2020-03

A COMPARATIVE ANALYSIS OF ADVANCED METHODOLOGIES TO IMPROVE THE ACQUISITION OF INFORMATION SYSTEMS WITHIN THE DEPARTMENT OF DEFENSE

Carlton, Benjamin J.

Monterey, CA; Naval Postgraduate School

NAVAL POSTGRADUATE SCHOOL

MONTEREY, CALIFORNIA

THESIS

A COMPARATIVE ANALYSIS OF ADVANCED METHODOLOGIES TO IMPROVE THE ACQUISITION OF INFORMATION SYSTEMS WITHIN THE DEPARTMENT OF DEFENSE

by

Benjamin J. Carlton

March 2020

Thesis Advisor:	Thomas J. Housel
Co-Advisor:	Raymond D. Jones
Second Reader:	Johnathan C. Mun

THIS PAGE INTENTIONALLY LEFT BLANK

REPORT DOCUMENTATION PAGE	*Form Approved OMB No. 0704-0188*

1. AGENCY USE ONLY *(Leave blank)*	**2. REPORT DATE** March 2020	**3. REPORT TYPE AND DATES COVERED** Master's thesis

4. TITLE AND SUBTITLE A COMPARATIVE ANALYSIS OF ADVANCED METHODOLOGIES TO IMPROVE THE ACQUISITION OF INFORMATION SYSTEMS WITHIN THE DEPARTMENT OF DEFENSE	**5. FUNDING NUMBERS**
6. AUTHOR(S) Benjamin J. Carlton	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Naval Postgraduate School Monterey, CA 93943-5000	**8. PERFORMING ORGANIZATION REPORT NUMBER**
9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES) N/A	**10. SPONSORING / MONITORING AGENCY REPORT NUMBER**

11. SUPPLEMENTARY NOTES The views expressed in this thesis are those of the author and do not reflect the official policy or position of the Department of Defense or the U.S. Government.

12a. DISTRIBUTION / AVAILABILITY STATEMENT Approved for public release. Distribution is unlimited.	**12b. DISTRIBUTION CODE** A

13. ABSTRACT (maximum 200 words)

This study examines whether five methodologies—balanced scorecard, earned value management, integrated risk management, knowledge value added, and lean six sigma—can support information system (IS) acquisition within the Defense Acquisition System. Each of these five methodologies offers a unique perspective to program managers that could increase their capability to monitor, predict, and adjust programs during the acquisition of IS and information technology intensive systems. The additional information gained from the methodologies could allow program managers to reduce cost and schedule overruns through greater insight into the program's performance. The research reviews the acquisition lifecycle and provides a detailed review of each approach to determine if the methodology could benefit program managers when acquiring ISs. In addition to the analysis of each technique within the context of the acquisition lifecycle, the research examines cases of the methodologies from an IS perspective. Using the cases as a guide, the thesis examines the benefits and challenges associated with each methodology. The research provides recommendations on which of the methodologies should be included and at which point in the acquisition lifecycle the methodologies should be used.

14. SUBJECT TERMS acquisition, earned value management, EVM, knowledge value added, KVA, lean six sigma, LSS, balanced scorecard, BSC, integrated risk management, IRM, comparative analysis, methodologies	**15. NUMBER OF PAGES** 125
	16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	**18. SECURITY CLASSIFICATION OF THIS PAGE**	**19. SECURITY CLASSIFICATION OF ABSTRACT**	**20. LIMITATION OF ABSTRACT**
Unclassified	Unclassified	Unclassified	UU

NSN 7540-01-280-5500

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

THIS PAGE INTENTIONALLY LEFT BLANK

A COMPARATIVE ANALYSIS OF ADVANCED METHODOLOGIES TO IMPROVE THE ACQUISITION OF INFORMATION SYSTEMS WITHIN THE DEPARTMENT OF DEFENSE

Benjamin J. Carlton
Major, United States Marine Corps
BS, U.S. Naval Academy, 2009

Submitted in partial fulfillment of the
requirements for the degrees of

MASTER OF SCIENCE IN INFORMATION TECHNOLOGY MANAGEMENT

and

MASTER OF BUSINESS ADMINISTRATION

from the

NAVAL POSTGRADUATE SCHOOL
March 2020

Approved by: Thomas J. Housel
Advisor

Raymond D. Jones
Co-Advisor

Johnathan C. Mun
Second Reader

Dan C. Boger
Chair, Department of Information Sciences

Glenn R. Cook
Academic Associate, Graduate School of Defense Management

THIS PAGE INTENTIONALLY LEFT BLANK

ABSTRACT

This study examines whether five methodologies—balanced scorecard, earned value management, integrated risk management, knowledge value added, and lean six sigma—can support information system (IS) acquisition within the Defense Acquisition System. Each of these five methodologies offers a unique perspective to program managers that could increase their capability to monitor, predict, and adjust programs during the acquisition of IS and information technology intensive systems. The additional information gained from the methodologies could allow program managers to reduce cost and schedule overruns through greater insight into the program's performance. The research reviews the acquisition lifecycle and provides a detailed review of each approach to determine if the methodology could benefit program managers when acquiring ISs. In addition to the analysis of each technique within the context of the acquisition lifecycle, the research examines cases of the methodologies from an IS perspective. Using the cases as a guide, the thesis examines the benefits and challenges associated with each methodology. The research provides recommendations on which of the methodologies should be included and at which point in the acquisition lifecycle the methodologies should be used.

THIS PAGE INTENTIONALLY LEFT BLANK

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

THIS PAGE INTENTIONALLY LEFT BLANK

LIST OF ACRONYMS AND ABBREVIATIONS

AC	actual cost
ACAT	acquisition category
ACWP	actual cost of work performed
AMF	Airborne, Maritime, and Fixed Station
AoA	analysis of alternatives
APB	Acquisition Program Baseline
ASN(RD&A)	Assistant Secretary of the Navy for Research, Development, and Acquisition
BCWP	budgeted cost of work performed
BCWS	budgeted cost of work scheduled
BSC	Balanced Scorecard
C4ISR	command, control, communications, computers, intelligence, surveillance, and reconnaissance
CCOP	Cryptologic Carry-On Program
CDD	capabilities development document
COTS	commercial off the shelf
CPI	cost performance index
CV	cost variance
DMAIC	define, measure, analyze, improve, and control
DoD	Department of Defense
EMD	engineering and manufacturing development
EV	earned value
EVM	Earned Value Management
GMR	ground mobile radio
GOTS	government off the shelf
HEMITT	heavy expanded mobility tactical truck
HMMWV	high mobility multipurpose wheeled vehicle
HMS	handheld mobile system
ICD	initial capabilities document
ICP	intelligence collection process
IRM	Integrated Risk Management
IS	information systems
ISR	intelligence, surveillance, and reconnaissance
IT	information technology

JCIDS	Joint Capabilities Integration and Development System
JPEO	joint program executive officer
JTRS	joint tactical radio system
KPP	key performance parameters
KSA	key system attributes
KVA	Knowledge Value Added
LCS	Littoral Combat Ship
LCSP	lifecycle sustainment plan
LOC	lines of code
LSS	Lean Six Sigma
MIDS	multifunctional information distribution system
MSA	materiel solution analysis
NED	network enterprise domain
NOAA	National Oceanic and Atmospheric Administration
NPV	net present value
OS	operations and support
PD	production and deployment
PM	program manager
PMB	performance measurement baseline
PV	planned value
POA&M	plan of action and milestones
PPBE	Planning, Programming, and Budget Execution
RDT&E	research, development and test and evaluation
RFP	request for proposal
RMF	Risk Management Framework
ROI	return on investment
ROK	return on knowledge
ROKI	return on knowledge investment
SMART	specific, measurable, assignable, relevant, and time-based
SPI	schedule performance index
SV	schedule variance
TMRR	technology maturation and risk reduction
TQM	Total Quality Management
TRA	technology readiness assessment
TRL	technology readiness level
WBS	work breakdown structure

ACKNOWLEDGMENTS

My gratitude extends to my wife, Stacy, for encouraging me to work on this thesis and for taking care of our children while I stared at the computer screen. Your support made this endeavor much easier and kept me from writing the entire paper in the last quarter. Also, I thank my advisory team for the time and effort they put forth reviewing numerous drafts and helping me understand the intricacies of the methodologies and process.

THIS PAGE INTENTIONALLY LEFT BLANK

I. INTRODUCTION

Parts of this chapter were previously published by the Naval Postgraduate School Acquisition Research Program (Housel, Mun, Jones, & Carlton, 2019).

Information systems (ISs) are a vital component of most major acquisitions the Department of Defense (DoD) makes in the modern operating environment. Everything from the airplanes flying overhead to the control systems used to fire artillery and the radios forward observers communicate with these systems rely heavily on IS for accurate and timely information. The advancement of technology promises future systems will remain equally or become more heavily dependent on IS intensive components to give warfighters a competitive advantage over their adversaries.

Unfortunately, the acquisition of IS has been fraught with problems including schedule and cost overruns. The pace of change of ISs is often faster than the required timeline to complete adequate testing, especially when problems with the program are discovered during development (Under Secretary of Defense, 2016). When developing new projects, contract requirements do not always meet the intended combat environment necessities, particularly when IT systems are involved (Under Secretary of Defense, 2016). This could be because the current methods of evaluating acquisition project performance do not adequately incorporate the risks inherent in IS development (Jones & Housel, 2018).

Possibly due to these reasons, DoD IS Acquisition Category (ACAT) 1 programs often run over budget and longer than the scheduled time. IT programs are often the most volatile and the return on investment (ROI) is difficult to predict. Despite the Earned Value Management (EVM) reporting requirements and oversight on these programs, costs are often incurred beyond the original plan and project completion rarely meets the initial projected date. In 1993, the average cost overrun on a DoD acquisition contract is forty percent (Christensen, 1994). According to Edwards and Kaeding (2015), "for 78 major programs examined in 2014, R&D costs were 53 percent over budget, and procurement costs were 46 percent over budget," (p. 3) showing a lack of significant improvement over the past two decades. The late delivery of promised IT acquisitions prevents the timely fielding of needed equipment to the operational forces (Under Secretary of Defense, 2016).

A. PROBLEM STATEMENT

The problem is the current process management and control tools program managers (PMs) use to support IS acquisitions do not provide adequate warning or sufficient information into the root causes of fiscal overruns and delays. This is a problem because PMs are unable to respond to issues in a timely manner, delaying the delivery of promised capabilities to the services. Additionally, the money and resources spent in excess of the original budget could be used in other acquisition programs. To better understand the possible causes and solutions to the problem, a study examining the strengths and weaknesses of five performance and project management methodologies is needed. These methodologies—EVM, Knowledge Value Added (KVA), Lean Six Sigma (LSS), Balanced Scorecard (BSC), and Integrated Risk Management (IRM)—are used to plan, measure, monitor, and forecast the value and progress of IS acquisitions. A thorough review of these project analysis and control methodologies will offer insights into the strengths and weaknesses each approach could offer acquisition professionals within the general phases of the Defense Acquisition System. This study could offer potential solutions to improve early warnings of cost and schedule overruns and value opportunities foregone in the acquisition process. This research will conduct a review of methodologies and their application to the acquisition process.

B. PURPOSE STATEMENT

The purpose of this research is to examine the potential impact of incorporating aspects of the five project analysis processes into the Defense Acquisition System. This is important because it has the potential to improve a PM's ability to make accurate and timely decisions for IS acquisitions. This study will review the strengths and weaknesses of the five methodologies in the context of the overall IS acquisition cycle. The research will provide a rationale for how these methodologies, or parts of the methodologies, should be incorporated in the Defense Acquisition System and beyond. Research was conducted with acquisition subject matter experts from Naval Postgraduate School in Monterey, CA.

C. RESEARCH QUESTIONS

The research will answer the following questions:

- Should the methodologies be used in the acquisition lifecycle to ensure successful acquisition of IS technologies?
- How should the methodologies be used in the acquisition lifecycle to ensure successful acquisition of IS technologies?
- What are the risks and limitations of using each of the methodologies for IS acquisition?

D. METHOD

The research is a historical study within the context of a pragmatic epistemology. The research will rely on peer-reviewed studies, published literature, and case studies of the methodologies within an IS context. The desired result of the study is to determine whether any of the project management and control tools would improve the performance of IS acquisition in the Defense Acquisition System.

The first step in the research is to conduct a thorough literature review of the topics in question. The study must identify problem areas for acquisition of IS within the Defense Acquisition System. Then, it must define and describe each of the five methodologies, noting their strengths and weaknesses and their applicability to DoD IS acquisitions. To assist in this endeavor, the study will examine IS acquisition cases where the methodologies might have been applied. Finally, the research will determine how the methodologies could be incorporated in the Defense Acquisition System within each phase of the acquisition lifecycle.

E. SCOPE

This study will examine the application of five methodologies within the Defense Acquisition System lifecycle. To limit the scope of the research, other components of the Defense Acquisition Decision Support System— specifically the Joint Capabilities Integration and Development System (JCIDS) and the Planning, Programming, and

Budgeting Execution (PPBE) components— are not covered within the context of the research. Additionally, while there are numerous other methodologies that may offer improvement in some areas of the acquisition lifecycle, only EVM, KVA, LSS, BSC, and IRM are considered for inclusion in this study as they are the most frequently used in IS investment decision making.

F. THESIS STRUCTURE

1. Introduction

This chapter details the research problem, purpose of the study, research questions, scope of the research and a general outline of the thesis.

2. Literature Review

Chapter II covers the Defense Acquisition System, containing an explanation of the phases, processes, and significant events within the acquisition lifecycle. It also discusses the key concepts of the five methodologies considered in the study.

3. Case Vignettes

This chapter reviews four different cases from a perspective of the different methodologies. Each vignette examines a government or hypothetical commercial example. EVM, BSC, and LSS cases are examined individually while KVA and IRM are combined studies.

4. Benefits and Challenges

This chapter covers the benefits and challenges of the five methodologies. It also compares the methodologies and examines their applicability within IS acquisitions.

5. Conclusion

The conclusion makes recommendations regarding which methodologies should be included within the Defense Acquisition System and at what phases in the acquisition lifecycle. It also proposes area for future research in related fields.

II. LITERATURE REVIEW

Parts of this chapter were previously published by the Naval Postgraduate School Acquisition Research Program (Housel, Mun, Jones, & Carlton, 2019).

This chapter discusses the Defense Acquisition System and the five methodologies considered for inclusion in support of the acquisition process. The descriptions of each methodology provide a basic understanding for the purpose of suggesting how the method can be applied to the acquisition process. This review provides a base level of understanding for how these methods can be used in development of subsequent case studies and for future analysis of potential improvements using these methods to the Defense Acquisition System.

A. DEFENSE ACQUISITION SYSTEM

The DoD manages the acquisition of new systems through the Defense Acquisition System, which manages national investment in technologies, programs, and product support for the United States Armed Forces (Department of Defense [DoD], 2003). Its primary objective is “to acquire quality products that satisfy user needs with measurable improvements to mission capability and operational support, in a timely manner, and at a fair and reasonable price” (DoD, 2003, p. 3). Within the DoD Decision Support System there are three separate but interrelated processes, JCIDS, PPBE, and the Defense Acquisition System (DoD, 2017b). This research focuses on program management, versus contract management, within the Defense Acquisition System.

Acquisition programs are divided into different ACATs based on the type of program and the dollar amount spent, or is projected to be spent within the program (DoD, 2015a). Figure 1 shows the various cost-based designations and categories within the Defense Acquisition System. All dollar amounts for ACAT classification are calculated in fiscal year 2014 dollars (DoD, 2015a). ACAT1 designates major defense acquisition programs with an estimated research, development, and test and evaluation expenditure (RDT&E) of more than $480 million or more than $2.79 billion for the total procurement

(DoD, 2015a). An ACAT1A designation is for major automated information systems that will exceed $520 million in total lifecycle cost, $165 million in the total program cost, or $40 million for any single year of a program (DoD, 2015a). ACATII programs do not meet the criteria for ACAT1 and will spend more than $835 million in the total procurement (DoD, 2015a) or more than $185 million in RDT&E. Finally, ACATIII programs are those that do not meet the criteria for ACATI or ACATII designation (DoD, 2015a). The designations allow for decentralized control of a program, as each category has different reporting requirements and designated decision makers (DoD, 2017b).

