hypothesis that implementation of a Modular Open Systems Approach would

improve the levels of Integration and Sustainment Knowledge on defense acquisition

programs was supported by the case studies and three out of the four correlations

among the independent and dependent variables were strongly positive. These

relationships indicated that levying requirements related to component reuse,

application of interface standards, and assessments of system openness prior to

Milestone B reduced the risk to the program during integration of the system and

improves long-term supportability. This conclusion was marginally supported by the

qualitative assessment of program personnel that Modular Open Systems Approach

scope executed during the Technology Development phase resulted in "Little" to "Moderate" improvement in the risk position of the program at Milestone B.

5.3.2 Conclusions Regarding Barriers to Success

This section provides conclusions regarding the validity of the potential barriers to program success identified during the case study interviews. The conclusions of this section are solely based on the results of the multi-program survey.

5.3.2.1 Government / Contractor Communication

The data shows that the free flow of information between the Government and contractor organizations during the Technology Development phase was inhibited by execution of the programs in competitive environments. The Government appeared to be more prone to withholding information than vendors, but as the survey sample included only contractor personnel, that could be a result of population bias.

This finding confirms that the Government limited communication due to competitive factors, but did not provide specific facets of the competition that inhibited the flow of information or specific types of information that were withheld. Interviews conducted during the case studies indicated that the prevalence of a concern among Government personnel that a protest of the eventual Engineering and Manufacturing Development phase contract would result from directing the contractors' work or inadvertent release of sensitive information. This explanation for the lack of communication from the Government was echoed in the free-response question data for Programs A and B. A

member of Program B provided the following suggestion for how the Government could have improved the outcome of the Technology Development phase:

"Better communication - they seemed worried more about being the one to cause a protest then to work toward a common solution. Definitely did not treat contractor as a team player."

The avoidance of protests was not cited, however, as C, D, or E. The lack of corroboration from the programs not included in the case studies may indicate that concern about protests was isolated to programs A and B, or that it was more pronounced on Programs A and B than other issues.

The case-study interviews also indicated that contractor-to-Government communication might be inhibited by a desire to limit negative information presented to the Government that might have impacted the later competition for the Engineering & Manufacturing Development phase. Although attempts to limit the exposure of negative information were the simplest explanation, no data were found in the survey free-response items to determine the specific cause of this lack of communication.

5.3.2.2 *Requirements Mismanagement*

The case studies and surveys both supported the confirmation of requirements mismanagement as a barrier to successful program execution. The majority of the programs experienced reluctance on the part of the Government to modify requirements during the Technology Development phase, followed by significant changes to the requirements after the establishment of the system allocated baseline at

the Preliminary Design Review. This sequence of events significantly reduced the level of Development Knowledge gained in the Technology Development phase by introducing requirements that were not fully understood by the contractor nor incorporated into the system baseline. Therefore, the impacts of these requirements could not be known until the requirement changes are traced to the system element definitions and the designs are updated.

There are two potential rationales for the resistance to contract changes during the Technology Demonstration phase. First, the competitive environment obstructed both open communication and contract actions due to the duplication of work and the desire to avoid the appearance of favoritism. These barriers are compounded by the fact that changes to requirements during a contract will often trigger an increase in cost commensurate with the size of the changes. The Government avoided these costs by introducing changes as part of a competitive Request for Proposals that would provide maximum incentive for the contractors to absorb the cost of the changes into their bids for the next phase.

The second rationale is that the Government initially produced a high-quality specification that was well traced to operational capabilities and that there was no need for significant changes to the allocated baseline. If this explanation is correct, it would be expected that the stability of the system-level requirements set would continue after the end of the Technology Development phase. However, significant changes did occur after establishment of the allocated system baseline and prior to the beginning of the Engineering & Manufacturing Development phase.

This result, coupled with the lack of accepted contractor-proposed changes during the Technology Development phase suggested that the specifications required significant refinement, but the Government did not make the necessary changes until the competition for the next phase began. The Government's behavior on these programs aligned with the results of the case studies that prompted inclusion of these questions. In addition, the observed correlation between Review Execution and Requirements Stability was significantly lower than the relationships among the other variables related to H_1. This indicated that execution of the reviews during the Technology Development phase did not have the intended positive impact, likely because the Government was permitted to significantly modify the requirements set as part of the competition for the next program phase.

5.3.2.3 *Prototype Focus*

The case studies and survey results indicated that there was excessive focus placed on system prototypes during the execution of most of the programs. This confirms the existence of this barrier to success of acquisition programs introduced by the new process. Misplaced focus can impede program success because limited resources spent on the prototype are not available for maturing the intended production design. This situation is compounded when the program views the execution of prototyping activities to support selection of the contractor for the next phase. As securing contracts for production of the system is the primary objective of the contractor, the prototype becomes the top priority of the program at the expense of the design of the system that will eventually be fielded.

On both of the case study programs, success in prototype testing was seen as a major factor in the competition for the Engineering & Manufacturing Development phase, which might explain why the concentration on this area existed to the detriment of the tactical system design. Part of the desire for the prototype to be representative of the final system design appeared to stem from a fundamental misunderstanding on the part of the contractor personnel in both programs regarding the Government's process for assessing technology maturity. The unproven technologies, not the integration of components with understood technology, are what must be demonstrated. In reviews on the programs, all components were assigned Technology Readiness Levels, but only critical technology elements are designated with Technology Readiness Levels in the Government's assessment process (TRA Deskbook, 2010). There was a general belief that the prototype must be representative of the final design which was driven by previous programs that included prototype evaluations and the strategy of demonstrating a low-risk production-ready solution to position the program for the Engineering & Manufacturing Development competition.

In this situation, the prototype design becomes an anchor point and design changes can be perceived as a weakness in the competition for the next phase, both internally and externally to the contractor organization. Because prototypes by definition are not required to meet all of the system requirements, use of the prototype design as a technical baseline is inadvisable and could cause the ability of the system design to perform the mission in operational environments to become suspect. The resulting lack of knowledge regarding the system significantly increases risk for the next phase.

5.3.2.4 <u>Program Gaps</u>

The existence of a gap between the Technology Development and Engineering & Manufacturing Development phases of the program was found to significantly increase risk levels on all of the programs studied, leading to the conclusion that these gaps are valid barriers to successful program execution. The gaps disrupted the continuity of effort from one phase to the next, sapping the program of the momentum gained during the execution of the Technology Development phase. The primary risk to the program appeared to be the fielding of the system within the timeline established at the outset of the program.

Some of the immediate effects of this barrier were identified by a member of Program E in response to one of the free-response questions:

"By letting the program go stale between TD and EMD, technology gets old, staffing turns over, and the program becomes more subject to turmoil in the federal budget. At best, the final system delivery to the warfighter gets delayed. At worst, the EMD phase doesn't happen and the TD money is wasted."

The primary driver of risk surrounding the gaps between program phases was the lack of the Government's ability to predict the length of the gap. In response to this uncertainty, contractors were forced to either maintain the program team indefinitely without assurance that there would be a contract awarded in the near future, or disband the team to work on other efforts. Upon award of the next contract, if the vendor even wins the competition, a program team must be reassembled. This team might

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experienced substantial turnover from the Technology Development team and would likely include many new team members due to the larger size of Engineering & Manufacturing Development phase contracts. The imposition of learning curves resulting from the gap in execution could severely impact the efficiency of the program, even for those that worked on the Technology Development phase and must refamiliarize themselves with the development effort.

5.3.2.5 *Government / Contractor Process Misalignment*

The contractors' processes are designed to facilitate success within the Government process. Therefore, it is natural to assume that major sudden modifications to the Government process would cause difficulty for the execution of the contractor processes on programs. Neither the case study of Program B nor the survey data revealed a substantial concern among contractor personnel that the development processes of the organizations were misaligned.

As the inclusion of the question was primarily driven by one of the Systems Engineering experts, the lack of concern among working-level personnel might indicate that the effects at the program level are less pronounced. If there were a barrier to program success that was primarily visible at higher levels, it would be more likely to be reported to management and addressed than if the barrier only manifested at the internal program level. Additionally, it is possible that the two processes were aligned overall, but that there were specific elements that caused problems. This analysis leads to the conclusion that the misalignment of contractor and Government processes was not a major impediment to the execution of the Technology

Development programs, though individual components of the process might have disrupted program execution to some degree.

5.4 Updated Research Model

As a result of the conclusions regarding the enablers and barriers, the research model was updated to support future studies. The revised model is presented in Figure 5.4-1.
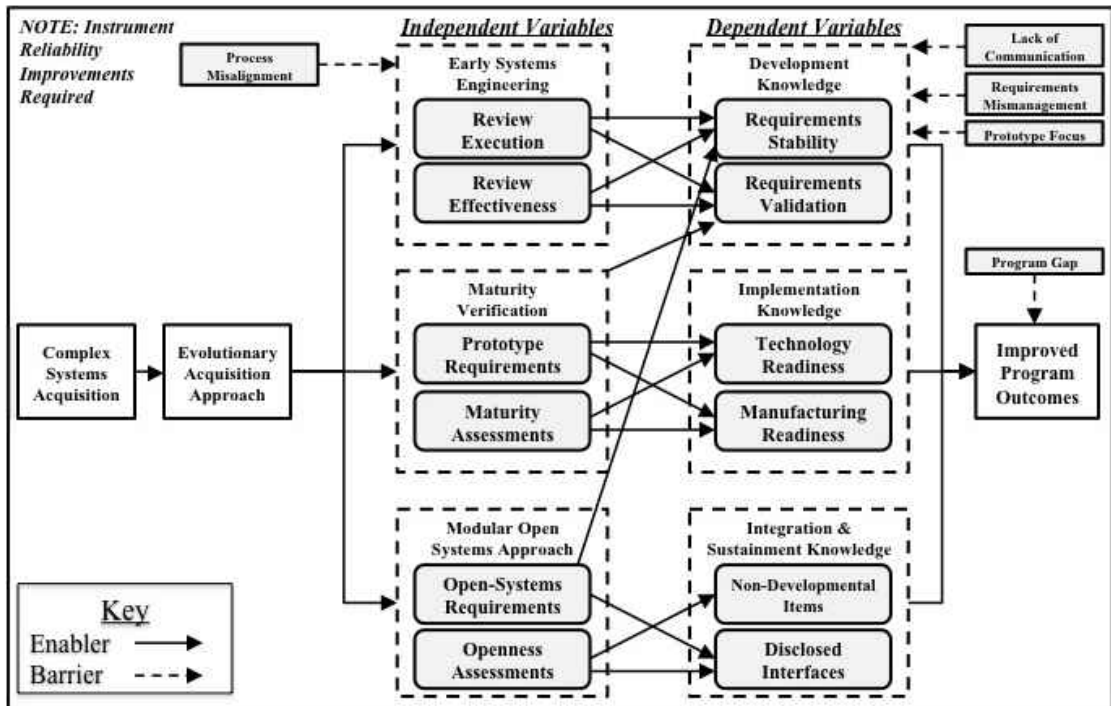
Figure 5.4-1: Updated Research Model Based on Conclusions

The model has been respecified with the hypothesized relationships at the level of interactions among operational measures. New hypotheses have been added to account for the observed associations between Maturity Verification and Requirements Validation and the negative correlation between Open-Systems Requirements and Requirements Stability. The four barriers confirmed by the study have also been added to the model and associated with the construct that they most appear to effect.