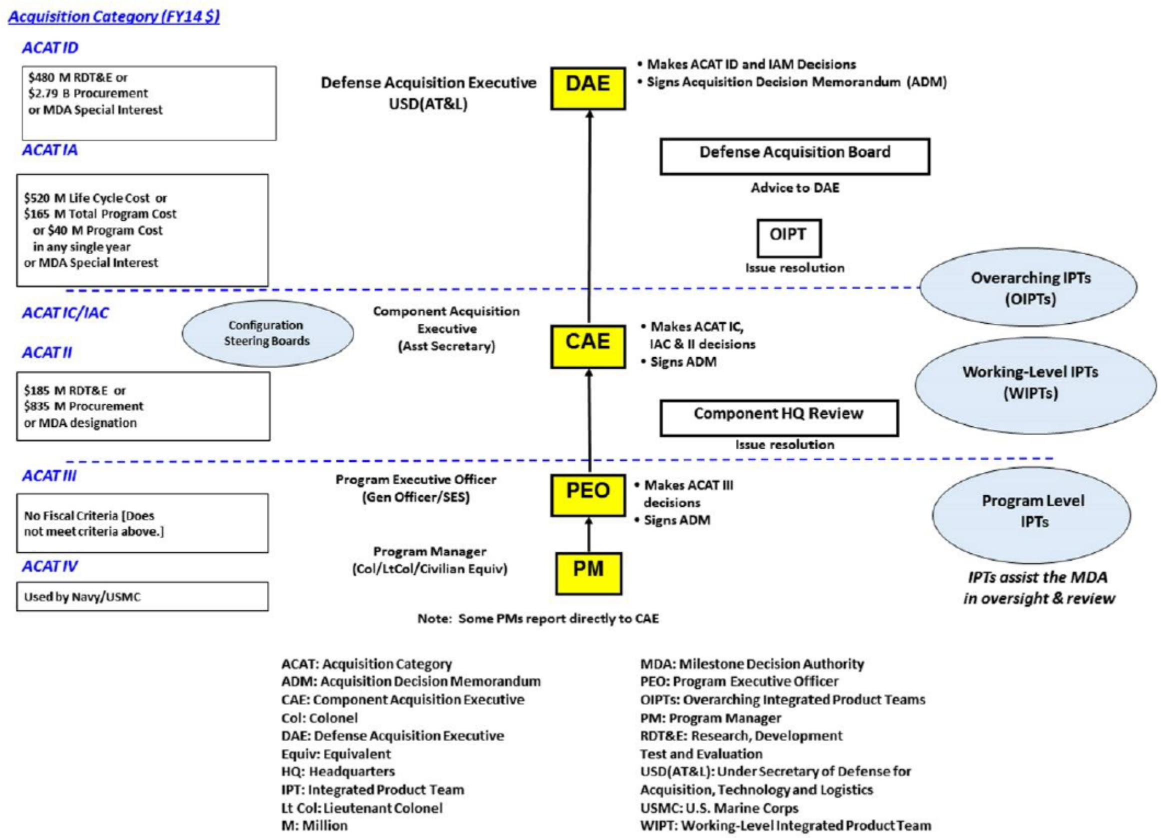


Figure 1. Acquisition Categories. Source: DoD (2017b).

There are five phases within the Defense Acquisition System:

1. Materiel Solution Analysis (MSA)

2. Technology Maturation and Risk Reduction (TMRR)

3. Engineering and Manufacturing Development (EMD)

4. Production and Deployment (PD)

5. Operations and Support (OS) phase.

Requirements for new or improved capabilities, delivered through JCIDS, drive the acquisition process (DoD, 2015a). Figure 2 illustrates the relationship between the acquisition and capabilities requirement processes and their interaction in the various acquisition phases. This study assumes the capabilities requested from the JCIDS process are accurate and necessary.

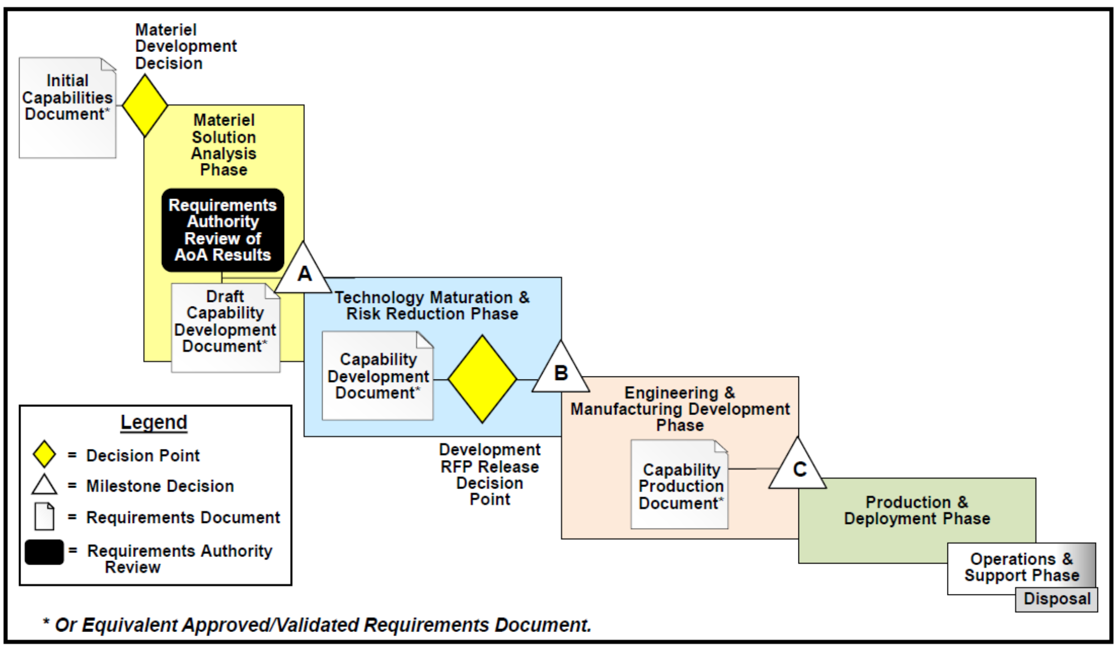


Figure 2. Interaction of Capabilities Requirement Process and Acquisition Process. Source: DoD (2015a).

Once an Initial Capabilities Document (ICD) has been validated, the Materiel Development Decision initiates the MSA phase (DoD, 2015a). This decision begins the acquisition process, although an acquisition program is not officially created until milestone B at the completion of the phase (DoD, 2015a). The purpose of the MSA phase is to choose the most promising potential solution for the acquisition process that will fill the needs of the ICD and to establish Key Performance Parameters (KPPs) and Key System Attributes (KSAs) for the system (DoD, 2015a). To accomplish this, an Analysis of Alternatives (AoA) is conducted to determine the suitability of potential acquisitions based on “measures of effectiveness; key trades between cost and capability; total life-cycle cost, including sustainment; schedule; concept of operations; and overall risk” (DoD, 2015a, p. 17). The PM is selected and the Program Office established during this time (DoD, 2015a). Once the necessary analysis is concluded, the decision authority—usually the Defense Acquisition Executive, head of the DoD component, or Component Acquisition Executive unless otherwise delegated—determines if the program will continue to the next phase based on the justification for the chosen solution, how affordable and feasible the solution is, how adequate the cost, schedule, and technical risk mitigation plan is, and how effective the acquisition strategy will be (DoD, 2015a). This decision is known as Milestone A (DoD, 2015a). The MSA phase takes a broad look at the potential solutions to a stated need and as such, may be an appropriate place to consider strategic methodologies like BSC, KVA, or IRM.

After approval at Milestone A, the program enters the TMRR phase to reduce the risk associated with the technology, engineering, life-cycle cost, and integration of the program to begin the EMD phase (DoD, 2015a). Design and requirement trades occur at this point that are based on the budget, schedule, and likelihood of completion (DoD, 2015a). As the requirements mature, resulting in a finalized Capabilities Development Document (CDD) from JCIDS prior to the next milestone (DoD, 2015a). Guided by the acquisition strategy approved at Milestone A, contractors develop preliminary designs—including competitive prototypes if feasible within the program—to demonstrate the feasibility of their proposed solutions to the Program Office (DoD, 2015a).

Technology Readiness Levels (TRLs) serve as benchmarks that indicate the level of risk associated with a solution reaching maturation per the schedule (DoD, 2015a). Technology Readiness Assessments (TRAs) are systemic, metric-based method to evaluate the maturity and risk associated with the critical technology in an acquisition program

(DoD, 2011). A TRA will assign a TRL for each critical technology in a program, ranging from 1 to 9 from the lowest to highest readiness level (DoD, 2011). Additional methods, to assess the likelihood a program will remain on schedule and on budget may be beneficial at this stage, such as IRM. The Development Request for Proposals (RFP) Release Decision Point authorizes the release of a RFP with firm and clearly stated program requirements for contractors to submit their bids (DoD, 2015a). The Preliminary Design Review occurs prior to the completion of the TMRR phase unless waived by the milestone decision authority (DoD, 2015a). Milestone B approves a program to enter the EMD phase and awards a contract while establishing the Acquisition Program Baseline (APB) (DoD, 2015a). The APB describes the approved program, specifically the cost and schedule for the life of the program and is a formal commitment to the milestone decision authority (DoD, 2015a).

EMD begins once Milestone B is approved. During EMD, the materiel solution is developed, built, and tested to verify all requirements have been met prior to production (DoD, 2015a). Hardware and software designs are completed and prototypes are built to identify any deficiencies in the design, which will be discovered during developmental and operational testing (DoD, 2015a). DoD acquisitions programs with a contract value greater than $20 million are required by federal regulation to use EVM to track and report the progress of the program, which begins during this phase (DoD, 2019). Once a stable design that meets the specified requirements has been verified, the manufacturing or software sustainment processes and production capability must be properly demonstrated (DoD, 2015a). Milestone C confirms these requirements are satisfied and approves entry into the PD phase (DoD, 2015a).

The objective of the PD phase is to deliver a product that fulfills the requirements specified in the earlier stages (DoD, 2015a). Initial operational deployment and testing occurs with Low Rate Initial Production for manufactured systems or limited deployment for more software intensive programs where the system undergoes Operational Testing and Evaluation to verify stated requirements were met (DoD, 2015a). Once satisfied with the fielded systems, full rate production begins and the product is deployed to operational units (DoD, 2015a). Design changes are limited at this point, although some changes may still occur based on noted deficiencies (Housel, Mun, Carlton, & Jones, 2019). Contracts typically revert to a fixed price strategy during this phase, reducing PM’s focus on cost and schedule variance (Housel et al., 2019).

OS is designed to maintain support for the product and sustain its performance throughout its lifecycle, ending with the disposal of the system (DoD, 2015a). OS overlaps with the PD phase since operational units are using the product while production continues, beginning after the production or deployment decision (DoD, 2015a). PMs will sustain the system using the Life Cycle Sustainment Plan (LCSP) developed during the acquisition process, providing the necessary resources and support to keep the system operational (DoD, 2015a). Sustainment and support may include technological upgrades, changes due to operational needs, process improvements, and other activities that may require updates to the LCSP (DoD, 2015a). Due to the long term, relatively stable nature of the OS phase, LSS may be a useful methodology to reduce lifecycle cost. Once the system has completed its useful life, the PM oversees the demilitarization and disposal of the product (DoD, 2015a).

There are six different models, four standard and two hybrid, on which PMs create their program structure, depending on the type of system being acquired (DoD, 2015a). These standard models are templates for hardware-intensive programs, software-intensive programs that are defense unique, incrementally deployed software-intensive programs, and accelerated-acquisition programs (DoD, 2015a). As shown in Figure 3, the hybrid models mix the incremental nature of software development within a hardware centric program. In this model, software development is organized via a series of testable software builds that will culminate with the fully required capability before reaching the Initial Operating Capability (DoD, 2015a). The incremental builds are synchronized with hardware testing requirements for prototypes and other developmental requirements (DoD, 2015a). Other models, with the exception of the accelerated program, use the same basic framework within the five phases.

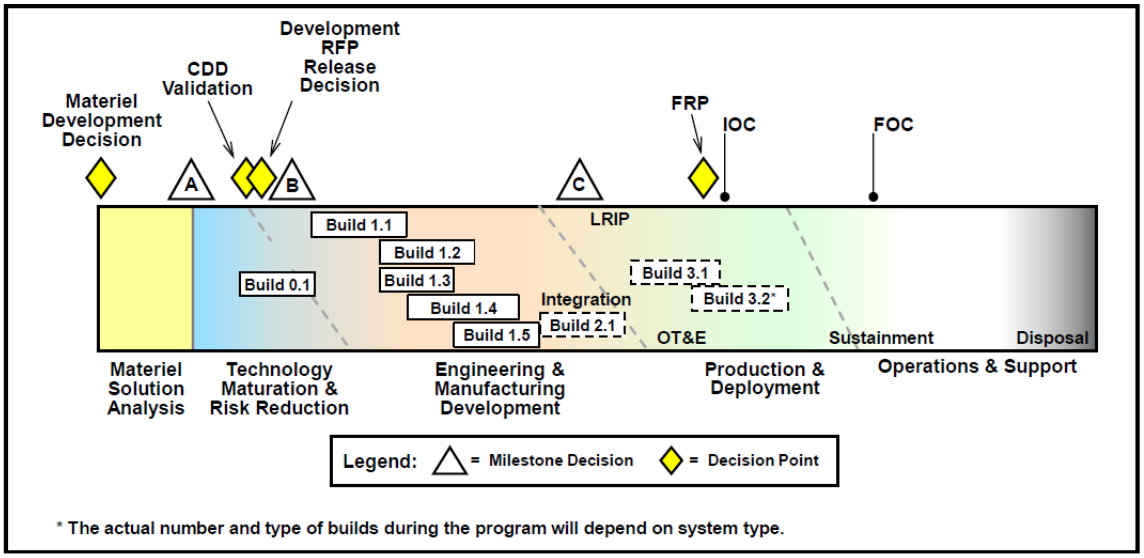


Figure 3. Hardware Dominant Hybrid Program. Source: DoD (2015a).

IS and IT systems are increasingly prevalent throughout the DoD along with their connection to weapon systems, facilities, and Command, Control, Communications, Computers, Intelligence, Surveillance, and Reconnaissance (C4ISR) (DoD, 2015b). With the integration, comes an increased security risk from adversaries, elevating the importance of effective cybersecurity capabilities and practices (DoD, 2015b). The DoD manages cybersecurity policy through the Risk Management Framework (RMF) by applying security controls founded on risk assessments throughout the lifecycle of a system (DoD, 2015b). RMF applies to “all DoD IT that receive, process, store, display, or transmit DoD information” (DoD, 2014, p. 2). Cybersecurity within RMF is more than simply information security, including items such as stable and secure engineering designs, training and awareness for all users, maintainers, and operators of a program, and the response, recovery, and restoration of a system following an internal or external failure or attack (DoD, 2015b). Figure 4 illustrates the six steps within the RMF. The RMF occurs throughout the acquisition process.

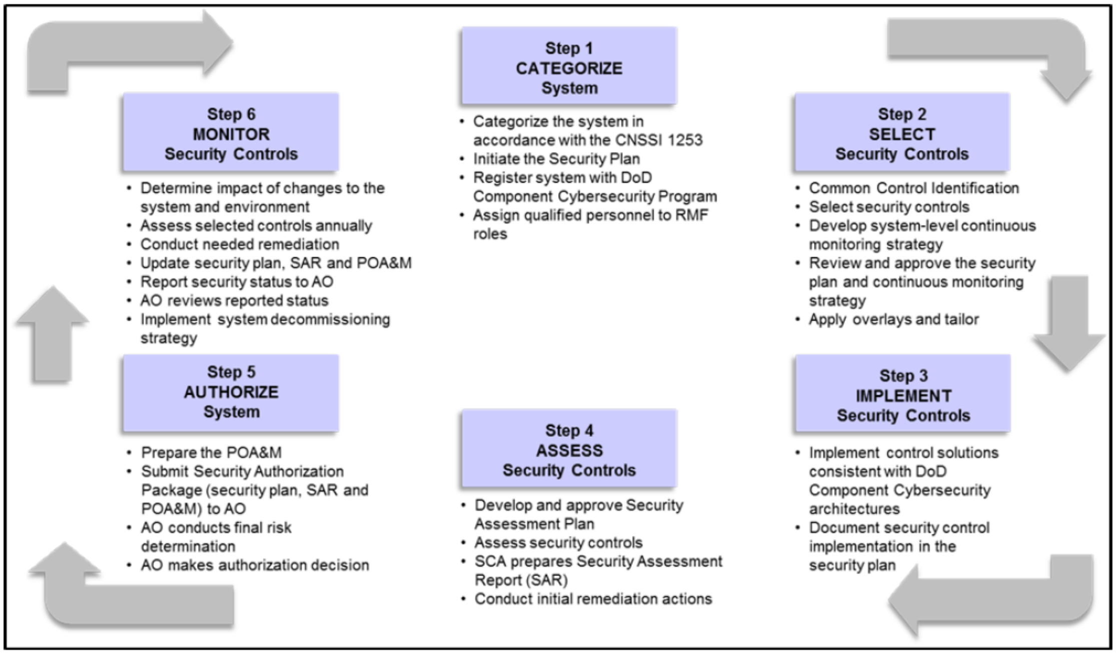


Figure 4. Risk Management Framework Process. Source: DoD (2014).

The first step is categorizing the system, during which the potential impact of a breach is analyzed and the system and its boundaries are described (DoD, 2014). The security plan is initiated, the system is registered with the DoD Component Cybersecurity Program, and the RMF team is formed (DoD, 2014). Cybersecurity requirements are included in the ICD, driving considerations in the MSA phase during the AoA (DoD, 2015b). The risk assessment considers the potential impacts on missions resulting from a cybersecurity breach (DoD, 2015b). The RMF provides a relatively objective method to determine the cybersecurity risk level that establishes the initial baseline security controls necessary, to ensure they are included in the acquisition plan for the system (DoD, 2015b).

In step two, the RMF team selects security controls, including those controls common to other DoD programs (DoD, 2014). A plan to continuously monitor the effectiveness of the controls is developed and documented (DoD, 2014). This plan is then submitted to the DoD components that review and approve the security plan (DoD, 2014). As the cybersecurity strategy is developed in the MSA phase, the acquisition and cybersecurity teams coordinate to ensure the appropriate level of security is implemented in the program throughout its lifecycle and in the system architecture and design (DoD, 2015b). The continuous monitoring strategy and security plan are also developed during MSA (DoD, 2015b).

Next, the approved security controls are implemented per DoD guidelines (DoD, 2014). The implementation must be appropriately documented in the system's security plan (DoD, 2014). Cybersecurity requirements are part of the system performance requirements in the TMRR phase (DoD, 2015b).

Then, the RMF team must develop, review, and approve a Security Assessment Plan that will allow proper assessment of the security controls (DoD, 2014). Once approved, the system security is assessed in accordance with DoD assessment procedures and the Security Assessment Plan, during which vulnerabilities are assigned severity values and the security risk for both the controls and the aggregate system is determined (DoD, 2014). This is documented in the Security Assessment Report, which is required before authorization of any system, and remediate actions on the security controls are conducted (DoD, 2014). The cybersecurity requirements stated in the Capability Development Document is validated during the TMRR phase prior to a Request for Proposals (DoD, 2015b). The Preliminary Design Review, which is also conducted during the TMRR phase, will include cybersecurity aspects, ensuring the approved plan is implemented in the chosen design and risks are mitigated to an appropriate level (DoD, 2015b). As the system develops in the EMD phase, all computer code follows applicable standards and secure coding practices with assessments conducted and documented in the Security Plan (DoD, 2015b).

Based on the recognized vulnerabilities, a Plan of Action and Milestones (POA&M) is created that identifies tasks needed to mitigate the vulnerabilities, resources necessary to complete the plan, and milestones towards completing tasks (DoD, 2014). The Authorizing Official receives the Security Authorization Package, who will determine if the risk level is appropriate prior to authorizing the system (DoD, 2014). Creation of the POA&M begins in the MSA phase and continues throughout system development (DoD, 2015b).

Finally, the security controls must be monitored throughout the life of the system to ensure any changes to the system or the environment do not negatively affect cybersecurity measures (DoD, 2014). Should someone detect vulnerabilities, the necessary remediation will be conducted and the security plan updated (DoD, 2014). Once a system is approved and operationally deployed, the cybersecurity is monitored in accordance with the continuous monitoring strategy and Security Plan (DoD, 2015b). New risk assessments are conducted when changes to the system, its environment, or the planned use of the system occur (DoD, 2015b). Should vulnerabilities occur, the PM updates Security Plan and POA&M to indicate how the vulnerability will be addressed (DoD, 2015b).

B. EARNED VALUE MANAGEMENT

Currently, the DoD uses EVM within the Defense Acquisition System to evaluate the progress of acquisitions. EVM is a system PMs use to integrate the work scope with the cost and schedule of that program to improve the control and planning of the acquisition. It establishes a baseline for the objectives of the program to measure cost and schedule performance while the project is being executed. EVM is used to identify problems, create corrective actions to fix those problems, and allow management to re-plan the program as required (Electronic Industries Alliance, 1998). The Federal Acquisition Regulation requires DoD acquisition programs whose contract value exceed $20 million are required to use EVM in the program office (DoD, 2019). Mandates within the federal government require reports on the progress and execution of acquisition projects, leading to an emphasis on performance measures.

In sum, EVM exists to provide an assessment of the actual, physical work a project has completed compared to a baseline plan (Fleming & Koppelman, 2010). In *Earned Value Project Management*, the authors explain that EVM integrates the actual cost spent on the project to date with the work that has been performed on the project, allowing managers to compare the progress of the project with their planned budget and schedule. It provides managers the ability to compare cost performance with work completion rather than simply cost performance and planned cost, as is done in traditional cost management (Fleming & Koppelman, 2010). According to Fleming and Koppelman (2010), when properly employed, EVM provides a reliable prediction of the total cost and schedule requirements for a project through three distinct dimensions: the planned value, earned value, and actual cost.

Planned value (PV), referred to within the DoD as Budgeted Cost of Work Scheduled (BCWS), is the amount of work, either physical or intellectual, scheduled to be completed by a certain point (Fleming & Koppelman, 2010). It is a time-phased budget reference and is used throughout the project as a baseline for the amount of work complete by the scheduled date (Vanhoucke, 2014). When depicted graphically (as in Figure 6), it is an upward-sloping function and shows the cumulative increase in all scheduled and budgeted activities from the beginning of the project until completion (Vanhoucke, 2014). Simply stated, BCWS is the authorized budget for authorized work (Fleming & Koppelman, 2010). This baseline should be established prior to a program's initiation and should remain constant throughout the program to maintain a fixed reference, although the baseline can be re-established if performance is drastically different from originally planned to improve future project control (Vanhoucke, 2014).

To establish a baseline, the scope of a project must be fully defined, the resources necessary to complete the project must be understood, and the compulsory tasks must be placed into the timeline required to complete each task (Fleming & Koppelman, 2010). "If you do not know what constitutes 100% of a project, how will you ever know if you are 10, 20, or 35 percent done?" (Fleming & Koppelman, 2010, p. 48). Project managers create a work breakdown structure (WBS) to produce an accurate baseline. A WBS is a division of tasks arranged in a hierarchical, tiered fashion portraying the breakdown of activities used to authorize, track, and report a program's progress. It relates the individual elements necessary to complete work to each other and the system as a whole (DoD, 2005). A WBS can be expressed in any level of detail, from high-level systems view, such as Figure 5, down to the distinct pieces of material needed to construct a component, depending on the level of detail needed (DoD, 2005). Within the 5000 series, the BCWS baseline is usually established during the TMRR phase.

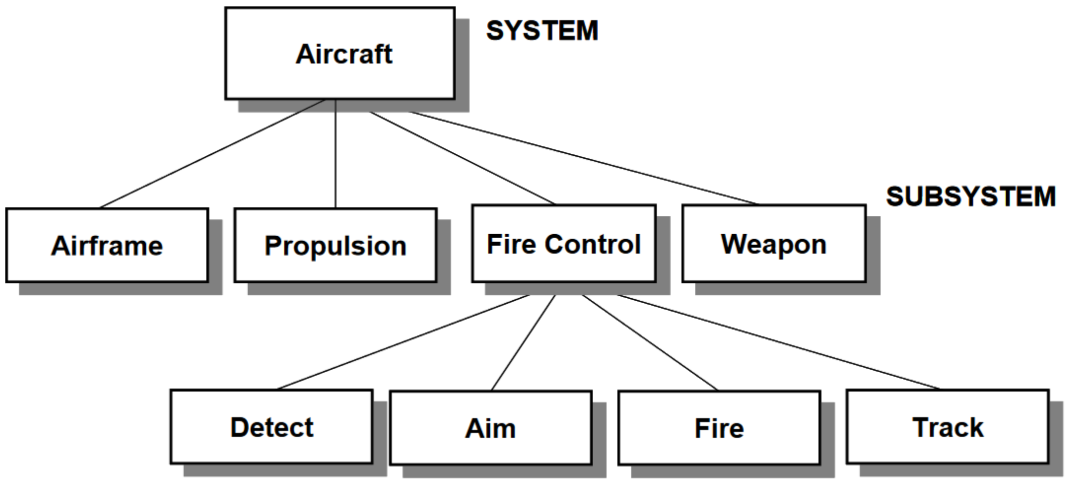


Figure 5. Sample WBS. Source: DoD (2005).

Earned value (EV), the second dimension within EVM, represents the amount of money from a project's total budget spent on the work accomplished at a certain point in time (Vanhoucke, 2014). Also referred to as the Budgeted Cost of Work Performed (BCWP), it shows the total budget of the completed work packages and finished sections of open work packages (DoD, 2019). BWCP is comprised of the amount of authorized work that was actually completed with the amount of the original budget for accomplishing the given work (Fleming & Koppelman, 2010).

The third dimension of EVM is actual cost (AC), or the Actual Cost of Work Performed (ACWP). ACWP is the cumulative total cost a program has spent to accomplish work at a given point in time (Vanhoucke, 2014). It measures the amount of money used to convert the planned value into earned value within the measured time frame (Fleming & Koppelman, 2010). ACWP depicts the amount of money spent on a project regardless of the output of the work. It is purely a financial metric illustrated over the elapsed time of a project and does not account for the amount of work actually accomplished.

Figure 6 gives a graphical depiction of PV (BCWS), EV (BCWP), and AC (ACWP) for a fictitious project. In blue is the PV, showing the amount of money budgeted to complete specific work packages based on the WBS. Green displays the budgeted cost of the work packages that have been completed at a specific time, or EV. At the project's completion, EV and PV are equal since EV is calculated as a percentage of the planned budget. AC, shown in red, portrays the money spent to complete the EV at the same point in time. Ideally, all three lines will overlap, indicating the project is exactly on schedule and budget. However, this is rarely the case and the differences indicate the need for additional information to determine what corrections are necessary, leading to the performance metrics.

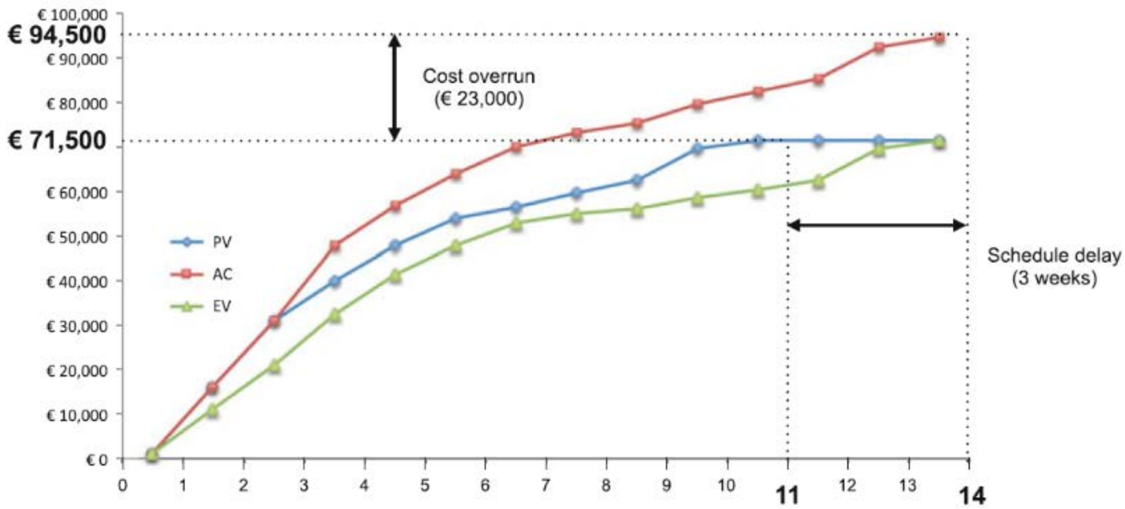
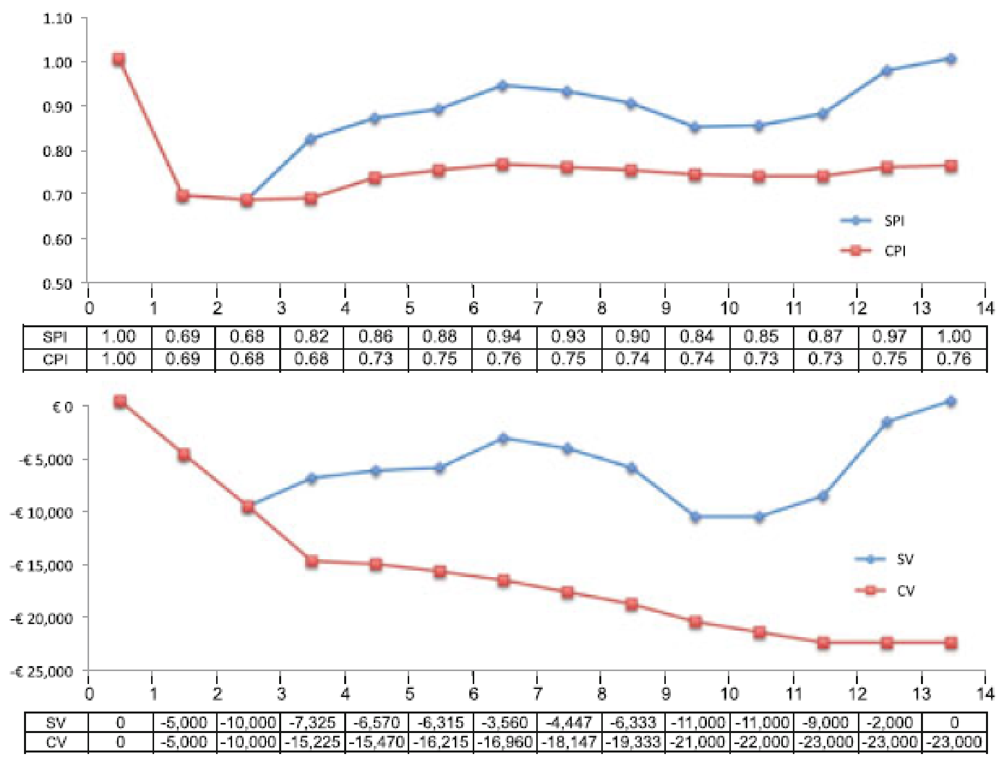


Figure 6. S Curve with the Three EVM Dimensions. Source: Vanhoucke (2014).

Four performance metrics within EVM provide indications of a program's current performance compared to the baseline cost variance (CV), cost performance index (CPI), schedule variance (SV), and schedule performance index (SPI) (DoD, 2019). CV determines the difference between the EV work completed and the AC: CV = EV – AC (Fleming & Koppelman, 2010). If the difference is less than zero, the project is over budget, greater than zero is under budget, and if equal to zero, the project is on budget (Vanhoucke, 2014). The CPI is the ratio of completed work to the budget, calculated by dividing EV by AC: CPI = EV/AC (Fleming & Koppelman, 2010). CPI can be used to forecast a range of total costs to finish a project based on the performance of the project to date (Fleming & Koppelman, 2010). If the CPI is greater than 1, the project is under budget, less than 1 is over budget, and if equal to 1, the project is on budget (Vanhoucke, 2014). Both CV and

CPI measure the deviation in the value of the completed work (EV) and the cost of the work (AC) (Vanhoucke, 2014). Figure 7 shows the performance metrics from the example project in Figure 6 with CV and CPI in red. The CPI drops to roughly 0.7 in just over a week before maintaining a relatively constant level, indicating the project is over budget, while the CV continues to become increasingly negative, showing the increasing amount of money spent above what was budgeted (Vanhoucke, 2014). Although the magnitude of the CV continued to increase, the CPI remained constant, denoting the project continued to earn value at 70% of the planned rate.