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5.5 <u>Recommendations</u>

In response to the research conclusions, recommendations were developed for incorporation of the findings into program execution and future research.

5.5.1 Recommendations to Improve Program Outcomes

Based on the findings of this study, it is recommended that both the Government and defense industry vendors modify their planning processes and approaches to program execution adapt to the new environment. The goal of these recommendations is to provide guidance to programs that leads to improved program outcomes within the structure of the revised acquisition framework.

5.5.1.1 <u>Recommendations to the Government</u>

It is recommended that the Government take action to implement the following recommendations. Each of these recommendations is a result of the research findings and is intend to improve the execution and outcomes of acquisition programs.

5.5.1.1.1 Communication with Contractors

The Government should take action to increase the level of communication with contractors before and during the Technology Development phase of programs. This requires the Government to perform more planning activities for the Technology Development phase prior to release of a request for proposals and to clearly identify the goals of the program to contractors during pre-bid discussions. This information will allow contractors to identify alternative activities that may require less time and funds to complete while achieving the same objectives. For example, clear

identification of the expectations and intended role of prototypes and their effect on source selection for Engineering & Manufacturing Development might cause the contractor to focus on the critical factors for the program rather than implementing strategies that mighty not align to customer objectives. Processes that encourage effective communication between the Government and contractors must be implemented at the Technology Development phase contract award and followed throughout the competitive stages of the program.

5.5.1.1.2 Prototype Testing and Source Selection

It is also recommended that the Government preclude the use of prototype test data as a primary factor in source selection for development and production contracts. While it is valid to use the results of technology maturation activities to determine risk levels related to specific approaches, prototype performance testing during a Technology Development phase is likely to provide a severely limited data set on which to base a competition. Reliance on a small set of data does not ensure a robust system will be produced in the end and might in fact negate the risk reduced by prototype development in the first place. Additionally, building a small number of prototypes in a few months is not representative of a firm's ability to deliver and support large production runs. Use of prototype testing in source selection encourages contractors to focus on prototype representativeness and performance at the expense of requirements development and design maturity prior to and during the Technology Development phase.

5.5.1.1.3 Requirements Management

The Government is also recommended to implement improvements to the process for modification of requirements in a competitive environment. For requirements that have not been previously validated by pre-contract testing or are not critical to the operational value of the system to the warfighter, objective and threshold values should be established to allow contractors to independently make cost/benefit trades during the system design. If substantial changes to the requirements are identified during the Technology Development phase, they should be implemented on the program prior to the Preliminary Design Review. If major changes are identified as a result of issues discovered at the Preliminary Design Review, then the review should not be closed until the issues are resolved.

5.5.1.1.4 Program Gaps

The Government should also acknowledge the realistic possibility and impacts of a gap between Technology Development and Engineering & Manufacturing Development phases prior to the start of the program. Steps to mitigate the effects should include working with contractors to ensure that the Engineering & Manufacturing Development phase is minimally impacted by the existence of the gap. The suggested tactic is to identify value-added scope to be performed by each team and appropriate funding levels based on team size. For instance, studies could be conducted regarding future increments as part of these activities which would allow for advancement of DoD evolutionary acquisition goals by performing requirements

analysis activities to support an Analysis of Alternatives study for the next system increment.

5.5.1.2 *Recommendations to Defense Contractors*

The following recommendations are presented for defense contractors to implement in the interest of improving program outcomes.

5.5.1.2.1 *Reduced Level of Focus on Prototypes*

Contractors must ensure that prototypes are designed primarily to meet the needs of the Technology Development phase, not what is believed to be the full system production design prior to thorough requirements analyses and design trade-offs. A prototype design that is intended to represent the production version of the system has the potential to become an anchor point in the design process from which the contractor would be discouraged to stray for fear that the advantage gained by such a mature design be eroded. Development of production-representative prototypes early in the program requires significantly more contractor investment prior to the Technology Development phase than integration of off-the-shelf components with novel critical technology elements. Additionally, because prototype development must start prior to the Technology Development phase in order to support delivery and test, the prototype design does not benefit from requirements refinement and knowledge gained during the Technology Development phase. Use of the prototype as a baseline therefore inhibits the production design from receiving these benefits as well.

5.5.1.2.2 Presentation of Requirements Trade-offs

Contractors should be more forward in presenting requirements trades at Preliminary Design Reviews or earlier events to identify cost and schedule drivers and show the Government how it can reduce program risk in future phases. The fact that the requirements included in system specifications prior to Milestone B often are not yet validated requires that the parties involved determine where the requirements need to be tailored to be implementable within cost and schedule constraints. Contractors should not interpret requests to modify requirements as an inability to meet requirements or a weakness in design acumen. Instead, requested requirements changes that provide the opportunity to reduce costs or accelerate schedules without sacrificing significant operational capability should be pursued throughout the system development process.

5.5.1.2.3 Gap Planning

Contractors should identify independently funded activities to be executed during program gaps to maintain the momentum gained during the Technology Development phase. These activities could include risk management and mitigation efforts for the next phase, studies of capabilities that could be implemented in future system increments, and pursuit of other programs that would benefit from similar technology. Additionally, contractors should assign personnel critical to the effort to adjacent efforts, ensuring that critical knowledge is available at the beginning of the next phase. In all cases, the activities should be planned in such a way as to provide value to the

contractor if not awarded a contract for the Engineering and Manufacturing
Development phase.

5.5.2 Recommendations to Improve Research Methodology

Analysis of the survey results found the concept model to be specified at the incorrect
level. The model should be modified to reflect the existence of the constructs at a
lower level and to signify the potential existence of additional relationships among the
variables. H_1 and H_3 should continue to be tested as currently proposed with
modifications to the survey instrument to improve reliability. The questions used to
assess all of the operationalized measures except for Requirements Validation,
Manufacturing Readiness, Openness Assessment, and Disclosed Interfaces should be
refined to improve the reliability of the instruments. H_2 should also be reassessed and
updated to incorporate Requirements Validation as a dependent variable.

5.5.3 Recommendations for Future Research

It is recommended that this research be extended to confirm or disprove the findings
via new sources of evidence. It is especially important that theory-building research
studies such as this be followed by additional inquiries to test the results. The
following sections identify suggestions for future work in this topic area.

5.5.3.1 <u>Additional Programs</u>

One of the simplest ways to extend the research would be to execute additional case
studies and surveys using the same methodologies and instruments to increase the size
of the research sample. In order to improve the applicability of the research, it is

recommended that the methodology be applied to a larger and more diverse set of programs as data becomes available. This includes programs currently in the planning stages as well as those that were not available to the researcher. Additionally, cases under the new process may be compared to previous cases or those that have received waivers for the new regulations. While this research used historical data and trends identified in the literature to establish "control" cases, side-by-side comparisons between similar systems development efforts governed by the old and new processes could provide further insight into the impacts of process changes at a deeper level.

This research was conducted primarily with regard to the opinions and perspectives of defense contractor organizations. It would be beneficial to complete similar studies on programs executed by different companies to determine the influence corporate culture. Future studies could also be executed within a Government organization and with data primarily gathered from Government personnel to assess the impacts of the constructs from the acquiring organization's point of view.

5.5.3.2 *Long-term Case Studies*

Unlike this study which sought to examine programs at a specific point in time, longitudinal case studies provide the capability to determine how cases evolve and adapt to circumstances over time. Long-term case studies could be conducted to assess the impact of the acquisition process modifications throughout the lifecycle of the system under development. Such a study would start prior to Milestone A and conclude during the operations and support phase to assess whether the program

experienced improved execution with regard to cost, schedule, and technical performance.

5.5.3.3 *Additional Program Types*

This research focused on major programs of a manageable size due to resource restrictions. To expand the research, additional program types may be examined to determine if the constructs and relationships maintain their validity outside of the structure of major DoD programs. Large-scale future programs such as the Next Generation Bomber, Next Generation Fighter, Joint Multirole Helicopter, Joint Future Theatre Lift Helicopter, future Ballistic Missile Defense systems, and naval ship-building programs should be assessed to better understand the dynamics of the new regulations within this class of program.

Acquisition Category II and III programs are not required to follow the same process. Studies of that class of program could be executed to determine to what degree, if any, that the new process requirements would benefit less complex systems. While it is unlikely that implementation of the entire process would provide benefit because of overhead costs, some aspects of the process may be worth applying to smaller programs.

5.5.3.4 *Effect of the Managing Service*

 Customer processes vary among services and even among program offices within a service. Different Government branches of the military stress different aspects of systems and have diverse levels of risk tolerance. This research collected data from at

least one program from each of the Army, Navy, and Air Force, however, service-specific factors were not addressed. Case studies that expressly analyze the differences among the services with regard to their acquisition processes and outcomes could facilitate better alignment of the individual methods, improving the ability of contractors to work effectively with multiple services and the efficiency of joint programs.

5.5.3.5 *Programs Managed by Other Agencies*

This study was limited to programs managed by the DoD, however other Government agencies face similar challenges with regard to system acquisition. Comparisons of DoD programs executed under the new process to programs administered by agencies such as NASA, the Missile Defense Agency, intelligence agencies, law enforcement agencies, and The Department of Homeland Security could be helpful in improving their acquisition processes as well. High-profile international programs could also be studied to determine the presence and relationships of the constructs in different Governmental structures and cultures. Programs such as these can be studied to identify the prominence and relationships among the constructs in the foreign defense market.