SPI	1.00	0.69	0.68	0.82	0.86	0.88	0.94	0.93	0.90	0.84	0.85	0.87	0.97	1.00
CPI	1.00	0.69	0.68	0.68	0.73	0.75	0.76	0.75	0.74	0.74	0.73	0.73	0.75	0.76

SV	0	-5,000	-10,000	-7,325	-6,570	-6,315	-3,560	-4,447	-6,333	-11,000	-11,000	-9,000	-2,000	0
CV	0	-5,000	-10,000	-15,225	-15,470	-16,215	-16,960	-18,147	-19,333	-21,000	-22,000	-23,000	-23,000	-23,000

Figure 7. Example Performance Metric Curves. Source: Vanhoucke (2014).

Similarly, SV and SPI compare the performance of a project with respect to its planned schedule. In the same manner that CV and CPI examine cost, these metrics quantify the divergence in the value of the completed work (EV) and the amount of value expected at a given point in time (PV) (Vanhoucke, 2014). SV is the difference between the EV work completed and the PV: SV = EV – PV (Fleming & Koppelman, 2010). If the difference is less than zero, the project is behind schedule, greater than zero is ahead of schedule, and if equal to zero, the project is on schedule (Vanhoucke, 2014). SPI is the ratio of completed work to the scheduled time that work was completed, calculated by dividing EV by PV: SPI = EV/PV (Fleming & Koppelman, 2010). This ratio can be used to estimate the project completion date (Fleming & Koppelman, 2010). If the SPI is greater than 1, the project is ahead of schedule, less than 1 is behind schedule, and if equal to 1 the project is on schedule (Vanhoucke, 2014). Once again, Figure 7 shows the SPI and SV for the previous project in blue. The SPI initially dips to roughly 0.7 before climbing back to 1 at the end of the timeline, while SV varies in a correlated curve until increasing back to 0 at the completion of the project (Vanhoucke, 2014). This indicates a slower start to the project and a recovery towards the schedule as work proceeds, even though SV never equals 0 and SPI never equals 1—the corresponding values for on-schedule performance—until the conclusion. While it may not be initially evident, this tells project managers the program did not finish within the planned timeline.

It is important to note the term *value* in EVM does not have the same meaning as in other methodologies, such as KVA. Within the context of EVM, *value* is defined as the work accomplished towards completion of the project. There is no reference to the quality of the completed work or additional (or missing) benefits the work might provide to a system. The value is assumed because the specifications were defined in the project requirements.

EVM has proven to be a reliable system to manage cost and schedule performance for manufacturing in both defense and commercial industries. However, as systems become more complicated and information technology (IT) and IS gain a more prominent place within even traditional manufacturing projects, EVM may need additional information from additional methodologies to improve its capabilities. Better incorporating the strategic guidance associated with a program, the value gained from subcomponents and sub-processes, the risk associated with developing subcomponents of a system, and incrementally improving a process may help improve the Defense Acquisition System as a whole.

C. BALANCED SCORECARD

BSC is a system designed by Robert Kaplan and David Norton to incorporate financial and non-financial measurements when assessing a company's performance (Keyes, 2011). Traditional accounting metrics, such as ROI and earnings-per-share, do not necessarily indicate long-term improvement or innovation (Kaplan & Norton, 1992). It is also important to place value on the intangible assets within a company (Keyes, 2011). BSC is founded on the concept that "what you measure is what you get" (Kaplan & Norton, 1992, p. 71). By developing measurements for an organization's intangible components, these aspects of a business should also improve. When properly employed, BSC gives managers complex information about the entire system in a readily identifiable format (Kaplan & Norton, 1992). Effective measurement is a key component of leading an organization, and the BSC methodology allows managers to focus their performance measures towards a comprehensive strategy for both present and long-term success (Kaplan & Norton, 1993).

The BSC concept is not an overly complex process. After an organization has determined its vision or mission, it then develops a strategy (Kaplan & Norton, 1993). The scorecard stems from the strategy, translating the vision into objectives and measures (Norreklit, 2000). Four categories—financial, customer satisfaction, internal business processes, learning and growth—within each scorecard correspond with separate but related components of a business, each of which answer a basic, but crucial, question (Kaplan & Norton, 1992). Figure 8 illustrates the various categories, the questions they address, and their interdependence. Limiting the BSC to only four categories minimizes information overload and concentrates efforts on specific, attainable objectives (Kaplan & Norton, 1992). Selecting a limited number of categories, and metrics within each category, focuses effort and helps define the strategic vision (Kaplan & Norton, 1993). Presenting the categories via the BSC assimilates seemingly contrasting components within a company's agenda in a single report (Kaplan & Norton, 1992). It allows leadership to determine if the company achieved success in one area, for instance, financial success, at the expense of another area, such as learning and growth (Kaplan & Norton, 1992).

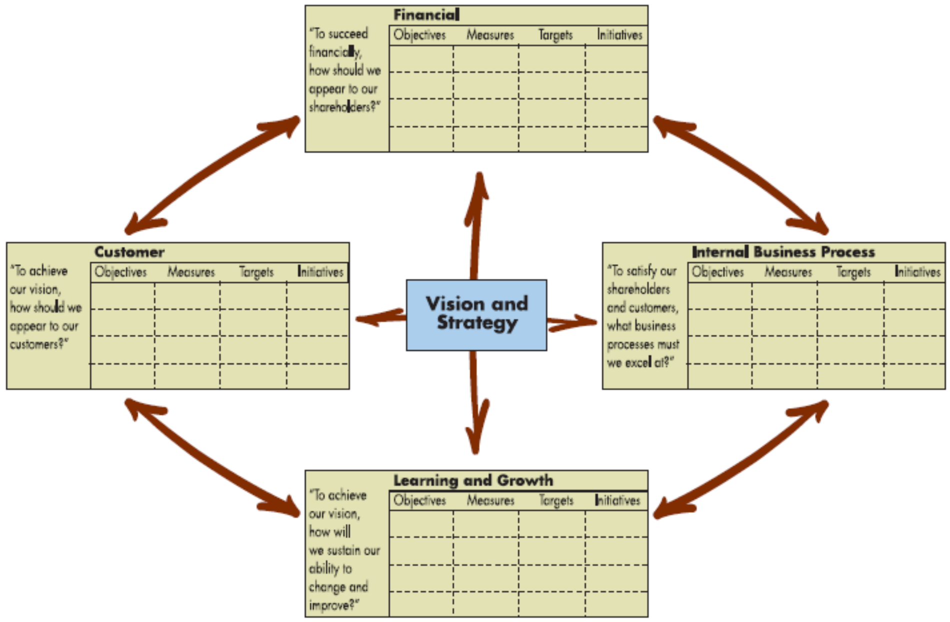


Figure 8. The Balanced Scorecard Framework. Source: Kaplan & Norton (2007).

Within each category, leadership sets goals for the company to achieve (Kaplan & Norton, 1992). For each goal on the scorecard, there is a corresponding measurement (Kaplan & Norton, 1992). Without a measurement, there is no way to objectively determine the performance towards each goal. Customer concerns often relate to time, quality, service level or performance, and cost (Kaplan & Norton, 1992). While the measures will vary for each company, aspects such as lead time, customer surveys, and third-party awards could indicate a company's customer performance (Kaplan & Norton 1992). Within the military, customer concerns- with the customer being the warfighter- are similar, relating to the accuracy of information and ordnance, timeliness of information and responses, overall performance, and cost to acquire the system. Measurements could compare the newly acquired system to the previous method for accomplishing tasks.

Internal business perspective addresses what the company can do to meet the expectations of its customers (Kaplan & Norton, 1992). As such, metrics should deal with components that will affect their customers—cycle time, quality, productivity, and so on—as well as the core competencies of the business (Kaplan & Norton, 1992). These same metrics also work within the DoD. The cycle time, quality, and productivity translate into a quicker response on the battlefield for the warfighter or for administrative tasks when away from the front. Readiness is an additional metric that should be included in this category, indicating how prepared a unit is to complete its mission.

Learning and growth concentrates on an organization's ability to transfer knowledge and innovate (Kefe, 2019). Measurements for the learning and growth category could include the amount and effectiveness of training or the employee retention rate (Kefe, 2019). The DoD can implement the same metrics within the military to analyze how effective it is at promoting learning and growth. When viewing all acquisition programs as a portfolio of projects, decision makers could determine how a potential IS or IT system may influence the organization's ability to transfer knowledge.

Financial measurements consist of a business's profitability, growth, and creation of value (Kefe, 2019). These are typically measured by traditional financial metrics, such as profit margin or return on investment (ROI), revenue to assets ratio, and market value added or stock price, respectively (Kefe, 2019). Since the DoD does not generate profit, these metrics are not as appropriate within defense acquisitions. However, evaluating the value of a system compared to the cost (or cost savings) associated with the system can provide useful financial metrics. A method to determine this value is discussed in the KVA section.

Leadership should use four management processes when implementing BSC (Kaplan & Norton, 2007). Figure 9 illustrates these cyclical processes. First, leadership should translate the vision to useful terms (Kaplan & Norton, 2007). Broad, strategic statements do not always transfer well to the operational level, so the strategy must be converted into goals and objectives (Kaplan & Norton, 2007). Next, managers must communicate the strategy throughout the organization and link their department's goals and objectives to the overarching vision (Kaplan & Norton, 2007). This includes linking the rewards and performance system to BSC metrics (Kaplan & Norton, 2007). Then, the business plan should be adjusted as necessary to reflect the BSC, ensuring targets are appropriately set and a suitable amount of resources are allocated to meet the stated objectives (Kaplan & Norton, 2007). Finally, establishing a feedback and learning system with the BSC at its center will allow managers to monitor performance, evaluate strategy, and adjust objectives as needed (Kaplan & Norton, 2007).

BSC could provide valuable perspective to the DoD when determining how to fill a specified need. Linking the various categories to acquisition categories could help determine the best solution for an IS or IT need. Rather than looking at each acquisition as an individual system, a BSC approach could help decision-makers assess the needs of the organization rather than just state requirements for a single program. However, the DoD Decision Support System does incorporate some of these considerations already, specifically in the interaction between JCIDS and the Defense Acquisition System, which may diminish some advantages typically gained from using BSC.

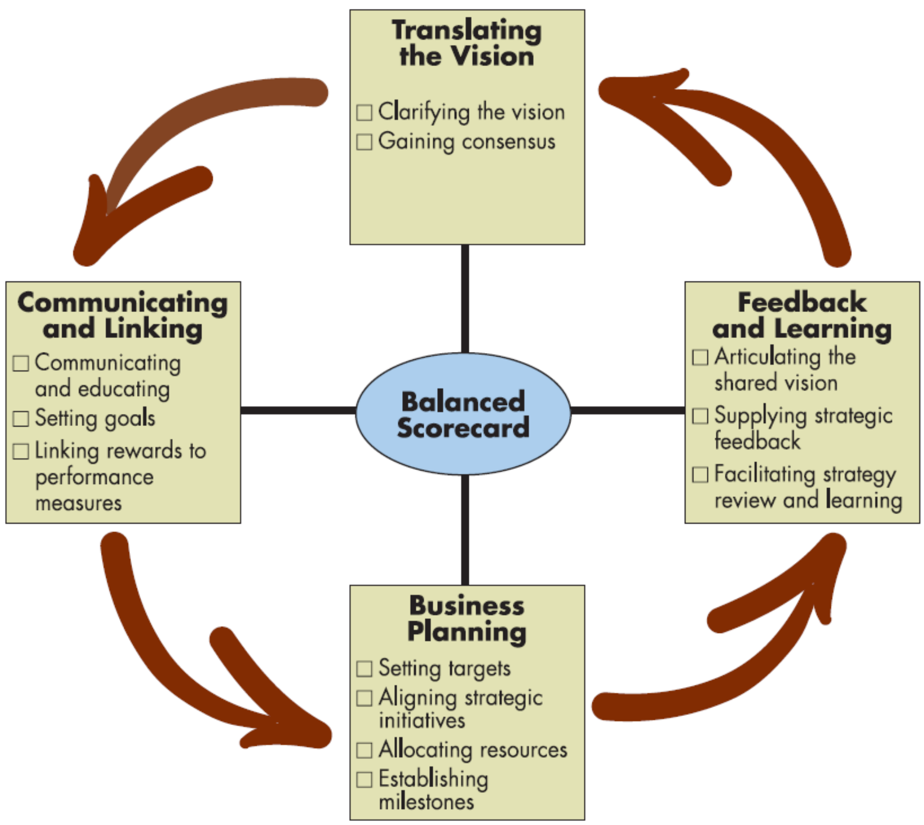


Figure 9. Managing Strategy. Source: Kaplan & Norton (2007).

D. KNOWLEDGE VALUE ADDED

KVA is an empirical model that focuses on the practical application and implementation of knowledge management (Tsai, 2014). Originally developed to assist in business process reengineering, KVA creates an objective, quantifiable method to measure the value of a process or service (Housel & Kanevsky, 1995). Typical financial approaches to business process reengineering use the dollar amount of a final product to determine the value of an object, failing to account for the knowledge required in the various sub-processes involved in making the product (Housel & Kanevsky, 1995). In its essence, KVA does a single function, describing all process outputs in common units. KVA accounts for the value of all components, processes, and support systems necessary to complete a task or create a product or service by describing all outputs in common units. It allows managers to compare the efficiency of the various steps across all processes within a common value reference point.

In KVA, value has a different meaning than it does in other methodologies, such as EVM or LSS. Instead, KVA bases its definition of value on complexity theory and views organizational processes by their ability to change their input—be that raw material, information, energy, etc.—into a common units of output, as shown in Figure 10 (Housel & Kanevsky, 1995). Per Figure 10, process P changes the input in some manner, creating a different product or service at the output, adding value to the system based on the number of common unit changes from input to output (Housel & Kanevsky, 1995). If process P did not change input X, then output Y is the same as input X, indicating no value was added by the system (Housel & Kanevsky, 1995). While the change from X to Y may be minute or large depending on the process, KVA converts all changes into common units, and these changes indicate the amount of value added by process P to produce the final product. The value generated through the process is proportional to the change in the state from X to Y, denoting the amount of knowledge required to make the changes (Yu, Chang, Yao, & Liu, 2009). Thus, the contribution to a process is equivalent to the sum of all knowledge necessary to produce a product and/or interpret meaning from an input (Housel & Kanevsky, 2006). This is true for all processes within a system, from production to service to management.

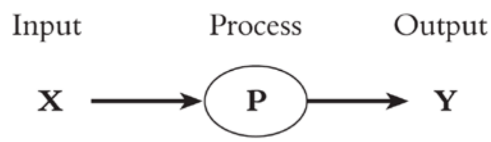


Figure 10. Value Added Process. Source: Housel & Kanevsky (1995).

The KVA methodology is best completed by following the seven-step process shown in Figure 11. Housel and Bell explain in their 2001 book, *Measuring and Managing Knowledge*, practitioners can use a number of methods to describe the units of change, such as tasks, Haye knowledge points, Shannon bits, units of knowledge, etc. For ease of measurement, they continue, three measures are typically used within KVA to estimate the embedded knowledge within a process. According to the authors, learning time, column two in Figure 11, measures the length of time it takes an average user to learn a process and correctly complete it. Process description, column two, is the number of process instructions used to transform the given input into the desired output (Housel & Bell, 2001). Housel and Bell note that each instruction must require an approximately equal amount of knowledge to complete a task. The binary query method uses the number of binary questions (i.e., bits) necessary to accomplish the process, roughly equivalent to the lines of code within a computer program (Housel & Bell, 2001). However, the authors assert that any measure that satisfies the basic concepts of KVA can be used to create a common-units measure.

Steps	Learning time	Process description	Binary query method
1.	Identify core process and its subprocesses.		
2.	Establish common units to measure learning time.	Describe the products in terms of the instructions required to reproduce them and select unit of process description.	Create a set of binary yes/no questions such that all possible outputs are represented as a sequence of yes/no answers.
3.	Calculate learning time to execute each subprocess.	Calculate number of process instructions pertaining to each subprocess.	Calculate length of sequence of yes/no answers for each subprocess.
4.	Designate sampling time period long enough to capture a representative sample of the core process's final product/service output.		
5.	Multiply the learning time for each subprocess by the number of times the subprocess executes during sample period.	Multiply the number of process instructions used to describe each subprocess by the number of times the subprocess executes during sample period.	Multiply the length of the yes/no string for each subprocess by the number of times this subprocess executes during sample period.
6.	Allocate revenue to subprocesses in proportion to the quantities generated by step 5 and calculate costs for each subprocess.		
7.	Calculate ROK, and interpret the results.		