5.5.3.6 *Focus Studies on Specific Program Elements*

Studies focusing on the specific hypotheses and barriers should be conducted to understand these elements at a deeper level. In particularly, the effects of competitive environments on communication and investigations into the roles and benefits of

prototyping during Technology Development phases would be particularly useful to both Government and industry.

5.5.3.7 *Effect of TD Scope and Performance on Source Selection Decision*

Inclusion of the factors in source selection decision-making process including emphasis of factors in proposals and use of data gathered during the Technology Development program. Such a study would require insight into multiple contractor teams and would be best executed by Government personnel with access to all of the relevant data. Additionally, the nature and factors included in Government proposal requests may be impacted by this new process and should be considered.

5.6 Research Summary

The goal of this research was to identify and explore the components of the DoD acquisition process execution that are critical to the success of individual programs as well as the Department as a whole. The research included a review of the relevant literature from academic, Government, and industry sources that identified three primary factors of the revised acquisition process that are purported to improve program knowledge at key decision points: Early Systems Engineering, Maturity Verification, and a Modular Open Systems Approach. The presence and impact of these factors was examined in two case studies of Major Defense Acquisition Programs and a survey of five acquisition programs.

The case studies, which included documentation analysis and interviews, demonstrated that the constructs identified in the conceptual model and the

hypothesized relationships among them were valid for the sample data set. The case studies also identified five potential barriers to program success that were to be examined in the second phase of the study: lack of open communication due to competition, requirements mismanagement, excessive prototype focus, gaps between program phases, and misalignment between contractor and Government development processes.

The goal of the survey phase was to obtain a larger population sample and determine the generalizability of the case study findings. Statistical testing indicated that two of the three hypotheses were supported by of the survey data from five programs. The remaining hypothesis was only partially supported by the data. Direct questions regarding the independent constructs and program risk levels supported these conclusions. Additionally, four of the five barriers to program success were confirmed to exist on the majority of the programs studied. It is recommended that the DoD and industry incorporate these findings into their system development processes to increase the efficiency of the acquisition system and improve program-level and enterprise-level outcomes. The results of this study should be confirmed by examination of a larger and more diverse set of programs to increase the generalizability of the results.

APPENDIX A: DOCUMENT ANALYSIS FOR CASE A

Construct	Operational Measure	QID	Document Review Question	Rating (1-4)	Evidence
Early Systems Engineering	Review Execution	1	Assessment of program status during Systems Engineering Reviews risk-based.	2	Risk management section included in PDR. Most other sections did not tie to risk. Minutes identify risks not in register. Action-items rarely tied to risk (PDR)
		2	Budget and schedule impacts of system design examined during Systems Engineering Reviews.	2	TD phase budget discussed, but EMD budget and schedule detail TBD. No CAIV/SAIV presented to tie requirements or scope to budget & schedule. Overall program schedule, including EMD and production, presented by Govt (PDR)
		3	Systems Engineering Reviews focused on requirements rather than implementation details.	3	Reviews focused on requirements and architecture, respectively (SRR & SFR) Requirements referenced in slides on design. Requirements management section presented. Minutes and action items focused on solution details rather than requirements feasibility and impact. (PDR)
		4	Appropriate Systems Engineering Reviews held during the Technology Demonstration phase.	4	SRR, SFR, PDR, and a prototype-focused TRR held during TD phase (SOW, SEMP, PDR)
	Review Effectiveness	5	Risks identified and documented as part of the System Engineering Review process.	1	No actions from PDR to include new risks on program register despite reference to risks in minutes. (PDR)
		6	Open requirements issues resolved at Systems Engineering Reviews.	2	One "TBD" included in allocated baseline at PDR. Not significant source of risk. Multiple requirements presented that conflict and open requests for change were present (PDR).
		7	Appropriate baselines established at the conclusions of Systems Engineering Reviews.	2	Requirements documents under contractor configuration control, but not approved by Government. (PDR)
		8	Subject matter experts from appropriate disciplines involved in Systems Engineering Reviews.	4	Subject Matter Experts and stakeholders in attendance covered entire system footprint and life-cycle. (PDR)

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Construct	Operational Measure	QID	Document Review Question	Rating (1-4)	Evidence
Development Knowledge	Requirements Stability	9	Requirements sufficiently refined and clarified during Technology Development phase.	2	Minor requirements changed during TD. Multiple requests for changes/clarification of requirements rejected by Government. Some unverifiable/ambiguous requirements related to MOSA deleted (SRR, SFR, PDR, Spec)
		10	System requirements were unchanged between the Preliminary Design Review and Milestone B consistent.	1	Significant new functionality added along with new interfaces. Performance requirements were modified. While some were relaxed, the net effect was a significant increase in system development risk (Spec)
		11	Disposition of optional requirements and capabilities determined.	1	Optional capability not resolved during TD phase that depended on CTE Deferred to proposal and Milestone B decision (Spec)
		12	"TBD/TBR/TBS" requirements resolved during the Technology Development phase.	3	TBD's, primarily in Interface requirements, resolved during TD phase through contractor/Govt interaction (PDR)
	Requirements Validation	13	The system-level requirements set is consistent and complete.	2	Multiple ambiguous requirements identified, including key performance capabilities. Requirements lack specificity and are not well aligned with environments. (PDR)
		14	Verification criteria for requirements established.	2	Most test & verification activity focused on prototype (SOW). Requirements verification nominally addressed at PDR. Significant questions related to verification methods remain including environments & objective measures of performance. (PDR)
		15	The system can be delivered within the program budget and schedule.	1	Feasibility of schedule not addressed during TD other than acknowledgement that schedule is extremely challenging and optimistic. Budget for EMD/Production not established during TD phase (PDR).
		16	An achievable system architecture that satisfies requirements developed and documented.	4	Architecture presented tied to functions and designs presented. Architecture appears to be well aligned to required capabilities and available technology and components. (SFR, PDR)

Construct	Operational Measure	QID	Document Review Question	Rating (1-4)	Evidence
Maturity Verification	Prototype Requirements	17	Prototype requirements focus on areas of substantial risk.	3	Prototype requirements marked as subset of system-level specification CTE addressed by prototype requirements. (Spec). System integration not addressed by
		18	Prototype performance and functional requirements align with system requirements.	3	Functional and performance requirements essentially only requirements applied to system. Performance to operational levels are required, however real-time performance during prototype test activities is not required. (Spec)
		19	Prototype requirements address size, weight, and power aspects of system.	1	No size, weight, or power requirements for prototype hardware included in Government prototype specification. (Spec). Size, weight, and power not bounded by Government test parameters. Prototype highly representative of final configuration (PDR).
		20	Manufacturing requirements for prototype align with system requirements.	1	No specific prototype manufacturing requirements present in Statement of Work or Prototype specification. Only applicable requirement pertains to compliance with federal laws, which has no effect on the manufacturing plans or processes (Spec & SOW). MRL required to be demonstrated during TD phase.
	Maturity Assessment	21	Prototype test program addresses Critical Technology Elements vs. previously demonstrated capabilities.	2	CTE is part of test program with multiple tests supporting demonstration. However, multiple tests were conducted to assess non-CTE capabilities and functions. Majority of testing was not focused on CTE maturation (Spec, SOW, PDR)
		22	Prototype requirements compliance formally verified by Government.	3	Acceptance testing conducted in a lab environment by contractor with Government witness prior to delivery of prototypes. Field testing not used for verification of requirements (SOW, Spec) Test-readiness Review held for prototype prior to delivery (SEMP).
		23	Technology Readiness assessment activities required by Government.	4	Formal Technology Readiness Assessment and multiple informal technology maturity self-assessments required (SOW, SEMP). Internal assessment results presented at PDR (PDR, SOW)
		24	Manufacturing Readiness assessment activities required by Government.	4	Formal Manufacturing Readiness Assessment and multiple informal required (SEMP, SOW). MRA and self-assessment results presented at PDR (PDR, SOW)

Construct	Operational Measure	QID	Document Review Question	Rating (1-4)	Evidence
Implementation Knowledge	Technology Readiness	25	All designated Critical Technology Elements sufficiently demonstrated in an operationally representative environment.	3	Critical Technology Elements demonstrated in Government-specified environment during prototype testing. System did not meet performance requirements, but demonstrated system functionality in real-time. Compliant performance demonstrated in high-fidelity simulation using data collected during prototype testing (SOW & PDR)
		26	Critical Technology Elements have been previously used for similar applications.	3	The CTE have been used for related purposes, but not for this specific application. Framework for technology leveraged from previous products (PDR)
		27	Technologies critical to meeting operational requirements have been used in fielded systems.	3	Similar technology used in fielded systems for different purpose. Some components repackaged from operational products. Only unproven technology relates to optional capability (PDR).
		28	Technology Readiness Levels increased to appropriate levels during the Technology Development phase.	4	Government TRA for CTE assessed at level 6 as required by statute. Was TRL 5 prior to TD phase (TRA).
	Manufacturing Readiness	29	Sourcing decisions for system components complete.	4	Make/buy for major components complete. Suppliers identified and engaged in Technology Development phase activities (PDR).
		30	Production environment for the system has been defined.	4	Production environment detailed at PDR. Pilot lines established to support prototype production. (PDR)
		31	System components have been manufactured in a production-representative environment.	4	Prototype systems produced on pilot production lines. Multiple components are commercial-off-the-shelf or modified-off-the-shelf. (PDR)
		32	Manufacturing Readiness Levels increased to appropriate levels during Technology Development phase.	4	MRL as evaluated through joint Government/contractor assessment progressed from 4 (initial assessment) to 6 at the end of the Technology Development phase. (PDR)

Construct	Operational Measure	QID	Document Review Question	Rating (1-4)	Evidence
Modular Open Systems Approach	Open-Systems Requirements	33	Implementation of a Modular Open Systems Approach or equivalent required by the program.	4	MOSA-equivalent explicitly required by SOW and specification. Some language was copied directly from Government MOSA guidance. (Spec & SOW).
		34	The contractor is discouraged from using proprietary interfaces.	3	The contractor was required to identify any proprietary interface implementations and provide justification. Specification required that the system minimize proprietary interfaces. (Spec & SOW)
		35	The system required to use Commercial Off The Shelf/ non-developmental components for non-application-specific functions.	3	Use of Commercial-off-the-shelf and non-developmental components strongly encouraged. Developmental items were required to be identified and justified. Additionally, a plan was required for transitioning to a commercial item. (SOW & Spec)
		36	Verification methods for MOSA requirements sufficiently identified.	3	Verification methods for all requirements are identified by the specification (primarily by analysis), however many of the MOSA-related requirements appear to be ambiguous and do not have associated objective verification criteria. (Spec). MOSA Analysis document required to support requirements verification (SOW).
	Openness Assessments	37	Program used market surveys to determine available off-the-shelf capabilities relative to requirements.	4	Market surveys required by the SOW to be presented at systems engineering reviews. Sufficient justification provided for internal sourcing of non-mission-specific components. (SOW, SRR, & SFR)
		38	Program identified components with a high risk of volatility.	4	Formal Government tool used by program with Government participation to assess component volatility, cost of system modification, and value of increasing openness (SFR).
		39	Business case analysis used to determine application of interface standards and COTS components.	3	Some business case analysis provided for interface and component selection (reference of COTS use). COTS and interface standards so prevalent that extensive justification not necessary. (SFR)
		40	Formal tools and processes used for MOSA evaluations.	4	Openness assessments used multiple MOSA evaluation tools from the Defense Acquisition University website. Such tools were specified by the SOW and results presented at PDR. (SFR & SOW)

Construct	Operational Measure	QID	Document Review Question	Rating (1-4)	Evidence
Integration & Sustainment Knowledge	Non-Developmental Items	41	Previously tested software code is reused from other programs.	3	Extensive leveraging of existing software code proven in other systems. Some software is reused, however most software in system is recoded. (PDR)
		42	Non-application specific functionality is implemented using commercial software elements.	4	Operating environment and software/hardware interfaces make extensive use of COTS and open-source software (PDR).
		43	Non-application specific functionality supported by commercial or non-developmental hardware components.	4	Extensive use of commercial processing resources, memory, and infrastructure. (PDR)
		44	Non-developmental hardware items from other programs are used where feasible.	3	Significant hardware reuse from other programs. Some components repackaged for form/fit. (PDR).
	Disclosed Interfaces	45	System components can be replaced with similar components from competitive sources without impacting system architecture.	3	Extensive use of COTS components and standard interfaces facilitates replacement of components. (PDR)
		46	System components that are most susceptible to obsolescence and upgrades are isolated behind standard interfaces.	4	KOSS analysis identified commercial or open interfaces for all major components with substantial obsolescence or upgrade risk. (SFR & PDR)
		47	Interface protocols allow for long-term growth of system capabilities and resources.	4	Commercial interface supported by commercial market used for majority of interfaces. Spare capacity included in system design. (PDR)
		48	Interface standards employed are well defined and widely used.	4	Interfaces implemented using commercial or open standards with significant market support and documentation. (PDR)

APPENDIX B: DOCUMENT ANALYSIS FOR CASE B

Construct	Measure	QID	Document Review Question	Rating (1-4)	Evidence
Early Systems Engineering	**Review Execution**	1	Assessment of program status during Systems Engineering Reviews risk-based.	**2**	All components "Low risk" regardless of maturity. Risks not tied to design sections. Action items not in risk terms (PDR). Risks managed discretely, not tied to overall program success (SEMP).
		2	Budget and schedule impacts of system design examined during Systems Engineering Reviews.	**1**	TD phase budget discussed, but EMD budget and schedule detail TBD. No CAIV/SAIV presented to tie requirements/scope to budget & schedule (PDR)
		3	Systems Engineering Reviews focused on requirements rather than implementation details.	**4**	Requirements management section presented at PDR. Key performance parameters tied to design. Driving requirements for each component/capability identified. Requirements issues and closure path identified. (PDR)
		4	Appropriate Systems Engineering Reviews held during the Technology Demonstration phase.	**4**	Combined SRR/SFR, System Software Review, multiple subsystem PDRs, system-level PDR (SOW, SEMP)
	Review Effectiveness	5	Risks identified and documented as part of the System Engineering Review process.	**2**	Risk management presented at reviews, but risks not identified during design sections. Risks assessed during review close-out. Risks not added to register as part of SRR/SFR (PDR). Reviews not noted as source of risk identification (SEMP)
		6	Open requirements issues resolved at Systems Engineering Reviews.	**4**	Closure plan for multiple open environmental requirements presented at PDR. Lower-level design requirements also presented with closure path. (PDR)
		7	Appropriate baselines established at the conclusions of Systems Engineering Reviews.	**4**	Requirements and functional baselines presented at SRR/SFR (SRR/SFR). Requirements and functional baselines accepted by Government. Appropriate documentation submitted to Government and under configuration control prior to PDR. Allocated baseline presented at PDR (PDR).
		8	Subject matter experts from appropriate disciplines involved in Systems Engineering Reviews.	**4**	Appropriate SME's from Govt, Contractor, and suppliers present at subsystem PDR's and system-level PDR (PDR)

Construct	Measure	QID	Document Review Question	Rating (1-4)	Evidence
Development Knowledge	**Requirements Stability**	9	Requirements sufficiently refined and clarified during Technology Development phase.	3	Contractor required to evaluate and suggest changes at PDR (SOW). Contractor planned to refine environmental requirements during TD phase (SEMP). Significant number of environmental requirements evaluated and refined, however some remain to be resolved during EMD (PDR)
		10	System requirements were unchanged between the Preliminary Design Review and Milestone B consistent.	2	Clarification of environmental requirements and identification of new platforms included in EMD RFP specification. Did not modify functionality or impact system design (Interview)
		11	Disposition of optional requirements and capabilities determined.	4	No optional requirements identified. Contractor identified objective requirements and whether they would be incorporated in baseline design (Spec & PDR)
		12	"TBD/TBR/TBS" requirements resolved during the Technology Development phase.	4	No TBD's in Govt spec (Spec). Only one open contractor requirement remained at PDR and closure path presented (PDR).
	Requirements Validation	13	The system-level requirements set is consistent and complete.	3	Some environmental requirements not completely defined. EMD testing required to obtain parameters (PDR, Spec)
		14	Verification criteria for requirements established.	3	Extensive verification plans required during Technology Development phase (SOW). Verification matrix presented during reviews (PDR).
		15	The system can be delivered within the program budget and schedule.	2	TD phase to be completed within budget and schedule. Budget and schedule for EMD and production phases, or achievement of IOC not addressed (PDR)
		16	An achievable system architecture that satisfies requirements developed and documented.	4	Architecture presented at PDR linked to driving requirements. Highly representative prototype built and tested (PDR)

Construct	Measure	QID	Document Review Question	Rating (1-4)	Evidence
Maturity Verification	**Prototype Requirements**	17	Prototype requirements focus on areas of substantial risk.	2	No direct prototype requirements. Prototype requirements driven by Government-dictated test scenarios which represent significantly challenging demonstration of capability (SOW).
		18	Prototype performance and functional requirements align with system requirements.	3	Scenarios are representative of mission and demonstrate critical capabilities, but do not include all functions (SOW)
		19	Prototype requirements address size, weight, and power aspects of system.	1	Prototype representative of final configuration. Mechanical design mostly unchanged between prototype and preliminary baseline (PDR). No SWaP requirements directly levied by Government. (Spec & SOW). Test scenarios drive SWaP (SOW)
		20	Manufacturing requirements for prototype align with system requirements.	1	Manufacturing requirements of prototype not addressed by specification or SOW (Spec & SOW).
	Maturity Assessment	21	Prototype test program addresses Critical Technology Elements vs. previously demonstrated capabilities.	4	CTE's focus of Government test requirements. Test scenarios seek to demonstrate CTE-driven functionality in operational environments (SOW)
		22	Prototype requirements compliance formally verified by Government.	4	Acceptance testing conducted in a lab environment by contractor with Government witness prior to delivery. Field testing not used for verification of requirements (SOW, Spec) Test readiness review held by Government. (SOW)
		23	Technology Readiness assessment activities required by Government.	2	Technology readiness of components presented at PDR (PDR). TRA performed by Government (SOW). Program maintained roadmap of technology maturation including events and associated predicted levels (SEMP).
		24	Manufacturing Readiness assessment activities required by Government.	3	Producibility studies required for select components (SOW). Program held design-for-producibility workshop, though not required (PDR). Formal MRL assessment conducted by the Government (SOW).Program maintained roadmap of manufacturing process maturation including events and associated predicted levels (SEMP).

Construct	Measure	QID	Document Review Question	Rating (1-4)	Evidence
Implementation Knowledge	**Technology Readiness**	25	All designated Critical Technology Elements sufficiently demonstrated in an operationally representative environment.	4	Prototypes tested in highly representative mission scenarios with platform integration (SOW). Contractor successfully demonstrated integrated system during testing (Press Release)
		26	Critical Technology Elements have been previously used for similar applications.	3	All CTE's have been fielded in different configurations. Combination of technologies is risk area (PDR)
		27	Technologies critical to meeting operational requirements have been used in fielded systems.	4	System heavily leverages existing designs. New elements are combinations of existing products. Technologies used in fielded designs. (PDR)
		28	Technology Readiness Levels increased to appropriate levels during the Technology Development phase.	3	TRA for only CTE assessed at level 6. Was TRL 5 prior to TD phase (TRA).
	Manufacturing Readiness	29	Sourcing decisions for system components complete.	4	Subcontractors identified at PDR. Sourcing decisions complete for entire system (PDR). Suppliers identified in organizational charts (SEMP)
		30	Production environment for the system has been defined.	4	Manufacturing plan and other production documents complete and provided to Government to support MRA. Prime and subcontractor production lines assessed using modeling and simulation. (PDR)
		31	System components have been manufactured in a production-representative environment.	4	Significant number of off-the-shelf and reused hardware components. Some components modified from existing products and not expected to impact producibility. Very few newly design components. (PDR)
		32	Manufacturing Readiness Levels increased to appropriate levels during Technology Development phase.	4	Most components at least MRL 6 prior to PDR. Path shown to achieve MRL 6 for all components by Milestone B. (PDR)