Figure 11. The KVA Approach. Source: Housel & Bell (2001).

The first step, regardless of which metric an analyst employs, is identifying the core process and its sub-processes (Housel & Bell, 2001). To fully understand and accurately measure the knowledge inherent in a process, the entirety of the process must be mapped and understood. Next, analysts determine the measure that will be used in the analysis to describe the sub-process outputs in common units (Housel & Bell, 2001). Learning time or lines of code are the commonly used units as they can be used to convert outputs into common units relatively quickly depending on the degree of accuracy required. Analysts must then calculate the number of units (i.e., learning time, tasks, or lines of code) within each sub-process (Housel & Bell, 2001). Then, the actual measurement of output occurs over a specified period of time (Housel & Bell, 2001). The sample period will vary from system to system depending on the complexity and the length of each process. After determining the output for a standard execution of the process and the corresponding unit of measure (i.e., learning time, tasks, or lines of code) is established, the output is multiplied by number of times each sub-process is used during the sample period (Housel & Bell, 2001). Next, a proportion of revenue (i.e., in for-profit organizations) is allocated to each of the sub-processes relative to the results from the previous step and costs are calculated for each process (Housel & Bell, 2001). In the case of not-for-profits (e.g., DoD organizations), a market comparable aggregate revenue estimate can be calculated which provides a means to establish a price or revenue per common unit of output. Finally, analysts should determine the Return on Knowledge (ROK: monetized or non-monetized output divided by cost) and interpret the results (Housel & Bell, 2001). Analysts should use two or more estimates of output based on method selected for describing the output (e.g., learning time, lines of code). These estimates can then be correlated to determine the reliability of the estimates. Those estimate with a resulting high correlation, ensure the reliability of the value calculations (Housel & Bell, 2001).

ROK, an important concept within KVA, is a ratio used to determine the value added from knowledge assets within the system (Housel & Bell, 2001). It is calculated by dividing the knowledge embedded within a process and its frequency of use by the cost associated with operating that process (Housel & Bell, 2001). ROK can be calculated for any manual or automated activity, IT system, and even management activities that have been observed and measured via the KVA approach due to the knowledge embedded in all of these processes. A higher ROK indicates more value returned for each dollar spent on the process (Housel & Bell, 2001). ROK gives managers a common reference point, objective way to examine the benefit and value of a process compared to other processes, allowing leadership to manage their processes within a portfolio framework to determine which, if any, process might benefit from moving knowledge from employees to automation (i.e., artificial intelligence, robotics, online applications) to make substantial improvements in productivity.

Figure 12 shows a rudimentary analysis of maintenance actions within a Marine Corps Motor Transport platoon via the learning time method previously discussed. The exercise was conducted to ascertain if an IT system would improve the timeliness of maintenance procedures while maintaining the same value in the output (Carlton, Ellis, Jones, & Schofield, 2019). Total knowledge was calculated by establishing the total amount of formal training required to complete a given task, including initial and recurring training (Carlton et al., 2019). Expenses were estimated by multiplying the average salary of the Marine performing the work and the average time to complete the task (Carlton et al., 2019). The ROK was computed by dividing the total knowledge (output within a productivity ratio) by the expenses (the cost component of the productivity ratio) (Carlton et al., 2019). After establishing the baseline, as-is measurements, the team estimated the time necessary to complete each task (Carlton et al., 2019). Some steps within the process were automated using the proposed IT system, reducing the cycle time. However, total knowledge remained constant since the output from both the as-is and to-be processes were equal. ROK form the to-be process increased compared to the as-is process, suggesting the proposed IT solution will either improve performance or reduce cost (Carlton et al., 2019). Since the total knowledge remained the same, this change suggests cost will be reduced. A more detailed example is presented in the next chapter.

As-Is Process

Process Description	Total Knowledge	Expenses ($)	ROK
Open SR	4320.00	$ 1,663.70	260%
Induction	87360.00	$ 3,327.39	2625%
Order Parts	10080.00	$ 332.74	3029%
Supply Opens Parts Requisition	20160.00	$ 1,663.70	1212%
Receive Part	41040.00	$ 1,996.43	2056%
Perform Maintenance	109920.00	$ 13,309.57	826%
Final Inspection	87360.00	$ 3,327.39	2625%
Totals	**360240.00**	**$ 25,620.91**	**1406%**

To-Be Process

Process Description	Total LT (Hrs)	Expenses ($)	ROK	ROK w/ Acq Costs
Open SR/Induction/OrderParts	101760.00	$ 3,992.87	2549%	2398%
Supply Opens Parts Requisition	20160.00	$ 1,663.70	1212%	1053%
Receive Part	41040.00	$ 1,996.43	2056%	1827%
Perform Maintenance	109920.00	$ 13,309.57	826%	811%
Final Inspection	87360.00	$ 3,327.39	2625%	2442%
Totals	**360240.00**	**$ 24,289.96**	**1483%**	**1468%**

Figure 12. Sample KVA Tables. Source: Carlton et al. (2019).

KVA is potentially an extremely valuable tool for inclusion in the Defense Acquisition System. Since the DoD is not a for-profit company, it does not have revenue to judge the effectiveness of its programs. Instead, it relies on various metrics and evaluations that are not comparable from system to system. If the DoD implements the KVA methodology, PMs may have an objective measure to compare various technological solutions to fulfill requirements. Understanding the value a system or process provides in direct comparison with the value of other systems, whether they are similar or unrelated processes, and this could provide beneficial information in the decision-making, budgeting, and planning processes.

E. INTEGRATED RISK MANAGEMENT

IRM is a system developed by Dr. Jonathan Mun designed to provide management the ability to analysis risk associated with the development of a new project or initiative. IRM combines several commonly accepted analytical procedures, such as predictive modeling, Monte Carlo simulation, Real Options analysis, and portfolio optimization, into a single, comprehensive methodology. The methodology uses existing techniques and metrics such as discounted cash flow, ROI, and other metrics within the analytical processes to improve the traditional manner of evaluating potential projects within a company or the DoD. In contrast to the other methodologies, IRM focuses on the risk involved with a decision. It seeks to mitigate negative effects from risk while maximizing rewards from potential outcomes. At its core, IRM is a technique to provide managers the best analytic information available to use during the real options process.

There are eight steps within the IRM methodology:

1. Qualitative management screening

2. Forecast predictive modeling

3. Base case static modeling

4. Monte Carlo risk simulation

5. Real options problem framing

6. Real options valuation and modeling

7. Portfolio and resource optimization

8. Reporting, presenting, and updating analysis

While each of the individual steps provide value to a project manager, incorporating all of them in a contiguous approach will allow decision makers the most effective use of the IRM process.

Figure 13 illustrates the comprehensive IRM process. The process begins with a qualitative management screening of potential projects, assets, and initiatives that could benefit the organization. These potential additions to a company's portfolio should align with the overall strategy, mission, and goals of the company (Mun, 2016). The risks to an organization must be identified and addressed for decision-makers to have a realistic picture of the challenges the projects may face (Mun, 2016). This step is not unique to IRM. Prior to a firm beginning any venture, senior leadership should ensure that the ventures they are funding are realistic options based on their expertise and vision. If these are not in alignment, the initiatives will almost certainly fail. However, by evaluating the suitability of the projects and programs at the outset, management can eliminate potential programs that are incompatible prior to additional costly analysis.

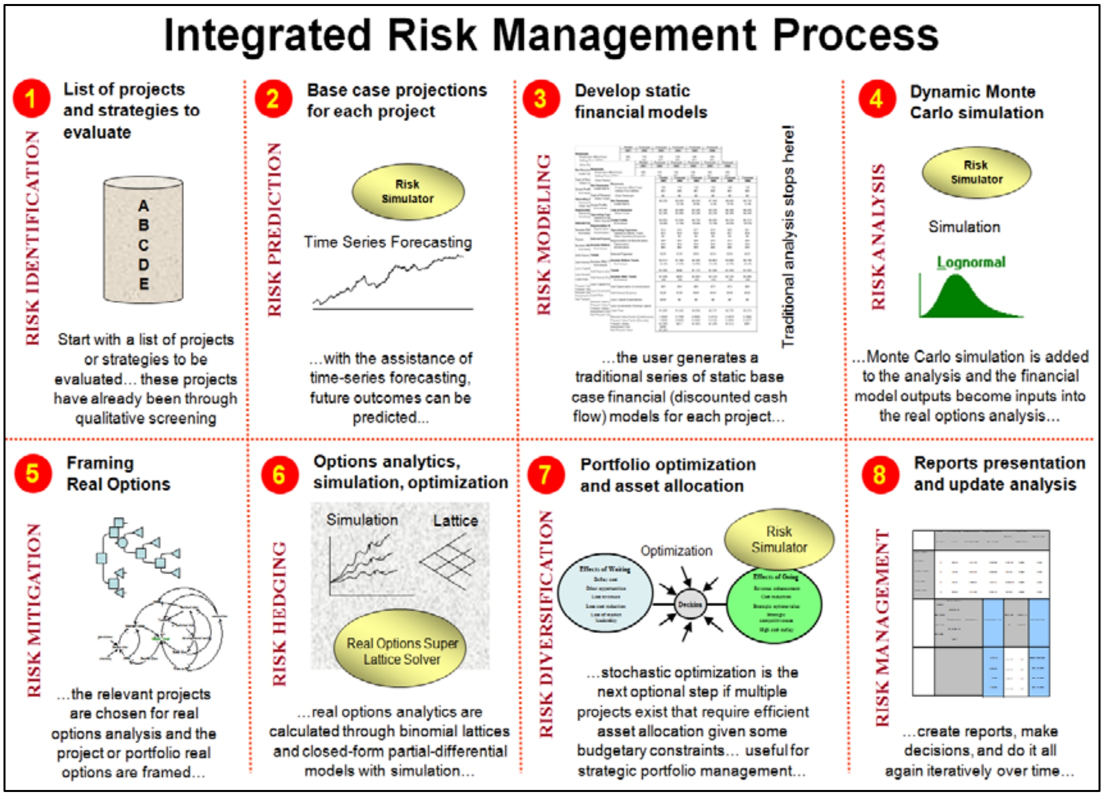


Figure 13. Integrated Risk Management Process. Source: Mun & Housel (2010).

The second step is to forecast results using predictive modeling. Ideally, management will have access to historical data to use during this evaluation. Using comparable data from similar firms or projects is an acceptable alternative when the historical information is not available. When analysts have access to this data, they will use techniques such as multivariate regression analysis, time-series analysis, and others to predict a project's performance (Mun, 2016). If the data are unavailable, qualitative forecasting methods and subject matter expert estimates can be substituted for the historical or comparable information (Mun, 2016). The qualitative techniques can vary from assumptions about the growth rate to expert opinions, subjective estimates, and the Delphi method (Mun, 2016). In both cases, the techniques are forecasting value and cost drivers within the project (e.g., quantity, volume, production, revenue, cost, schedule, etc.) (Mun, 2016). In a nonprofit context such as the DoD acquisition life cycle, surrogates should be used for revenue. The metrics that will define the value of a project can be projected in this analysis in place of for-profit financial measurements.

Using the results from the forecasting step, a model of discounted cash flow or similar models with a future projection of cost and benefit is created for each project, which serves as the base case analysis for future decisions (Mun, 2016). The net present value (NPV) or other ROI for the initiative is calculated via the traditional method, i.e., projecting both revenue and cost and discounting the net value at an appropriate rate adjusted for standard financial risks (Mun, 2016). Additional profitability, productivity, and cost-benefit metrics, such as other variations of return on investment, are calculated during this phase (Mun, 2016). The DoD and other nonprofit organizations do not collect revenue, making the profitability ratios listed meaningless without a surrogate for revenue. (KVA offers this surrogate in the form of value. Using KVA as the base case analysis allows a quantitative, common-units comparison of nonprofit projects in the same manner as a traditional, revenue-generating industry.)

Next, the analyst will conduct a Monte Carlo risk simulation to obtain a better assessment of the potential risks and value of the proposed venture. While the base case static model developed in step three is a useful tool, it is based on static information and, as such, produces a single-point estimate (Mun, 2016). The information gleaned from the model may not be accurate due to the uncertainty and risks involved in future cash flows (Mun, 2016). Since financial problems inherently contain uncertainty of some form, a model that accounts for this uncertainty is necessary (Brandimarte, 2014). The Monte Carlo simulation will increase confidence in the value of a project by using statistical analysis to give a probability of ranges for different variables.

Monte Carlo simulation, also known as probability simulation, "is a technique used to understand the impact of risk and uncertainty in financial, project management, cost, and other forecasting models" (Risk Amp, n.d., p. 1). In a Monte Carlo simulation, analysts generate random scenarios and gather relevant statistics to assess situations that are affected by uncertainty (Brandimarte, 2014). Using historical data and the opinions of subject matter experts, analysts can input a range of possible values to simulate potential future outcomes (Risk Amp, n.d.). Since the input variables are given in a range of estimates, the model’s outputs will also be a range indicating the likelihood of the possibilities. (Risk Amp, n.d.). The Monte Carlo simulation can also be run using only historical data and the computer will make a custom distribution of the variables to produce its output or with a prescribed probability distribution (Mun, 2015). In IRM, the analyst will set NPV or any of the computed ROI variations as the resulting variable(s) and run the Monte Carlo simulation thousands of times, adjusting each of the other variables to predict a range and probability of potential NPVs for the project (Mun, 2015).

The quantitative data gleaned from the Monte Carlo simulation is only useful if it provides decision-makers with improved information to make decisions. The information must be converted into actionable intelligence (Mun, 2016). While the statistical analysis and other preceding steps are important, the crux of the IRM methodology is the real options assessment. To begin that process, leaders must conduct real options problem framing, step five in the IRM methodology. Real options allow managers to hedge, value, and take advantage of risks, reducing the potential downside while maximizing potential gains from volatile projects (Mun, 2016). By framing the problem through a real options lens, an organization’s leadership can generate a strategic plan for the problem from several options, (Mun, 2016). Analysts will then examine chosen options in more detail (Mun, 2016).

Real options provide investors the ability to adjust the course of previous decisions based on the performance of the investment to date. They allow management to make “better and more informed strategic decisions when some levels of uncertainty are resolved through the passage of time, actions, and events” (Mun, 2015, p. 438). Options are opportunities for a company; they have a right to conduct an action without the obligation to take the future action (Dixit & Pindyck, 1995). There are several types of options and the number of names of available options varies depending on the literature source. Some of the more common categories are briefly covered below.

The option to delay gives managers the ability to adjust the timing of a project (Damodaran, 2000). When analyzing the cash flows of a project, a negative NPV or ROI indicates a project is not a good investment at the current time (Damodaran, 2000). As illustrated in Figure 14, waiting until the NPV turns positive allows an organization the option to delay the initiative until it will benefit the company. NPV is not the sole source to make an option decision within IRM and is included to illustrate the concept in a simple manner. The statistical analysis conducted in previous steps allows analysts to determine the optimal time to make project investment decisions. This option is also referred to as a deferment option, option to wait, or option to execute (Mun, 2015). The option to delay is often executed through pre-negotiated prices or similar contracted terms that offer the choice to purchase something without an obligation to do so (Mun, 2015). These terms could include options based on a build, buy, or lease contract; a proof of concept test; market research; research and development; or other negotiated terms (Mun, 2015).

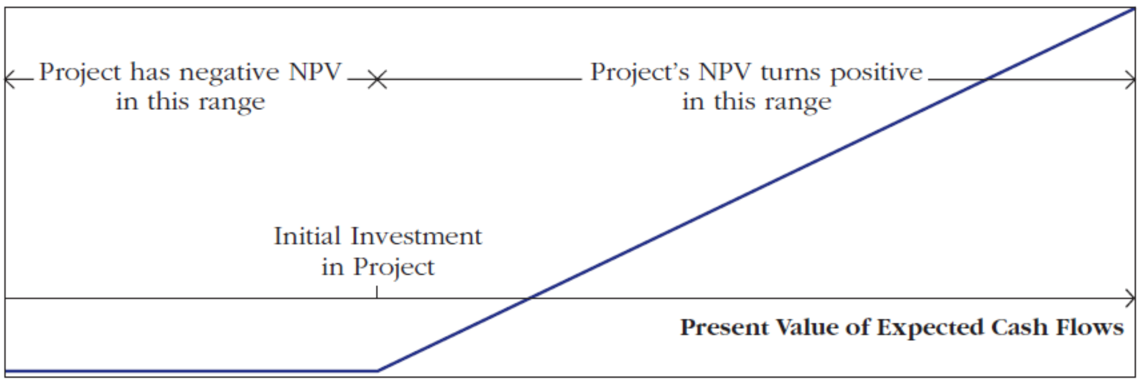


Figure 14. The Option to Delay. Source: Damodaran (2000).