Construct	Measure	QID	Document Review Question	Rating (1-4)	Evidence
Modular Open Systems Approach	**Open-Systems Requirements**	33	Implementation of a Modular Open Systems Approach or equivalent required by the program.	4	MOSA required along with partitioning of proprietary components (SOW) "Open Systems Architecture" and modularity required in design. Processors required to be upgradeable and replaceable without modification of other components (Spec). Open System Architecture described in SEMP mirrors SOW language with no other mention of MOSA (SEMP)
		34	The contractor is discouraged from using proprietary interfaces.	3	Industry standard interfaces to be used where feasible. (Spec) Open interface standards for reconfiguration and new capabilities required (SOW).
		35	The system required to use Commercial Off The Shelf/ non-developmental components for non-application-specific functions.	3	Computing resources must be designed for modularity and upgradeability (Spec).
		36	Verification methods for MOSA requirements sufficiently identified.	2	All MOSA requirements are non-specific and verified via analysis rather than defined tests (Spec). No details regarding MOSA verification or analysis in SOW (SOW).
	Openness Assessments	37	Program used market surveys to determine available off-the-shelf capabilities relative to requirements.	1	No market surveys required or presented at PDR in support of make/buy or develop/reuse decisions (SOW, PDR)
		38	Program identified components with a high risk of volatility.	1	No requirement for or evidence of volatility assessments to assess upgrade and obsolescence risk (SOW, PDR)
		39	Business case analysis used to determine application of interface standards and COTS components.	1	External interface selection based on legacy platform requirements No business case presented for MOSA implementation (PDR).
		40	Formal tools and processes used for MOSA evaluations.	1	No formal evaluations evident (SEMP, SOW, PDR)

Construct	Measure	QID	Document Review Question	Rating (1-4)	Evidence
Integration & Sustainment Knowledge	**Non-Developmental Items**	41	Previously tested software code is reused from other programs.	3	Significant use of tested software from other programs, both fielded systems and demonstrations (PDR).
		42	Non-application specific functionality is implemented using commercial software elements.	3	Operating system is COTS. Most other software is mission-specific. (PDR)
		43	Non-application specific functionality supported by commercial or non-developmental hardware components.	3	Significant use of COTS processing modules (PDR)
		44	Non-developmental hardware items from other programs are used where feasible.	4	Significant number of non-developmental hardware components used from similar systems. Substantial modified designs also used (PDR).
	Disclosed Interfaces	45	System components can be replaced with similar components from competitive sources without impacting system architecture.	1	Processing resources are COTS and may be replaced. Most other components are tightly coupled and do not support easy upgrade with third-party solutions (PDR).
		46	System components that are most susceptible to obsolescence and upgrades are isolated behind standard interfaces.	2	Very few standard interfaces. Most components communicate in non-standard protocol or through discrete interfaces. (PDR)
		47	Interface protocols allow for long-term growth of system capabilities and resources.	2	Growth interface based on standards, however most other interfaces are discrete lines or primitive serial protocols with little growth capability (PDR).
		48	Interface standards employed are well defined and widely used.	2	Legacy external interfaces are well defined, but only used on similar platforms. Some internal interfaces are based on standards, but many are not. (PDR)

APPENDIX C: INTERVIEW DATA COLLECTION INSTRUMENT

Case _____ Subject_____ Date_____ Time: _____

How would you characterize your role on the TD program?

How long have you been working in the field of national defense and what roles have you performed?

How did the new TD/EMD structure affect the planning and execution of the program?

How did the scope of the TD program impact the risk position of the Government with regard to completing the acquisition of this system on-time and within budget?

How did completion of systems engineering reviews (e.g., PDR) during the TD phase impact the risk position of the program for EMD and later phases?

How did prototype development and testing during the TD phase impact the risk position of the program for EMD and later phases?

How did the execution of Modular Open Systems scope during the TD phase impact the risk position of the program for EMD and later phases?

What additional actions could the Government have taken during the TD phase to improve the risk position of the program for EMD and later phases?

What additional actions could the contractor have taken during the TD phase to improve the risk position of the program for EMD and later phases?

Is there anything else you would like to add regarding the acquisition process or program execution that might benefit this research?

NOTES

APPENDIX D: SURVEY INSTRUMENT

Potential Respondent:

You are invited to participate in a research survey to assess the impact of changes to the Defense Acquisition System at the program level. Your participation is voluntary and you will incur no material benefit, penalty, or risk whether you agree or decline to participate. It is anticipated that the survey will take approximately 30 minutes complete. This study is conducted by Brig Bjorn as part of doctoral research in the Department of Industrial Engineering and Management Systems at the University of Central Florida. The supervising faculty member for this research is Dr. Timothy Kotnour.

This questionnaire seeks to determine the impact of activities conducted during the Technology Development phase of the program on the levels of knowledge and risk during the Engineering & Manufacturing Development, production, deployment, and operational phases of the program. The survey is divided into the following segments:

I. Role, Experience, and Program Information
II. System Engineering Reviews and System Requirements
III. System Prototyping and Product Maturity
IV. Modular Open Systems Approach, Standards, and Non-Developmental Items
V. General Acquisition Process Modification Impacts

Please answer the questions openly and honestly in terms of the program risk position at the end of the Technology Development phase. The questions are not intended to assess the Government source selection process or decisions and it is requested that your answer not include information related to source selection. If you do not wish to provide a response to any question or are unsure of your answer, please leave it blank. Data gathered will be aggregated prior to presentation and any quotes from free-response questions used in the published results will be reported without attribution. The study results will be reviewed prior the publication to ensure that they contain no proprietary or personally identifiable information.

Research at the University of Central Florida is carried out under the oversight of the Institutional Review Board. Questions or concerns about research participants' rights may be directed to the UCF IRB office:
Phone: (407) 882-2276 or (407) 823-2901
Mail: University of Central Florida, Office of Research & Commercialization, 12201 Research Parkway, Suite 501,
Orlando, FL 32826-3246.

If you have any questions, concerns, or complaints about this survey or if you wish to withdraw your participation after submission of the survey, please contact Brig Bjorn (BrigBjorn@knights.ucf.edu) or Dr. Timothy Kotnour (Timothy.Kotnour@ucf.edu).

By clicking on the button below, you are granting consent to the collection and reporting of the data provided in accordance with above conditions

Thank you for your consideration,

Brig Bjorn
Principal Investigator

Please provide responses for the program in which you have participated that best fits the following criteria:
- Designated as a Major Defense Acquisition Program to develop a tactical system
- The Government acquisition strategy includes a multi-vendor Technology Development contract followed by a single-vendor Engineering & Manufacturing Development contract
- The Technology Development phase includes competitive prototyping
- The program Preliminary Design Review was held or is scheduled to be held prior to the end of the Technology
Development phase

1. **What type of system is under development?**
❍ Aerospace Vehicle
❍ Land or Amphibious Vehicle
❍ Maritime Vehicle
❍ Communications
❍ Munition
❍ Sensor
❍ Radar
❍ If other, please specify

_____

2. **Which service is managing the procurement of this system?**
❍ Air Force
❍ Army
❍ Navy
❍ If other, please specify

_____

3. **What is the Acquisition Category (ACAT) designation for the program?**
❍ ACAT I
❍ ACAT II
❍ ACAT III
❍ Don't Know

4. **What is the current program acquisition phase?**
❍ Pre-Milestone A
❍ Technology Development (TD)
❍ Pre-Milestone B (between TD and EMD)
❍ Engineering & Manufacturing Development (EMD)
❍ Production

5. **What Systems Engineering Reviews were held during the Technology Development phase of the program?**
❑ System Requirements Review
❑ System Functional (or Design) Review
❑ Preliminary Design Review
❑ Critical Design Review

6. **What was the primary purpose of the prototype development and test efforts on the program?**
❍ Evaluation of system performance to support the EMD source selection evaluation
❍ Evaluation of the maturity of critical technologies
❍ Evaluation of manufacturing capabilities

❍ Evaluation of integrated production-representative components
❍ There was no prototyping during the TD phase
❍ If other, please specify

_____

7. **What is your primary role on the program?**
❍ Program Manager
❍ Technical Manager
❍ Systems Engineer
❍ Software Engineer
❍ Hardware Engineer
❍ Logistics and Sustainment Engineer
❍ If other, please specify

_____

8. **How many years of experience in defense systems development do you possess?**

_____

9. **What is the name of the system or program to which your responses pertain? (Optional)**

_____

Page 3 – Early Systems Engineering and System Requirements

The following questions relate to the Systems Engineering Reviews that were conducted during the Technology Development phase of the program and the characteristics of the system requirements set at the end of the Technology Development phase. For the purposes of this survey, Systems Engineering Reviews are defined as major program events where the Government and contractor participate in an assessment of the program status and progress of the design. Examples of Systems Engineering Reviews typically held during a Technology Development phase include System Requirements Review, System Functional Review, and Preliminary Design Review.

Please provide your assessment of the degree to which the following statements are/were true of the program at the end of the Technology Development phase according to the following scale:

None - No inclusion of the activity or characteristic on the program
Little - Nominal or marginal inclusion of the activity or characteristic on the program
Moderate - Significant inclusion of the activity or characteristic on the program
Large - Extensive inclusion of the activity or characteristic on the program

10. **System Engineering Reviews assessed program progress in terms of the risk to meeting cost, schedule, and technical objectives.**

None	Little	Moderate	Large
○	○	○	○

11. **Systems Engineering Reviews accounted for cost and schedule in addition to technical aspects of the program.**

None	Little	Moderate	Large
○	○	○	○

12. **Systems Engineering Reviews focused on requirements and the proposed system design's ability to meet requirements.**

None	Little	Moderate	Large
○	○	○	○

13. **Systems Engineering Reviews addressed all phases of the system lifecycle.**

None	Little	Moderate	Large
○	○	○	○

14. **Systems Engineering Reviews identified and documented risks to be addressed during system development.**

None	Little	Moderate	Large
○	○	○	○

15. **System Engineering Reviews facilitated resolution of open requirements issues.**

None	Little	Moderate	Large
○	○	○	○

16. **System Engineering Reviews facilitated establishment of baselines prior to system implementation.**

None	Little	Moderate	Large
○	○	○	○

17. **Systems Engineering Reviews included appropriate subject matter experts and stakeholders.**

None	Little	Moderate	Large
○	○	○	○

18. **Requirements were sufficiently clarified during the Technology Development phase.**

	None	Little	Moderate	Large
	❍	❍	❍	❍

19. Requirements were stable between completion of PDR and the Engineering & Manufacturing Development phase.

	None	Little	Moderate	Large
	❍	❍	❍	❍

20. Requirements are expected to be stable during the Engineering & Manufacturing Development phase.

	None	Little	Moderate	Large
	❍	❍	❍	❍

21. Incomplete system-level requirements (i.e. To Be Specified/Determined) and optional requirements were dispositioned prior to or during the Technology Development phase.

	None	Little	Moderate	Large
	❍	❍	❍	❍

22. The system-level requirements baseline was consistent and complete at the end of the Technology Development phase.

	None	Little	Moderate	Large
	❍	❍	❍	❍

23. Verification criteria for system-level requirements were established by the end of the Technology Development phase.

	None	Little	Moderate	Large
	❍	❍	❍	❍

24. The system-level requirements were achievable within program budget and schedule.

	None	Little	Moderate	Large
	❍	❍	❍	❍

25. An achievable system architecture that satisfies requirements has been developed and documented.

	None	Little	Moderate	Large
	❍	❍	❍	❍

Page 4 - System Prototyping and Product Maturity

The following questions relate to system prototyping efforts executed during the Technology Development phase of the program and the maturity of the technical solution at the end of the Technology Development phase.

Please provide your assessment of the degree to which the following statements are/were true of the program at the end of the Technology Development phase according to the following scale:

None - No inclusion of the activity or characteristic on the program
Little - Nominal or marginal inclusion of the activity or characteristic on the program
Moderate - Significant inclusion of the activity or characteristic on the program
Large - Extensive inclusion of the activity or characteristic on the program

26. **Prototype requirements were focused on areas of substantial risk rather than previously demonstrated capabilities.**

None	Little	Moderate	Large
❍	❍	❍	❍

27. **Prototype performance requirements were aligned with system performance requirements.**

None	Little	Moderate	Large
❍	❍	❍	❍

28. **Prototype requirements addressed size, weight, power, and cooling considerations.**

None	Little	Moderate	Large
❍	❍	❍	❍

29. **Prototype manufacturing requirements were aligned with system manufacturing requirements.**

None	Little	Moderate	Large
❍	❍	❍	❍

30. **Prototype demonstration activities were aligned with system technology risk.**

None	Little	Moderate	Large
❍	❍	❍	❍

31. **Prototype requirements were formally verified with Government involvement.**

None	Little	Moderate	Large
❍	❍	❍	❍

32. **Effective assessments of technology readiness were completed during the Technology Development phase.**

None	Little	Moderate	Large
❍	❍	❍	❍

33. **Effective assessments of manufacturing readiness were completed during the Technology Development phase.**

None	Little	Moderate	Large
❍	❍	❍	❍

34. **System technologies have been demonstrated in operationally relevant environments.**

None	Little	Moderate	Large
❍	❍	❍	❍

35. **The technologies employed by this system have been used previously for similar purposes.**

None	Little	Moderate	Large
❍	❍	❍	❍

36. **The technologies implemented in the system have been demonstrated to be consistent in multiple evaluations.**

None	Little	Moderate	Large
❍	❍	❍	❍

37. **The feasibility of using the system's technologies for the intended application have been demonstrated.**

None	Little	Moderate	Large
❍	❍	❍	❍

38. **Sourcing decisions for system components have been completed and documented.**

None	Little	Moderate	Large
❍	❍	❍	❍

39. **The production environment has been sufficiently defined to support accurate producibility and cost assessments.**

None	Little	Moderate	Large
❍	❍	❍	❍

40. **Manufacturing equipment to be used during system production has been identified.**

None	Little	Moderate	Large
❍	❍	❍	❍

41. **Manufacturing processes to be used during system production have been documented.**

None	Little	Moderate	Large
❍	❍	❍	❍

<u>**Page 5 - Modular Open Systems Approach, Standards, and Non-Developmental Items**</u>

The following questions relate to the implementation of a Modular Open Systems Approach during the Technology Development phase of the program and the use of standards and non-developmental items (e.g. commercial hardware/software components or components used from other programs) in the system solution. This survey considers "Modular Open Systems", "Open Architecture", "Open Systems Architecture", and similar terms to represent equivalent concepts.

Please provide your assessment of the degree to which the following statements are/were true of the program at the end of the Technology Development phase according to the following scale:

None - No inclusion of the activity or characteristic on the program
Little - Nominal or marginal inclusion of the activity or characteristic on the program
Moderate - Significant inclusion of the activity or characteristic on the program
Large - Extensive inclusion of the activity or characteristic on the program

42. **Implementation of a Modular Open Systems Approach or equivalent was required by the program.**

None	Little	Moderate	Large
❍	❍	❍	❍

43. **The program discourages the use of proprietary interface implementations and data formats.**

None	Little	Moderate	Large
❍	❍	❍	❍

44. **The system is required to employ non-developmental items and/or commercial off-the-shelf components for non-application-specific functions.**

None	Little	Moderate	Large
❍	❍	❍	❍

45. **Verification methods for Modular Open Systems technical requirements were sufficiently defined.**

None	Little	Moderate	Large
❍	❍	❍	❍

46. **Market surveys were performed to determine availability of off-the-shelf components capable of meeting requirements.**

None	Little	Moderate	Large
❍	❍	❍	❍

47. **The program identified system components and interfaces most likely to change in the future.**

None	Little	Moderate	Large
❍	❍	❍	❍

48. **Business case analyses were used to determine which system interfaces should be open and which components should be non-developmental.**

None	Little	Moderate	Large
❍	❍	❍	❍

49. **Compliance with a Modular Open Systems Approach was assessed by the program using formal tools and processes.**

None	Little	Moderate	Large
❍	❍	❍	❍

50. **The system design incorporates reuse of software source code developed on previous programs.**

None	Little	Moderate	Large
❍	❍	❍	❍

51. **The system design incorporates commercial off-the-shelf and/or open-source software for non-application-specific functions.**

None	Little	Moderate	Large
❍	❍	❍	❍

52. **The system design incorporates commercial off-the-shelf (COTS) hardware components for non-application specific functions.**

None	Little	Moderate	Large
❍	❍	❍	❍

53. **The system design incorporates reuse of hardware component designs developed on previous programs.**

None	Little	Moderate	Large
❍	❍	❍	❍

54. **System components can be replaced with similar components from competitive sources without impacting the system architecture.**

None	Little	Moderate	Large
❍	❍	❍	❍

55. **Components that are most susceptible to obsolescence and upgrades are isolated behind standard interfaces.**

None	Little	Moderate	Large
❍	❍	❍	❍

56. **Interface protocols chosen allow for long-term growth of system capabilities and resources.**

None	Little	Moderate	Large
❍	❍	❍	❍

57. **System interfaces are based on well defined and widely used standards.**

None	Little	Moderate	Large
❍	❍	❍	❍

The following questions relate to the overall impact of the defense acquisition process modifications on the outcomes of the program's Technology Development phase. Please answer all questions in terms of how the execution of the Technology Development phase affects the risk position of the program during Engineering & Manufacturing Development and later phases.

58. **To what degree did the two-phase (TD/EMD) structure of the program improve the risk position of the program?**
❍ No Improvement
❍ Little Improvement
❍ Moderate Improvement
❍ Large Improvement

59. **To what degree did the execution of a Preliminary Design Review prior to funding of full system design implementation improve the risk position of the program at the end of the Technology Development phase?**
❍ No Improvement
❍ Little Improvement
❍ Moderate Improvement
❍ Large Improvement

60. **To what degree did the execution of prototype development and testing in parallel with system development activities improve the risk position of the program at the end of the Technology Development phase?**
❍ No Improvement
❍ Little Improvement
❍ Moderate Improvement
❍ Large Improvement

61. **To what degree did the inclusion of Modular Open Systems Approach requirements and related activities improve the risk position of the program at the end of the Technology Development phase?**
❍ No Improvement
❍ Little Improvement
❍ Moderate Improvement
❍ Large Improvement

62. **To what degree was effective communication from the Government to the contractor adversely affected by the competitive environment during the Technology Development phase of the program?**
❍ No Adverse Effect
❍ Little Adverse Effect
❍ Moderate Adverse Effect
❍ Large Adverse Effect

63. **To what degree was effective communication from the contractor to the Government adversely affected by the competitive environment during the Technology Development phase of the program?**
❍ No Adverse Effect
❍ Little Adverse Effect
❍ Moderate Adverse Effect
❍ Large Adverse Effect

64. **To what degree did the development and test of a prototype system during the Technology Development phase adversely affect the focus on development of the design to be presented at the Preliminary Design Review?**
❍ No Adverse Effect
❍ Little Adverse Effect
❍ Moderate Adverse Effect
❍ Large Adverse Effect

65. **To what degree was the prototype that was developed and tested during the Technology Development phase representative of the intended production system design?**
❍ No Representativeness
❍ Little Representativeness
❍ Moderate Representativeness
❍ Large Representativeness

66. **To what degree were the internal company processes aligned with the Government's current acquisition process?**
❍ No Alignment
❍ Little Alignment
❍ Moderate Alignment
❍ Large Alignment

67. **To what degree were contractor-proposed changes to the Government's system specification incorporated during the Technology Development phase of the program?**
❍ No Incorporation
❍ Little Incorporation
❍ Moderate Incorporation
❍ Large Incorporation

68. **To what degree did the transition from the end of the Technology Development phase to the beginning of the Engineering & Manufacturing Development phase add risk to the program?**
❍ No Added Risk
❍ Little Added Risk
❍ Moderate Added Risk
❍ Large Added Risk

69. **What could the Government have done during the Technology Development phase to improve the risk position of the program for later phases?**

_____

_____

70. **What could the contractor have done during the Technology Development phase to improve the risk position of the program for later phases?**

_____

_____

Thank you for your participation in this research. It is intended that the results of this study will be used to improve the effectiveness of the acquisition process to the benefit of contractors, the Government, and ultimately the Warfighter. Please click the button below to submit the survey.