The option to abandon a project provides management a way to reduce future losses in a project that is not performing as anticipated (Damodaran, 2000). Figure 15 shows one example when the option to abandon should be considered. As the present value of the project decreases below the liquidation or salvage value of the project, managers should abandon the project and salvage as much as possible from the existing infrastructure and investment (Damodaran, 2000). Salvage is not the only way to execute the option to abandon. Companies can also execute the option to abandon through contractual buyback provisions, termination for convenience, divestitures, or early exit clauses (Mun, 2016).

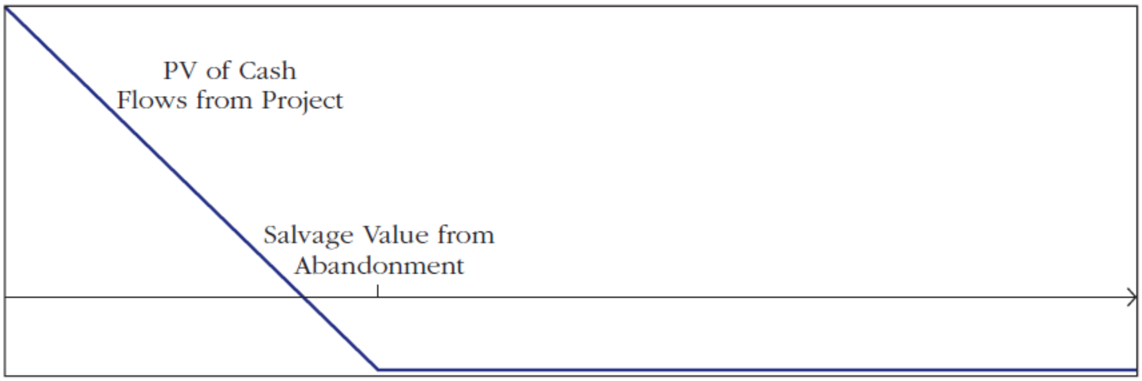


Figure 15. The Option to Abandon. Source: Damodaran (2000).

A third real option available to leaders is the option to expand (Damodaran, 2000). In this instance, an investment in a project allows a company to undertake additional projects or to enter new markets, expanding the scope of the original investment (Damodaran, 2000). While not always the case, businesses may be willing to accept a negative NPV for the initial project to have access to the expansion options it will create with the promise of higher NPVs (Damodaran, 2000). By investing in the original initiative and maintaining the option to expand, the company is limiting the potential upside from an initial investment into the entire project; however, it is also reducing the downside risk of a failed, high capital investment (Damodaran, 2000). For example, a company may recognize a potential market in creating a suite of sensors for a new autonomous vehicle. Without the existing infrastructure to compete in this market, leadership decides to develop a project that will create a single sensor for the vehicle. When the project is completed, managers assess the financial feasibility of creating additional sensors. The original investment must be a requirement for the subsequent project to be an option to expand. That is, the additional sensors could not be developed without the investment into the first sensor. Otherwise, these are simply a collection of separate but related projects.

Other real option strategies include barrier options, chooser options, contraction options, sequential options, and switching options (Mun, 2016). Barrier options become available when an artificial barrier is either breached or not breached (e.g., profits exceed a certain level or vendor prices fall below a specified threshold) (Mun, 2015). Chooser options permit management to choose between one or multiple strategies, such as expanding, abandoning, etc. (Mun, 2015). Contraction options allow a firm to contract its existing operations to cut operating expenses under certain conditions (Mun, 2015). This could happen through outsourcing, subcontracting, leasing, or other alternatives (Mun, 2015). Sequential options require a previous option to successfully finish prior to initiating a subsequent option, compounding the options and reducing the downside risk from a large up-front investment (Mun, 2015). Finally, switching options provide management the ability to switch operating conditions, such as technologies, markets, or products (Mun, 2015). This type of option gives a firm strategic flexibility in choosing a course of action, keeping its current project while exploring possible substitutions (Mun, 2015).

After determining which real option may be appropriate, analysts conduct simulations on the chosen options to complete the real options valuation and modeling. The results from the Monte Carlo simulation and previous evaluations give a probability distribution of values that illustrate the uncertainties and risks associated with each project, which, when combined, give a distribution of the NPVs and the initiative's volatility (Mun, 2016). The assumption within a real options context is that future profitability of the project is the fundamental variable of interest, measured by future cash flow series (Mun, 2016). Analysts use the future cash flow and the present value of the future cash flows to determine the total asset value of the project in a real options model (Mun, 2016).

The real options analysis reveals the financial and economic strengths and weaknesses of the project's available strategic options, allowing analysts to make recommendations to management on which projects to pursue. Projects are typically not conducted individually within businesses and initiatives are often correlated (Mun, 2016). If managers view the future projects as a portfolio, they can hedge and diversify the risks associated with each singular project (Mun, 2016). Using traditional portfolio analysis will assist leadership in determining the optimal allocation of investments throughout their collection of projects (Mun, 2016).

Generating coherent and concise reports detailing the analysis is the eighth, and final, step in IRM (Mun, 2016). If decision-makers do not understand the complicated procedures that led to the investment recommendations, they will not trust the results enough to follow those recommendations (Mun, 2016). Transforming the "black-box set of analytics into transparent steps” is vital to ensuring leadership has the best possible information with which to make decisions for the company’s project portfolio (Mun, 2016, p. 95). Although this is the final step within the IRM process, as additional information becomes available and the uncertainty and risk are reduced or resolved, analysts should revisit the models with updated information (Mun, 2016). Reworking the original models with the new data allows managers to make midcourse corrections to improve the performance of both the individual project and the portfolio of projects (Mun, 2016).

The IRM methodology is a systematic technique to determine the best possible projects to pursue based on the statistical likelihood of their success. Using historical knowledge of defense acquisition programs and IT systems in both the government and commercial realms could improve the budgeting and scheduling processes. Determining the likely range of outcomes through dynamic statistical modeling may improve the program’s performance. By better understanding the risk associated with various components, a more appropriate schedule and budget could be developed. IRM may also help determine which real options should be included in acquisition contracts. A high-risk program may need more options, such as the options to abandon, delay, or expand, based on its actual performance. Finally, IRM could prove useful in portfolio management, helping decision-makers determine which programs to initiate when viewing the portfolio of other programs in progress and used operationally.

F. LEAN SIX SIGMA

Currently employed as a means to help justify the future use of an IT system to incrementally improve process productivity within the DoD, LSS is a combination of two complementary concepts, Lean and Six Sigma, designed to eliminate waste and variation to attain customer satisfaction in the areas of quality, delivery, and cost (Salah, Rahim, & Carretero, 2010). Six Sigma evolved from the Total Quality Management (TQM) program and is focused on reducing variability and removing defects within a process (Apte & Kang, 2006). The Lean concept centers on reducing waste and increasing the speed of a process (Apte & Kang, 2006). In the past, practitioners often chose one concept or the other, believing the two approaches to be contradictory in nature (Apte & Kang, 2006).

However, many managers now view the concepts as synergistic (Apte & Kang, 2006). Together, they lead to the ultimate goal of a continuous process flow via a cycle of iterative improvement.

The Lean foundation centers on the production of a product and its associated value stream while eliminating all waste within the system (Pepper & Spedding, 2009). Lean processes use the absolute minimum resources necessary to create the value for a service or product (Apte & Kang, 2006). Any process that does not add value is considered waste (Apte & Kang, 2006). To effectively eliminate waste, managers must determine what adds value to the system. In this model, value added activities are "those activities that the customer would pay and that add value for the customer" (Cudney, Furterer, & Dietrich, 2013, p. 41). Conversely, if a customer does not consider an activity valuable or would not pay for an activity, it is a non-value-added activity (Cudney et al., 2013). Many non-value-added activities are required to deliver a product or run a business, such as accounting departments, process documentation, transportation, etc. (Cudney et al., 2013). Other non-value-added activities exist because of inefficiencies in a process, such as material storage, delays in a process, etc. (Cudney et al., 2013). Value-added activities typically make up only 1–5% of the total process time, while the remaining 95–99% consists of non-value-added activities (Cudney et al, 2013). Leadership must determine which steps in the development of a product or service add value to the customer and reduce the non-value-added activities, resulting in a more efficient, or lean, process.

The term "Six Sigma" refers to the statistical measurement of the defect rate for a particular system (Pepper & Spedding, 2009). The goal of the Six Sigma process is to improve customer satisfaction, thereby increasing profit, by reducing the defects in the system (Apte & Kang, 2006). For military customers, this could be reducing defects that provide false information, cause delays in prosecuting targets, lead to component failure or inaccuracy, or any other defects present in the civilian sector. If a system operates with an efficiency of six sigma from its measure of perfection, there will be only 3.4 defects per million items (Apte & Kang, 2006). Most companies operate between three and four sigma, losing 10–15% of the company's total revenue due to defects (Apte & Kang, 2006). In some service-based industries, such as the financial sector, even a defect rate of six sigma is considered unacceptable (Apte & Kang, 2006). As a result, “Six Sigma” now refers to the continual effort to eliminate defects and reduce variation in order to deliver a reliable, high-quality product or service to the customer (Apte & Kang, 2006). Achieving these results stems from an organizational culture and infrastructure designed on continuous process improvement (Apte & Kang, 2006).

Combining the Lean and Six Sigma methodologies, LSS involves five key phases: define, measure, analyze, improve, and control (DMAIC) (Pepper & Spedding, 2009). Within the LSS methodology, managers can choose to focus on different aspects of improvement before moving on to other areas. For example, leadership may decide to concentrate on the Lean component of improvement by eliminating waste rather than on the Six Sigma elements of reducing variation (Apte & Kang, 2006). Which tactic to utilize will vary depending on the situation, with accuracy or completeness issues typically resolved using Six Sigma and Lean aspects applied to timeliness or productivity complaints (Apte & Kang, 2006). Figure 16 shows various tools that can be used within the various phases. Some of these tools may be used in different phases depending on the project manager’s implementation.

Define	*Measure*	*Analyze*	*Improve*	*Control*
• Project Charter • Stakeholder Analysis • Supplier-Input-Process-Output-Customer (SIPOC) • Project Plan • Responsibilities Matrix • Ground Rules • Critical-to-Satisfaction (CTS) Tree	• Process Map • Voice of Customer (VOC) • Data Collection Plan • Pareto Chart • Histogram • Scatter Diagram • Process Capability • Process Statistics • Benchmarking • Gauge R&R • Cost of Poor Quality • Current State Map	• Cause & Effect • Diagram • 5 Whys • Test for Normality • Failure Modes and Effects Analysis (FMEA) • Correlation Analysis • Regression Analysis • Hypothesis Tests • 8 Wastes • 5S • Kaizen	• Quality Function Deployment • Action Plan • Cost/Benefit Analysis • Future State Map • Design of Experiments • Main Effects and Interaction Plots • Dashboards/ Scorecards	• Control Plan • Mistake Proofing • Standard Work • FMEA • Training Plan • Process Capability • Statistical Process Control (SPC) • Standard Operating Procedures (SOP) • Lessons Learned

Figure 16. Lean Six Sigma DMAIC Process and Tools. Source: Cudney & Kestle (2011).

In the *define* phase, managers gain understanding into what provides value to a customer (Salah et al., 2010). Identifying and delineating the problem is the first step in the define phase, which is often done by creating a project charter to express the scope and goals of the project (Cudney et al., 2013). Next, the PM must determine who the customers and stakeholders are in the process before conducting stakeholder analysis to understand the roles and concerns of the various parties as well as their attitudes toward potential change (Cudney et al., 2013). According to Cudney et al., uncovering the initial voice of the customer gives insight to the needs and items that are critical to their satisfaction (2013). After determining this information, the leader must form a team consisting of individuals with the appropriate knowledge and commitment to advance the project before the final step of creating a project plan to track progress through the remaining phases (Cudney et al., 2013).

The *measurement* phase, phase two of the DMAIC process, determines the baseline performance for the as-is process (Salah et al., 2010). To understand the performance, the project team must map the process in detail and establish the operational definitions, metrics, and data collection techniques they will use throughout the project (Cudney et al., 2013). At this point, the team will map the value stream, revealing which steps are value-added and which are non-value added (Salah et al., 2010). Benchmarking, histograms, Pareto charts, and other techniques may be used to measure the current performance, which may illuminate problems in the system during this phase (Cudney et al., 2013). Finally, the measurement system must be validated to ensure the correct data is captured and the data matches the actual system output (Cudney et al., 2013).

The purpose of phase three, *analyze*, is to identify the root cause of problems within a process based on the information gathered during the measurement phase (Cudney et al., 2013). The five whys (Figure 17) is one technique the team can use to determine the root cause and effect for issues discovered in the process (Apte & Kang, 2006). For each issue, asking why that incident occurred leads to a deeper cause. By asking enough times why a customer left, the team could have discovered the product orders were insufficient, preventing the customer from making a purchase. The phase also includes waste analysis. LSS identifies eight waste categories that add cost to a product without adding value: transportation of people, equipment, tools, etc.; overproduction of material; unnecessary motion; defects in a product; delay while waiting for people or equipment; storing inventory; excessive processing not desired by the customer; and failing to utilize people's talents (Cudney et al., 2013).

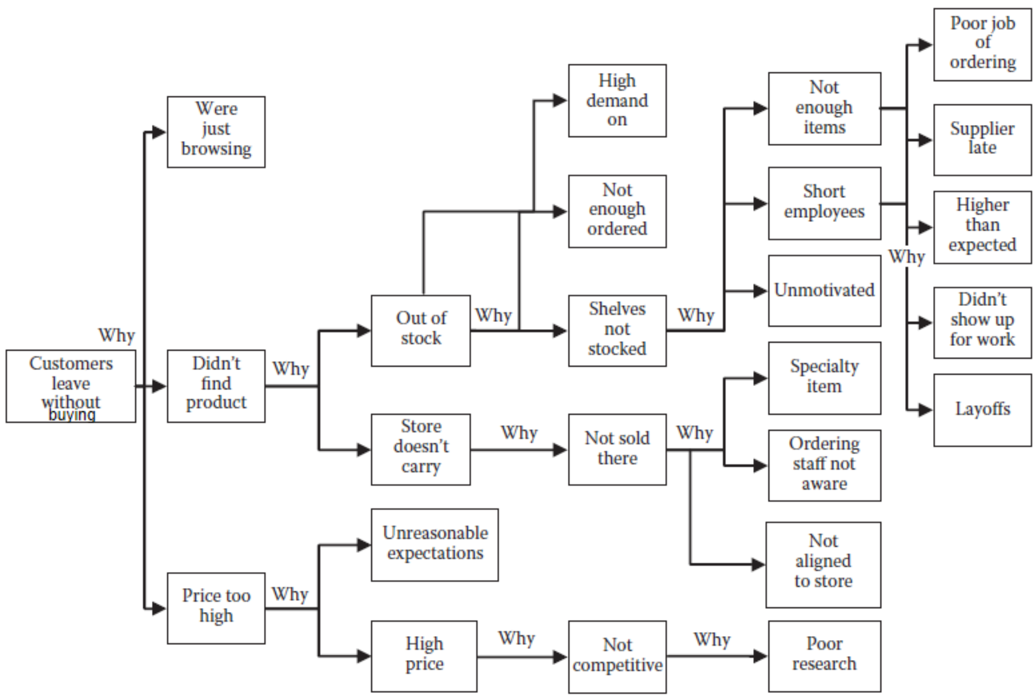


Figure 17. Five Whys Diagram. Source: Cudney et al. (2013).