APPENDIX E: IRB APPROVAL LETTER

Approval of Exempt Human Research

From: **UCF Institutional Review Board #1**
          FWA00000351, IRB00001138

To: **Brig J Bjorn**

Date: **October 03, 2011**

Dear Researcher:

On 10/3/2011, the IRB approved the following activity as human participant research that is exempt from regulation:

Type of Review:	UCF Initial Review Submission Form
Project Title:	Critical Success Factors for Evolutionary Acquisition Implementation
Investigator:	Brig J Bjorn
IRB Number:	SBE-11-07824
Funding Agency:	None

This determination applies only to the activities described in the IRB submission and does not apply should any changes be made. If changes are made and there are questions about whether these changes affect the exempt status of the human research, please contact the IRB. When you have completed your research, please submit a Study Closure request in iRIS so that IRB records will be accurate.

In the conduct of this research, you are responsible to follow the requirements of the Investigator Manual.

On behalf of Sophia Dziegielewski, Ph.D., L.C.S.W., UCF IRB Chair, this letter is signed by:

Signature applied by Janice Turchin on 10/03/2011 03:06:18 PM EDT

IRB Coordinator

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REFERENCES

Aerospace Industries Association (2008). "U.S. Defense Acquisition: An Agenda for Positive Reform." (November).

Anderson, David K. and Tony Merna. (2003)."Project Management Strategy - Project management represented as a process based set of management domains and the consequences for project management strategy." International Journal of Project Management. vol. 21, pg. 387-393.

Angelis, Diana, John Dillard, Raymond Franck, and Francois Melese. (2008) " Exploring the Implications of Transaction Cost Economics on Joint and System-of-Systems Programs." Naval Postgraduate School, 2008.

Arnold, Scot A., David L. McNicol, and Kenton G. Fasana. (2009) "Can Profit Policy and Contract Incentives Improve Defense Contract Outcomes?" Tech. no. P-4391. Institute for Defense Analyses.

Artto, et al. (2007) "What is project strategy?" International Journal of Project Management, Vol. 26.

Atkinson, Roger. (1999). "Project Management: Cost, Time and Quality, Two Best Guesses and a Phenomenon, It's Time to Accept Other Success Criteria." International Journal of Project Management. Vol. 17, No. 6, pp 337-342.

Avison, David, Francis Lau, Michael Myers, and Peter Axel Nielsen. (1999) "Action Research." Communications of the ACM. (January). Vol. 42, No. 1.

Babbie, Earl. (1990). Survey Research Methods. 2nd edition. Wadsworth Publishing Company. Wadsworth, CA.

Bahill, A.T. and F.F. Dean, (2009) "Discovering System Requirements," Handbook of Systems Engineering and Management. A.P. Sage and W.B. Rouse (Editors), Wiley, New York, pp. 205-266.

Blanchard, Benjamin S. and Wolter J. Fabrycky. (2005) Systems Engineering and Analysis. 4th ed. Upper Saddle River, NJ.

Boudreau, M. (2007). "Acoustic Rapid COTS Insertion: A Case Study in Modular Open Systems Approach for Spiral Development," IEEE International Conference on System of Systems Engineering, 2007. pp.1-6, 16-18 April

Boynton, Andrew C. and Robert W. Zmud. (1984). "An Assessment of Critical Success Factors." Sloan Management Review. 25, 4; pp. 17-27 (Summer)

Buede, Dennis M., and Terry A. Bresnick. (2006) "Applications of Decision Analysis to the Military Systems Acquisition Process." Advances: Military Systems Acquisitions 7.26.

Carter, Ashton. (2010) "Carter Briefing on Acquisition Efficiency." June 28, 2010. Retrieved August 14, 2010. https://dap.dau.mil/policy/Documents/Policy/Carter%20Briefing.pdf

Chairman of the Joint Chiefs of Staff (2009). "Chairman of the Joint Chiefs of Staff Instruction: Joint Capabilities Integration and Development System." CCJCSI 3170.01G. (March 1).

Christensen, David S. and James A. Gordon. (1998). "Does a Rubber Baseline Guarantee Cost Overruns on Defense Acquisition Contracts?". Project Management Journal. 29:43-51. (September).

Cockburn, Alistair. (May 2008). "Using both Incremental and Iterative Development". STSC CrossTalk (USAF Software Technology Support Center) 21 (5): 27–30.ISSN d0000089

"The Constitution of the United States," Article X.

Corning Systems Engineering Directorate (2009). Corning-Cornell Project to Evaluate Effectiveness of Systems Engineering Techniques: Results from a Literature Review and Interview Research. Final Report. Available electronically at http://www.cee.cornell.edu/uploads/loader.cfm?csModule=security/getfile&pageid=40278

Costello, Rita J. and Dar-Biau Liu. (1995). "Metrics for Requirements Engineering." Journal of Systems Software. Vol. 29, pp 39-63.

Cunningham, J. Barton (1993). Action Research and Organizational Development. Praeger Publishers, Westport CT.

Cunningham, J. Barton (1993). Action Research and Organizational Development. Praeger Publishers, Westport CT.

Dahmann, Judith S., Aumber S. Bhatti, and Michael Kelley. (2009). Importance of Systems Engineering in Early Acquisition. IEEE SysCon 2009 - 3rd Annual IEEE International Systems Conference. Vancouver, Canada, March 23-26, 2009.

Defense Acquisition Performance Assessment Project (2006). Defense Acquisition Performance Assessment Report. Available at: https://acc.dau.mil/adl/en-US/18554/file/733/Defense%20Acquisition%20Performance%20Assessment%20Report%202006.pdf.

Defense Acquisition University (2011). "Defense Acquisition Guidebook". Dated: June 27.

Defense Acquisition University. (2009) "Integrated Defense Acquisition, Technology, and Logistics Life Cycle Management System." Version 5.3.4. 15 June 2009. Authors: Chuck Cochrane and Bill Bahnmaier.

Defense Science Board. (2005) "Creating a DOD Strategic Acquisition Platform."

Defense Science Board. (2008). "Creating an Effective National Security Industrial Base for the 21st Century: An Action Plan to Address the Coming Crisis." Report of the Defense Science Board Task Force on the Defense Industrial Structure for Transformation. (July).

Department of Defense (2006). "Risk Management Guide for DoD Acquisition". Sixth Edition, Version 1.0. (August). Available at: http://www.dau.mil/pubscats/PubsCats/RMG%206Ed%20Aug06.pdf

Department of Defense. (2010) "Overview - FY 2011 Budget."

Department of Defense. (2010) "FY 2011 Program Acquisition Costs by Weapon System."

Department of Defense (2010). Quadrennial Defense Review Report. www.defenselink.mil/pubs/qdr2010.pdf.

Department of the Air Force (2008). "Guidance Memorandum: Prototyping and Competition" October 14.

Dobbins, Hames H. and Richard G. Donnelly (1998). "Critical Success Factor Analysis for DoD Program Management." Acquisition Review Quarterly. No. 5, pp 61-81.

Dombrowski, Peter J., Eugene Gholz, and Andrew L. Ross. (2002) "Selling Military Transformation: The Defense Industry and Innovation." Orbis, Summer 2002: pp.523-36

Dubos, Gregory, Joseph H. Saleh, and Robert Braun (2007). "Technology Readiness Level, Schedule Risk and Slippage in Spacecraft Design: Data Analysis and Modeling." AIAA SPACE 2007 Conference and Exposition (18 - 20 September), Long Beach, California.

Drezner, Jeffrey A. and Meilinda Huang. (2010) "On Prototyping: Lessons from RAND Research". RAND Corporation.

Eisenhardt, Kathleen M. (1989) "Building Theories from Case Study Research." The Academy of Management Review. (October) Vol. 14, No 4.

Eisenhardt, Kathleen M. and Melissa E. Graebner (2007). "Theory Building from Cases: Opportunities and Challenges." Academy of Management Journal. Vol. 50, No. 1, pp. 25-32.

Eisenmann, Thomas R., Parker, Geoffrey and Van Alstyne, Marshall W., (2008). Opening Platforms: How, When and Why? (August 31, 2008). Harvard Business School Entrepreneurial Management Working Paper No. 09-030. Available at: ssrn.com/abstract=1264012

Elder, Kevin Lee and Michael R. Garman. (2008). "Private Sector Versus Public Sector Research on Software Project Management: An Exploratory Study." Issues in Information Systems. Vol. IX, No. 2. pp. 466-475.

Elm, Joseph P., et al. (2008). "A Survey of Systems Engineering Effectiveness: Initial Results (with detailed Survey Data)." Software Engineering Institute. (December). http://www.sei.cmu.edu/reports/07sr014.pdf

Flyvbjerg, Bent. (2006). "Five Misunderstanding About Case-Study Research." Qualitative Inquiry. Vol. 12, No 2 (April).

Ford, David N. and John T. Dillard. (2009) "Modeling the Integration of Open Systems and Evolutionary Acquisition in DoD Programs." Naval Post Graduate School. NPS-GSBPP-09-10. 2009 Aug 19. http://www.acquisitionresearch.net/_files/FY2008/NPS-AM-08-108.pdf

Freidman, George and Andrew P. Sage. (2004) "Case Studies of System Engineering and Management in Systems Acquisition." Systems Engineering, Vol. 7, No. 1.

Gable, G.G. (1994). "Integrating Case Study and Survey Research Methods: An Example in Information Systems." European Journal of Information Systems. Vol. 3, No. 2, pp 112-126.

Gallagher, Brian P. and Sandy Shrum. (2004) "Applying CMMI to Systems Acquisition." CrossTalk: the Journal of Defense Software Engineering. (August)

Gansler, J. S., and W. Lucyshyn. (2005). "A Strategy for Defense Acquisition Research." College Park, MD: University of Maryland, Center for Public Policy and Private Enterprise. (August)

Government Accountability Office [GAO]. (2005). "Information for Congress on Performance of Major Programs Can Be More Complete, Timely, and Accessible." GAO- -05-182.

GAO. (2006). "Improved Business Case Is Needed for Future Combat System's Successful Outcome." GAO-06-367.

GAO (2008). "A Knowledge-based Funding Approach Could Improve Major Weapon System Program Outcomes." GAO-08-619. (July).

GAO. (2009). "Assessment of Selected Weapon Programs." GAO-09-326SP.

GAO. (2010a). "Observations on Weapon Program Performance and Acquisition Reforms." GAO-10-706T.

GAO. (2010b). "Strong Leadership Is Key to Planning and Executing Stable Weapon Programs." GAO-10-522.

GAO. (2010c) "Assessment of Selected Weapons Programs." GAO-10-388SP.

GAO. (2011a). "Application of Lessons Learned and Best Practices in the Presidential Helicopter Program." GAO-11-380R.

GAO. (2011b). "Assessment of Selected Weapons Programs." GAO-11-233SP

Hobday, Michael, Andrew Davies, and Andrea Prencipe. (2005) "Systems Integration: a Core Capability of the Modern Corporation." Industrial and Corporate Change : 1-35. Print.

Kaplan, Robert S. and David P. Norton. (2001). The Strategy-focused Organization: How Balanced Scorecard Companies Thrive in the New Business Environment. Boston, Mass: Harvard Business School.

Keisler, Jeffery. (2004) "Value of Information in Portfolio Decision Analysis." Decision Analysis, Vol. 1, No. 3 (2004), pg. 177–189.

Kendall, Frank. (2012). "The Acquisition Implications of the DOD Strategic Guidance and the FY 2013 Budget" Transcript by Federal News Service. February 6th. Washington, D.C. Available at: http://csis.org/files/attachments/120206_FY13_event_transcript.pdf

Kendall, M. (1938). "A New Measure of Rank Correlation". Biometrika 30 (1-2): 81–89.

Kerzner, Harold. (2006). Project Management: *A Systems Approach to Planning, Scheduling, and Controlling*. Hoboken, NJ: John Wiley and Sons.

Kludze, A.K. (2003) "Engineering of Complex Systems: the Impact of Systems Engineering at NASA." Ph.D. Dissertation, George Washington University.

Kwak, Young Hoon and Brian M. Smith. (2009) "Managing Risk in Mega Defense Acquisition Projects: Performance, Policy, and Opportunities." International Journal of Project Management. 2009. Vol. 27. Pp 812-820.

Leedy, Paul D. (1989). Practical Research: Planning and Design. 4th ed. Macmillan
    Publishing Company. New York.

Mankins, John C. (2002) "Approaches to Strategic Research and Technology Analysis
    and Road Mapping." Acta Astronautica. Vol. 51 (2002) No. 1-9, pp. 3-21.

Marshall, Catherine, and Gretchen B. Rossman. (1989). *Designing Qualitative Research*.
    Sage Publications. Newbury Park, CA.

Meier, Steven R. (2009). "Causal inferences on the cost overruns and schedule delays of
    large-scale U.S. federal defense and intelligence acquisition programs." Project
    Management Journal. Vol. 41, Issue 1. Pg 28-39. (December 8).

National Research Council. (2009) "Optimizing U.S. Air Force and Department of
    Defense Review of Air Force Acquisitions Programs." National Academies Press.
    Washington, D.C. Available at: http://www.nap.edu/catalog/12673.html

"Naval Open Architecture Contract Guidebook For Program Managers." (2010). Naval
    Open Architecture Enterprise Team. https://acc.dau.mil/adl/en-US/375114/file/
    51790/FOR%20E-DISTRIBUTION_NOA%20Contract%20Guidebook%20
    V2.0_Statement%20A_FINAL.pdf

Niazi, Mahmood, David Wilson, and Didar Zowghi (2005). "A framework for assisting
    the design of effective software process improvement implementation strategies."
    Journal of Systems and Software. Vol. 78. pg 204-222.

Office of the Secretary of Defense. (2010). Quadrennial defense Review.

Open Systems Joint Task Force. (2004, September). "Program manager's guide: A
    modular open systems approach (MOSA) to acquisition (Ver. 2.0)." Washington,
    DC: Author. (September) http://www.acq.osd.mil/osjtf.

Pedhazur, Elazar J. and Liora Pedhazur Schmelkin. (1991). Measurement, Design and
    Analysis: An Integrated Approach. Student Edition. Lawrence Erlbaum
    Associates. Hillsdale, NJ.

Pinto, Jeffery K. and John E. Prescott. (1988). "Variations in Critical Success Factors
    Over the Stages in the Project Life Cycle." Journal of Management. Vol. 14, No
    1, pp 5-18.

Purser, Ronald E., William A. Pasmore, and Ramkrishnan V. Tenkasi. (1992) "The
    influence of Deliberations on Learning in New Product Development Teams"
    Journal of Engineering and Technology Management. Vol. 9. Pgs 1-28.

R Development Core Team (2011). R: A Language and Environment for Statistical
    Computing. R Foundation for Statistical Computing. Vienna, Austria.
    http://www.R-project.org.

Readiness Level within Defense Acquisition." International Journal of Defense
Acquisition Management. Vol. 1 (2008) pg. 39-58

Rendon, Rene G. (2008). Management of Defense Acquisition Systems. Reston, VA:
American Institute of Aeronautics and Astronautics, 2008.

Roedler, Garry, Donna Rhodes, Howard Schimmoller, and Cheryl Jones (Eds.), (2010)
Systems Engineering Leading Indicators Guide Version 2.0, MIT Lean Aerospace
Initiative. January 29. Available at: http://www.incose.org/ProductsPubs/pdf/
SELI-Guide-Rev2-01292010-Industry.pdf

Rockart, John F. (1979). "Chief Executives Define Their Own Data Needs." Harvard
Business Review. (March-April).

Rouse, William, Michael Pennock, and Diane L. Kollar. (2006). "Transforming the
Enterprise of Acquiring Public Sector Complex Systems." Proceedings of the
Third Annual Acquisition Research Symposium: Creating Synergy for Informed
Change. May 17-18, 2006. Monterey, CA. NPS-AM-06-065.

Sauser, Brian, et al. (2009) "A Systems Approach to Expanding the Technology
Readiness Levels within Defense Acquisition." Naval Post Graduate School.
Available at: http://www.dtic.mil/cgi-
bin/GetTRDoc?AD=ADA530242&Location=U2&doc=GetTRDoc.pdf

Schreiber, J. B., A. Nora, F.K. Stage, E. A. Barlow, J. King (2006). "Reporting Structural
Equation Modeling and Confirmatory Factor Analysis Results: A Review."
Journal of Educational Research. Vol. 99; No 6, pages 323-338.

Schwartz, Moshe. (2009) "Defense Acquisitions: How DOD Acquires Weapons Systems
and Recent Reform Efforts." Congressional Research Service, 7-5700, Report
#RL34026. July 10, 2009.

Shenhar, Aaron J. (2004) "Strategic Project Leadership: Toward a strategic approach to
project management." R&D Management. 2004. Vol. 34, No. 5.

Sherman, Daniel J. and Richard G. Rhoads. (2010) "Cycle Time Reduction in Defense
Acquisitions." Research-Technology Management. Vol. 53, No. 5 (September-
October). pp 46-54.

Smirnoff, James P. and Michael J. Hicks. (2008) "The impact of economic factors and
acquisition reforms on the cost of defense weapon systems." Review of Financial
Economics 17 (2008) pg 3-13.

Srivannaboon, Sabin and Dragan Z. Milosevic. (2006) "A Two-way Influence between
Business Strategy and Project Management." International Journal of Project
Management Vol. 24 (2006) Pg. 493–505.

Steves, Michael R. (1997). "Addressing Risk Management in Non-Developmental Items Acquisition Programs." Acquisition Review Quarterly (Winter). Pgs 39-53.

Thompson, Bruce. (2004) Exploratory and Confirmatory Factor Analysis. American Psychological Association. Washington, D.C.

Under Secretary of Defense (AT&L). (2003a, May 12). The Defense Acquisition System (DoD Directive 5000.1). Washington, DC: Author.

Under Secretary of Defense (AT&L). (2003b, May 12). Operation of the Defense Acquisition System (DoD Instruction 5000.2). Washington, DC: Author.

Under Secretary of Defense (AT&L). (2007, November 20). The Defense Acquisition System (DoD Directive 5000.01). Washington, DC: Author.

Under Secretary of Defense (AT&L). (2008, December 8). Operation of the Defense Acquisition system (DoD Instruction 5000.02). Washington, DC: Author.

Under Secretary of Defense for Acquisition, Technology, and Logistics. Office of Industrial Policy. (2010) "Annual Industrial Capabilities Report to Congress." (May)

Undersecretary of Defense for Acquisition, Technology, and Logistics. (2009) "Directive-Type Memorandum 09-027 - Implementation of Weapon Systems Acquisition Reform Act of 2009". December 4, 2009.

Undersecretary of Defense for Acquisition, Technology, and Logistics. (2010) "Better Buying Power: Mandate for Restoring Affordability and Productivity in Defense Spending." (June 28). Available at: http://www.acq.osd.mil/docs/USD(AT&L)_Memo_to_Acquisition_Professionals_June_28_2010.pdf

Valerdi, Ricardo and Heidi L. Davidz. "Empirical Research in Systems Engineering: Challenges and Opportunities of a New Frontier." Systems Engineering, Vol. 12, No 2.

Vanek, Francis, Peter Jackson, and Richard Grzybowski. (2008) "Systems Engineering Metrics and Applications in Product Development: A Critical Literature Review and Agenda for Further Research." Systems Engineering, Published On-Line February 25.

Vanek, Francis, Peter Jackson, Richard Grzybowski, and Matt Whiting. (2010) Effectiveness of Systems Engineering Techniques on New Product Development: Results from Interview Research at Corning Incorporated. Presented at 2010 INCOSE International Symposium, Chicago, IL, July 13, 2010.

Watts, Barry. (2008) "U.S Defense Industrial Base: Past, Present, and Future." 2008.

Wessa, P. (2012), Free Statistics Software, Office for Research Development and Education, version 1.1.23-r7, URL http://www.wessa.net/

Weapons Systems Acquisition Reform Act of 2009, United State Code § 4 (2009).

Williams, Larry J., Lucy R. Ford, and Nhung Nguyen (2004). "Basic and Advanced Measurement Models for Confirmatory Factor Analysis." Handbook of Research Methods in Industrial and Organizational Psychology. Rogelberg, Steven G. (Editor). Blackwell Publishing. Malden, MA. Pages 367-389.

Woodside, Arch G. and Elizabeth J. Wilson. (2003). "Case Study research Methods for Theory Building." Journal of Business and Industrial Marketing. Vol. 18, No. 6/7. pp. 493-508.

Yin, Robert K. (2009). Case Study Research: Design and Methods. Fourth Edition. SAGE Publications. California, 2009.