After analyzing the process, team members seek to *improve* the production or service method, which is the fourth step of the DMAIC model. The purpose of this phase is identifying improvement recommendations, designing the to-be system, developing pilot programs as needed, and training employees in the new techniques (Cudney et al., 2013). The "5 S system" (sort, straighten, scrub, stabilize, sustain) can help managers determine methods to better organize a workplace and eliminate or reduce many types of waste. Teams should sort or simplify by removing unnecessary elements in the workplace, straighten and organize items so they are more easily used and returned, scrub to fix the root cause of disorganization, stabilize processes after implementing changes from the first 3 S's, and sustain the practice by continually using the 5 S method (Cudney et al., 2013). Recommendations should stem from the discoveries made during the analysis phase to ensure the root cause of an issue is addressed rather than resulting in an action designed to cover a symptom of the root cause (Cudney et al., 2013). Depending on the recommendations, it may be worthwhile to conduct a cost-benefit analysis prior to applying any new changes to ensure the cost of the improved system is worth implementation

(Cudney et al., 2013). Teams should document the standard operating procedures and revised process map for the to-be system prior to beginning the action plan so that improvements to the system can be easily recognized (Salah et al., 2010). Mistake-proofing techniques should be developed and inserted into processes to safeguard from accidents and oversights causing errors in the final product (Salah et al., 2010). Employees should then receive training in the updated procedures prior to their implementation to assure consistency in the revised process (Cudney et al., 2013).

The *control* phase is the final phase of the DMAIC process and is designed to maintain the improvements to the system gained during the improvement phase (Cudney & Kestle, 2011). To accomplish this, a team must validate the results compared to the baseline measurement, create a process control plan, and turn over responsibility to the process manager (Salah et al., 2010). If there is not a conscious effort to maintain the gains resulting from the improved process, employees will most likely revert to the original manner, slipping back into the familiar, inefficient routines (Cudney et al., 2013). A control plan should include methods to prevent this from occurring and measurement techniques that alert management of potential pitfalls (Cudney et al., 2013). Mistake-proofing must continue in the control phase whenever possible to reduce the need for rework and eliminate waste resulting from defects (Cudney et al., 2013). Finally, the team must document lessons learned during the LSS improvement process to ease the burden for future projects (Cudney et al., 2013).

There are numerous examples of the DoD implementing LSS within military programs. Naval Air Systems Command saved over $133 million during 2006 and more than $420 million across the entire life of the Joint Standoff Weapon Block II program after applying LSS (Robinson, 2008). The Army Red River Depot overhauled their Humvee refitting operations with a LSS mindset, increasing the number of vehicles they processed from three a day to twenty-three a day (Robinson, 2008). The next chapter will explore an example case of LSS within the DoD to determine its suitability within the acquisition of IS and IT systems.

To effectively implement an LSS project, an organization must have the appropriate support structure. In his 2010 book *Six Sigma*, Deepali Desai explains that LSS cannot be employed exclusively from a single branch, such as quality control; it must instead permeate throughout the company to achieve the desired results. He notes that there is a regimented, consistent with the rest of the program, prescriptive staffing structure within companies that utilize LSS. The executive leadership group decides whether to implement an LSS program, and their public support throughout the company is essential for the program's success while champions or project sponsors advocate for projects to the executive leadership on behalf of the team leaders (Desai, 2010). Additional roles and responsibilities within the Six Sigma methodology are defined by belt levels attained through LSS certification. Desai explains that master black belts are experts within all aspects of LSS and have extensive academic training and field experience with the program and serve as mentors and guides for the team leaders and as black belts within a company. Team leaders are black belts assigned to projects based on their training and experience and serve as the technical experts and change agents within a team and run the DMAIC process for a project (Desai, 2010). Desai goes on to say, master black belts and black belts are full-time LSS employees within the organization, using their expertise to improve processes and maintain the improvements. Green belts are individuals that have received LSS training and have some real-world experience with LSS implementation (Desai, 2010). The author observed that some companies train large portions of their workforce at the green and white belt level so their employees can bring LSS concepts and tools into their daily activities. He further noted addition to the belt holders, team members are individuals assisting with LSS projects in the DMAIC process. Teams often consist of three to ten members from various branches within a company relevant to the process being improved and although team members may or may not possess an LSS belt, they should be familiar with LSS concepts (Desai, 2010).

LSS is an effective technique to improve the processes within a system. A detailed understanding of a procedure is required prior to implementing any changes to a process. This acumen could give decision-makers insight in to the as-is system, that is, the current process or system the acquisition program is seeking to improve. Having a firm grasp on the as-is system may assist the PM when deciding the best course of action to fulfill stated requirements. LSS offers the most benefit when applied to processes that are already established. Incrementally improving procedures during the operations and support phase may provide significant cost savings and improved performance over the life of an acquisition.

G. SUMMARY

The Defense Acquisition System is a complicated process. Each of the five methodologies reviewed— EVM, BSC, KVA, IRM, and LSS— are valuable tools with different benefits and drawbacks and could be used in different applications. There are potential places within the acquisition process to insert these methodologies, or portions of the methodologies, to improve the acquisition of IS. Case studies conducted in the following chapter will help illuminate some of the benefits and challenges associated with these methodologies.

THIS PAGE INTENTIONALLY LEFT BLANK

III. CASE VIGNETTES

Parts of this chapter were previously published by the Naval Postgraduate School Acquisition Research Program (Housel, Mun, Jones, & Carlton, 2019).

This chapter reviews examples from several cases that used one or more of the five methodologies. Some of these cases deal with actual systems while others use hypothetical examples detailing how a methodology may be used in the given circumstances.

A. JOINT TACTICAL RADIO SYSTEM: EVM

EVM measures the progress of a project based on the cost spent on the project (the ACWP) and the amount of work completed at a given time (the BCWP) compared to the amount of work that should be completed at that point (the BCWS). Comparing these metrics shows project managers any CV and SV from the baseline. Project managers have used these techniques for many years with success, especially in traditional manufacturing programs. However, there are issues with the methodology when it is applied to complex programs, such as integrated hardware/software systems. The Joint Tactical Radio System (JTRS) case is an example of the government's use of EVM in an IS acquisition that required both hardware and software development.

JTRS was a DoD program designed to create a software-defined network of radios that would link platforms from across the services across the spectrum of existing capability. The DoD initiated the JTRS program in 1997 as part of an effort to update equipment in concert with the concept of network-centric warfare (Francis, 2006). JTRS was envisioned to be a group of software-defined radios that would replace the 25 to 30 families of radios used in the military during the mid-1990s (Feickert, 2005). The radios were to operate across the entirety of the radio frequency spectrum, allowing wireless voice, data, and video communication seamlessly between all services (Feickert, 2005). The hundreds of thousands of radios the DoD planned to acquire would allow warfighters to access maps and other visual data, directly view battlefield sensors, and communicate via voice and video (Francis, 2006).

In his 2006 Government Accountability Office Report, Paul Francis explained that software-defined radios, such as JTRS, use software to control the operation of a radio rather than hardware as used in traditional radio operation. He described waveforms as the software applications the radio uses to transmit messages, including the frequency, modulation, message format, and/or transmission system. The report noted that JTRS was designed for a single radio to transmit multiple types of waveforms, allowing a single radio to communicate with different types of legacy radio systems and other JTRS. The radios would be able to operate on multiple waveforms simultaneously depending on the number of channels in the radio, meaning a single radio could transmit and receive video, data and voice communications at the same time (Francis, 2006). Figure 18 demonstrates the reach and some of the various platforms JTRS would utilize once full operational capability was attained. Since the radios must operate on a battlefield in any environment, JTRS was designed to operate without any fixed infrastructure such as cell phone towers or fiber optic lines, and all network components had to have enough power to transmit data over long distances while maintaining connectivity and security of the information (Francis, 2006). Francis noted that "the development of the individual waveforms and their ability to function effectively on different JTRS sets [was] critical to the success of JTRS" (2006, p. 8).

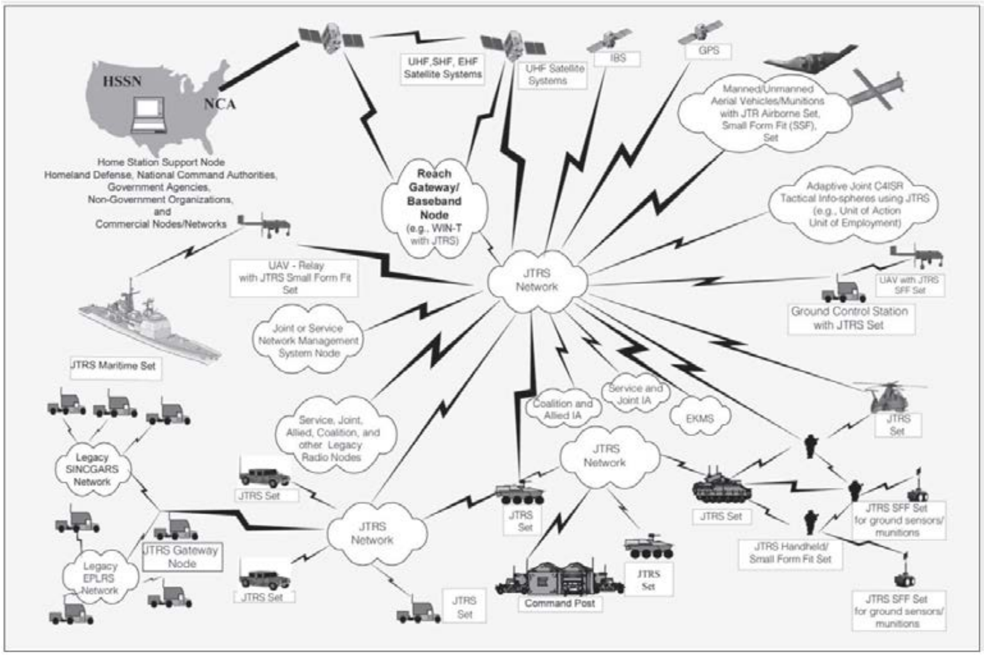


Figure 18. JTRS Operational Overview. Source: Francis (2006).

The original program was designed to establish a universal DoD standard in which the services could develop independent hardware solutions using a common network architecture. Table 1 illustrates the five original clusters and their respective leads. Based on research suggesting a combined approach would result in a more efficient process with improved results, clusters three and four were merged in 2004, forming the JTRS Airborne, Maritime, and Fixed Station (AMF) cluster jointly managed by the Air Force and the Navy (Feickert, 2005). However, the programs were not managed correctly and changes needed to occur. For instance, cluster one began development on the Wideband Networking Waveform, the main waveform for use in Army units, with "an aggressive schedule, immature technology, and a lack of clearly defined and stable requirements" (Francis, 2006, p. 10).

Table 1. JTRS Clusters. Source: Feickert (2005)

Cluster	**One**	**Two**	**Three**	**Four**	**Five**
Description	Ground Vehicle and Helicopter Radios	Hand-Held Radios	Fixed Site and Maritime Radios	High Performance Aircraft (Fixed Wing) Radios	Handheld, Dismounted, and Small Form Factor Radios
Service Lead	U.S. Army	U.S. Special Operations Command (USSOCOM)	U.S. Navy	U.S. Air Force	U.S. Army

After several years of slow performance by the services to develop new JTRS radio products, the DoD developed the JTRS joint program office, realigning all clusters under a single Joint Program Executive Officer (JPEO) (Francis, 2006). The slow progress was likely due to the marginal budgets allocated to common architecture efforts prior to 2001 and the changing priorities due to the war in Afghanistan and Iraq. Consequently, the JTRS enterprise was chartered to consolidate the various clusters and develop an acquisition strategy that would accelerate the networking capability across the DoD. Additionally, in 2002 the Army's Future Combat System acquisition strategy was accelerated, mandating that a new consolidated approach toward delivering the network was required in order to meet these goals.

The JTRS JPEO established five ACAT ID program offices aligned around the original clusters, Ground Mobile Radio (GMR), Handheld Mobile System (HMS), Multifunctional Information Distribution System (MIDS), AMF, and Network Enterprise Domain (NED), shown in Figure 19. These programs were intended to be interoperable with each other via the various waveforms being developed by NED. Unfortunately, the JPEO for JTRS failed to realign the acquisition strategies between the programs and allowed each program to develop independent operating environments that were not compatible with each other. The unintended impact of this strategy required each program to develop a different version of the basic waveforms in order to work on their platforms. This was a significant driver in the escalating cost for waveform development across the

JTRS enterprise. Additionally, the acquisition strategies across the enterprise were not synchronized toward a common DoD architecture resulting in a disconnected operational capability. Ultimately, the inability of the various JTRS hardware solutions to create the intended integrated DoD network began to erode support for the system, and the increasing demands of the Global War on Terrorism led the DoD to search for different network strategies leading to the termination of the JTRS enterprise as an organization.

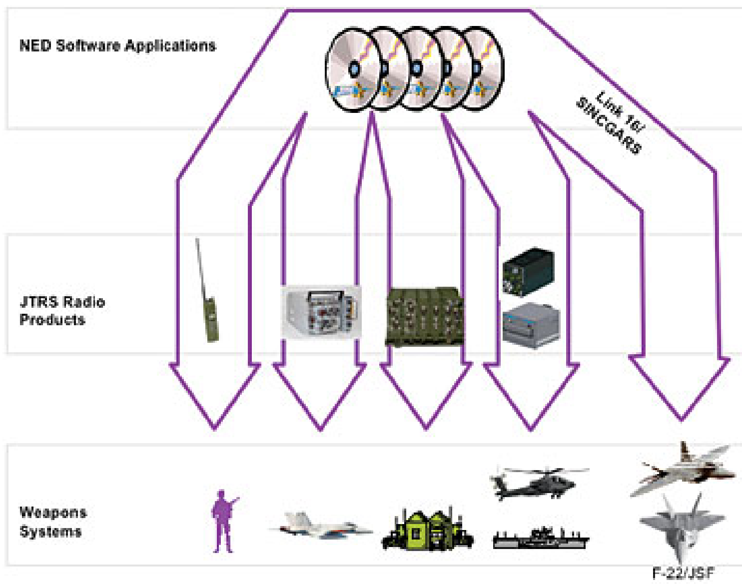


Figure 19. JTRS Program Structure. Source: Housel et al. (2019)

The inability to anticipate the logical outcome of the JTRS enterprise may lie in the DoD's failure to recognize the need for better and different ways to actually manage and control complex hardware/software programs. Per the statutory requirements, JPEO used EVM to manage the production of the JTRS program. According to Col (Ret.) Raymond Jones, former PM and deputy PEO of the JTRS program, the WBS divided the necessary tasks into various blocks of work typical of the EVM process (personal communication, September 12, 2019). The project schedule was based on the estimated completion dates of the different components within the WBS (R. Jones, personal communication, September 12, 2019). Establishing a viable WBS for an integrated hardware/software program was not possible due to the uncertainty of software development and the lack of management control on the quality of software being delivered to the JTRS software repository by NED and the participating vendors. The hardware programs had little voice in the quality control and schedules being used by NED, the program office responsible for delivering the software waveforms to the hardware program offices. Consequently, it was virtually impossible for the hardware program offices to logically establish a valid performance measurement baseline (PMB) for their programs since the disparate program operating environments for each of the radio programs was constantly being changed because of the uncertainty of the waveform development. In order to establish an effective PMB, a program must have some level of certainty in the WBS. Lacking this certainty leads to a variable baseline that is not manageable using traditional methods. Unfortunately, the DoD mandates the use of legacy methods, reinforced by antiquated legislation such as Nunn-McCurdy, driving programs to use management tools that are ineffective in complex integrated hardware/software programs. While measuring programs using the traditional PMB methods was suitable for more predictable, less complex programs, it is not sufficient to provide insight into dynamic integrated programs that are dependent on the uncertainty of capability development methods with potentially limitless permutations of solutions driven by individuals such as software developers.

Without end-to-end synchronization of requirements across the entire capability set, trying to develop software hardware solutions in a coherent manner is not possible. Perhaps the simplest analogy might be the difference between Apple's IOS and Google's Android system architecture. It is not possible to run IOS apps on an Android architecture, nor do these companies attempt to do so. Yet in the DoD, the acquisition leadership actually created a program structure that tried to do exactly that. Each of the radio programs had different operating environments (think iOS versus Android) with the expectation that the waveforms being developed by NED and its contractors were actually going to work on all of the radio programs without significant change. In fact, while the waveforms were called the same thing on each platform, they were actually fundamentally different and not interoperable.

Understanding the fundamental challenges experienced by JTRS is critical to understanding why current management controls are not sufficient for managing complex hardware/software programs. A primary measure of progress in the JTRS program was the use of lines of code (LOC) completed. Software development progress was tracked using LOC, meaning software developers estimated how many LOC were needed to complete the different elements of the WBS (R. Jones, personal communication, August 22, 2019). Rather than establishing capability measures that can be discretely measured, completion rate of LOC drove the perception that software was being completed in support of the PMB. LOC is not an accurate method to estimate cost and schedule for a program developing new technology that does not have similarly complex software on which to base the estimates. When developing the schedule, a software developer approximated the cost and time needed to write the stated LOC for the task, which had a risk factor added to account for unknown and unexpected issues (R. Jones, personal communication, August 22, 2019).

When deadlines arrived for delivery of software that was not yet completed, developers would deliver a preliminary version of the program, promising a fully functional version later (R. Jones, personal communication, September 12, 2019). For example, if the schedule called for software delivery to complete a task on the ground and aviation platforms but the software was only functional for the ground component, they may deliver version 3.0 on deadline with the promise of 3.0.1 a month later (R. Jones, personal communication, September 22, 2019). However, PMs developed the schedule assuming the entire software would be completed on schedule; the resulting software delay also pushed back the aviation program schedule that depended on the software to continue its development (R. Jones, personal communication, September 22, 2019).

The program used forward leaning technology and the schedule was planned years in advance using predictions of future processing capabilities including Moore's Law, which states the number of transistors in a circuit doubles every two years, increasing the processing power (R. Jones, personal communication, August 22, 2019). None of the 20 critical technologies identified for cluster one were mature when system development began (Francis, 2008). While Moore's Law held true during this time, the necessary advances needed to complete the design requirements were not always available per the baseline schedule. For instance, as advances in technology occurred, the aviation radio design fit within the specified dimensions (R. Jones, personal communication, August 22, 2019). However, the reduction in size led to overheating issues with the equipment as the airflow over the heat syncs was insufficient (R. Jones, personal communication, August 22, 2019). These issues (and others) caused unforeseen delays that significantly affected the cost and schedule baseline.

The JTRS program continued to have issues through its development, and many of the larger components of the program were canceled. The GMR, originally part of cluster one, did not undergo testing by operational users until 2010, 13 years after the project's inception (Gallagher, 2012). One of the main subprograms within JTRS, the GMR eventually received certification for the hardware portion of the radio in May 2012 (Gallagher, 2012). Unfortunately, Undersecretary of Defense Kendall had already canceled the GMR in October 2011, citing a reduction in quantity required by the services (Kendall, 2011). The reduction in the number of radios requested stemmed from the increasing price of individual radios (Francis, 2008). The JPEO officially closed on September 30, 2012, and the Joint Tactical Networking Center was given the responsibilities related to developing and sustaining software defined radios (Roosevelt, 2012). Elements of the JTRS program are still being developed. HMS and the AMF radios continue the development begun during the JTRS process (Dodaro, 2019). However, there are still problems associated with these systems. HMS has seen a 133% increase in its development cost, a 45.88% increase in acquisition time, and a 17.5% reduction in the total quantity requested from 2004 to 2019 due to issues with immature technology, even with a reduction in the complexity of requirements (Dodaro, 2019).

The JTRS acquisition was relatively standard for the acquisition of IS, using EVM and the RMF as the typical methods required by federal regulation (R. Jones, personal communication, September 22, 2019). According to Powner's GAO report in 2009, the JTRS HMS program used EVM successfully. Of the eleven key practices the GAO identified within EVM, the program fully completed ten of them and partially met the last practice, "schedule the work." Figure 20 shows the GAO assessment and key practices. The program received praise for constant reviews to validate the baseline although the "schedule contained some weaknesses, such as out-of-sequence logic and activities without resources assigned," which were blamed on subcontractor schedules that are integrated monthly (Powner, 2009, p. 42). Nevertheless, the program had significant CV and SV, indicating EVM did not provide sufficient information in a timely manner to correct these issues.

Program management area of responsibility	Key practice	GAO assessment
Establish a comprehensive EVM system	Define the scope of effort using a work breakdown structure	●
	Identify who in the organization will perform the work	●
	Schedule the work	◐
	Estimate the labor and material required to perform the work and authorize the budgets, including management reserve	●
	Determine objective measure of earned value	●
	Develop the performance measurement baseline	●
Ensure that the data resulting from the EVM system are reliable	Execute the work plan and record all costs	●
	Analyze EVM performance data and record variances from the performance measurement baseline plan	●
	Forecast estimates at completion	●
Ensure that the program management team is using earned value data for decision-making purposes	Take management action to mitigate risks	●
	Update the performance measurement baseline as changes occur	●

Figure 20. GAO Review of JTRS HMS Key EVM Practices.
Source: Powner (2009).

B. BSC FRAMEWORK IN ACQUISITIONS FOR THE DEPARTMENT OF THE NAVY

BSC can be applied to the Defense Acquisition System. Strategies and visions for future force composition are disseminated throughout the DoD on a regular basis. The acquisition community could create specific metrics to ensure its actions align with high-level policy. Terry Buss and David Cooke developed the following vignette in 2005 as a framework for implementing BSC within the acquisition process.

Then-Secretary of Defense Donald Rumsfeld sought to run the DoD in line with a more corporate structure than it had been previously, leading to a more business-like focus that included strategic plans and goals to achieve the desired end state (Buss & Cooke, 2005). Assistant Secretary of the Navy for Research, Development, and Acquisition (ASN[RD&A]) John Young, Jr., led his Blueprint for the Future with the vision that Naval acquisitions must "build a strategic capability to strike anyone, anywhere, anytime" (Young, 2004). Three principles along with specific goals guided the organization toward his vision:

- Principle 1: The Naval Acquisition Team must think like a business and run a tight ship.
- Principle 2: The Naval Acquisition Team must innovate and collaborate to deliver effective, affordable weapons for Sailors and Marines.
- Principle 3: The Naval Acquisition Team will operate as a neighborhood to jointly integrate systems and develop people. (Buss & Cooke, 2005, pp. 212–213)

The ASN developed a BSC blueprint for the organization to utilize, shown in Figure 21. The categories are similar to the traditional BSC groupings. Internal Business Processes looks at what must be done to excel (Buss & Cooke, 2005). Learning and Growth examines how to continue improvement and how to create value (Buss & Cooke, 2005). The customer for naval acquisitions is the Warfighter and this category asks how the warfighter sees the acquisition community (Buss & Cooke, 2005). The financial perspective is replaced with weapons systems—how acquisitions spends its money—and examines if the expenditures are providing the best capabilities for the warfighter (Buss & Cooke, 2005).

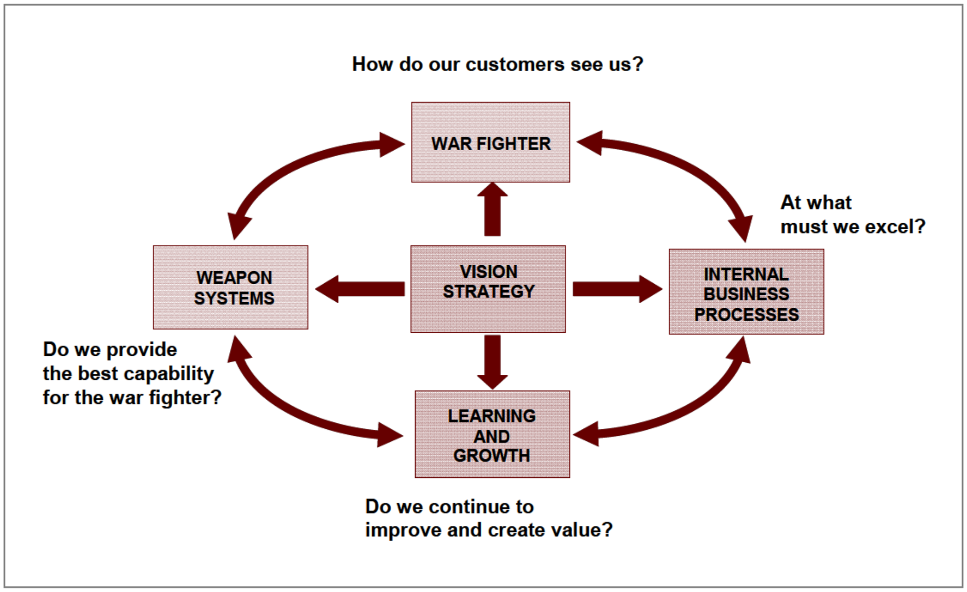


Figure 21. Four BSC Perspectives of the ASN. Source: Buss & Cooke (2005).

Leaders gain the strategic guidance needed to develop BSC measures from a variety of sources. The National Security Strategy, National Defense Strategy (formerly the

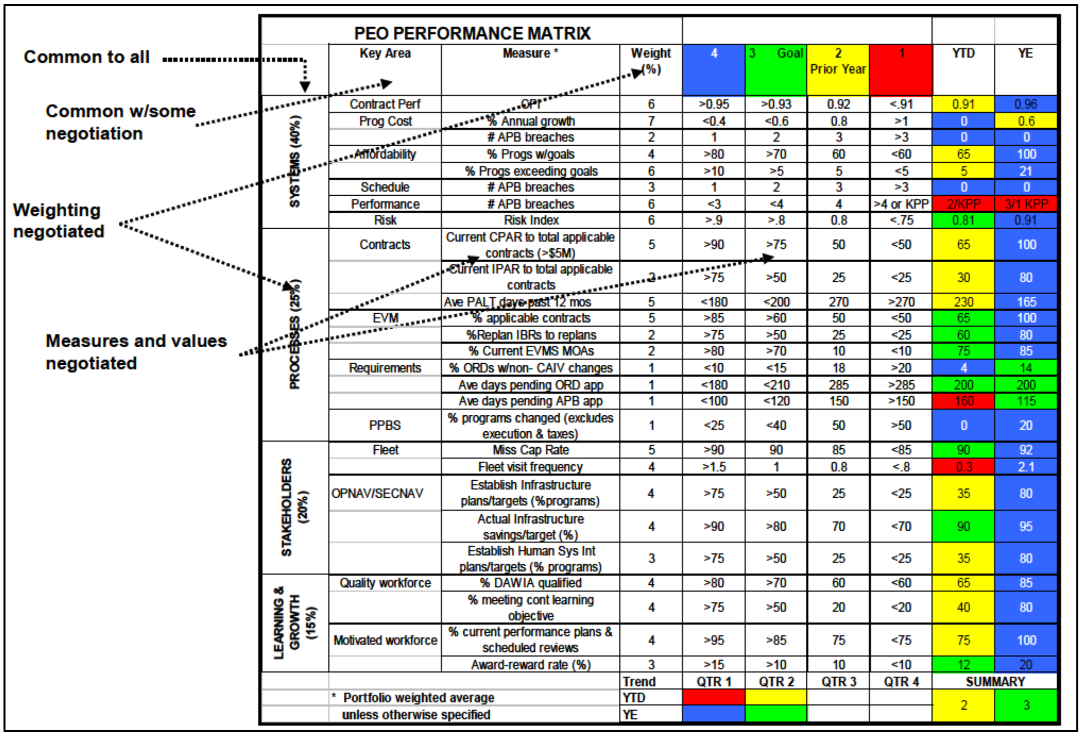
Quadrennial Defense Review), and National Military Strategy provide top-level guidance for the current vision and strategy of the DoD (Buss & Cooke, 2005). The Defense Planning Guidance provides direction, priorities, and goals for military acquisitions. The civilian and military heads of each service also provide input for their ideal force structure and equipment. While some of these visions may be inconsistent with each other, the overarching vision for naval acquisitions is taken from these sources (Buss & Cooke, 2005). For PMs to effectively use BSC within their area of influence, they should understand the strategic vision of the level immediately superseding their program and develop metrics based on these goals.

When using the vision to create a BSC approach, leaders must focus their metrics on areas beyond cost, schedule, and risk (Buss & Cooke, 2005). They must include metrics that enhance performance in every BSC category. They should be specific, measurable, assignable, relevant, and time-based (SMART) metrics that are tied to outcomes of performance rather than to activities (Buss & Cooke, 2005). Metrics development and implementation begins at the top level within the Department of the Navy (DoN) and works down with an increasing amount of detail at each level (Buss & Cooke, 2005). The DoN vision leads to metrics for both long-term goals for capabilities and transformation that must be useful to decision-makers and managers and effective at driving change and managing performance (Buss & Cooke, 2005). The span of control decreases for each level down from the strategic guidance, meaning the impacts of decisions made at each level also decrease (Buss & Cooke, 2005). However, the measurements at the lower levels must act like a pyramid, supporting the measures of the level above them (Buss & Cooke, 2005).

As managers throughout the organization develop metrics for their level of control, they need to consider the need for baseline reviews, performance data collection and analysis, performance measurement, flexibility, community involvement, and institutional commitment (Buss & Cooke, 2005). There are several other challenges when creating metrics. As civilian leaders such as the president and members of Congress and senior leaders within the DoD change, the BSC must be flexible enough to deal with the change in control and focus (Buss & Cooke, 2005). Even when leaders are anticipating future changes, unforeseen events such as the end of the Cold War or the terrorist attacks of

September 11, 2001, can have dramatic effects on the DoD’s vision (Buss & Cooke, 2005). With numerous stakeholders, it can prove difficult to gain consensus on proposed metrics (Buss & Cooke, 2005). Some metrics are defined by law and policy, even if the metrics do not fit the current vision within the DoD. Laws such as the Government Performance and Results Act of 1993 and Chief Financial Officers Act of 1990 (along with numerous others) dictate some measurements that must be integrated into any BSC criteria (Buss & Cooke, 2005).

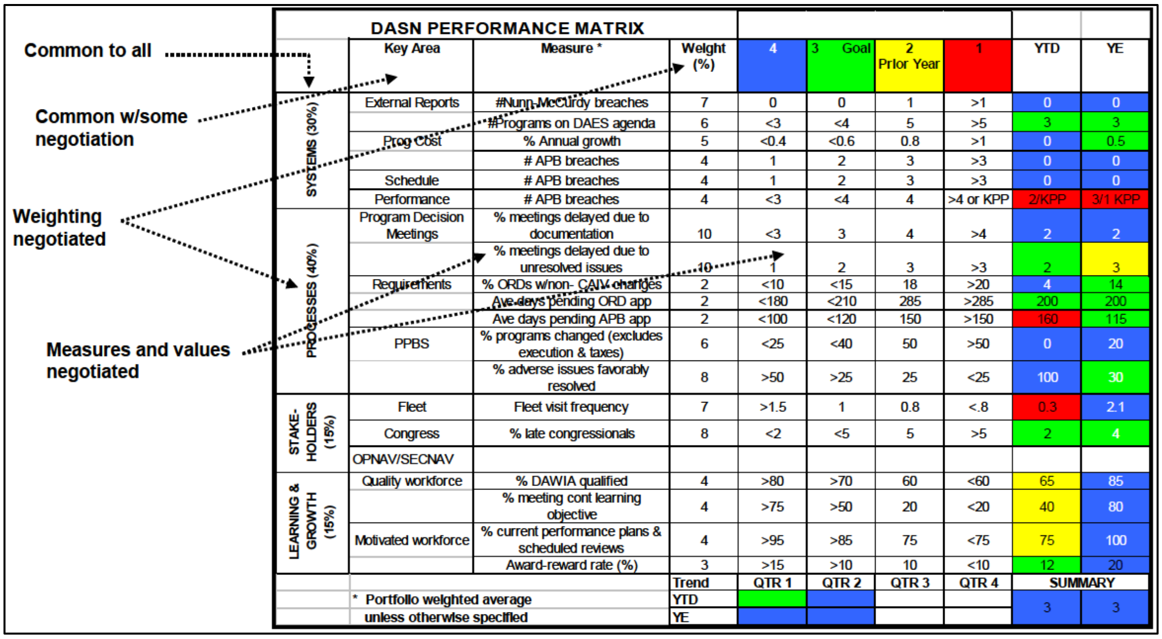
Using the guidance received from their leaders, managers develop the measures, targets, and initiatives to accomplish their specific goals (Buss & Cooke, 2005). Figure 22 provides an example BSC for a program executive officer (PEO). The BSC contains the same four categories from the higher scorecard in Figure 23. Within each category, the PEO identified specific measures within key areas that will lead to strategic success. Each measure was assigned a weight, indicating the importance of that metric toward meeting the overall objective. While traditional BSC does not assign weights to each measurement, doing so allows managers to assign an overall grade to their performance.



PEO PERFORMANCE MATRIX									
	Key Area	Measure *	Weight (%)	4	3 Goal	2 Prior Year	1	YTD	YE
SYSTEMS (40%)	Contract Perf	CPI	6	>0.95	>0.93	0.92	<.91	0.91	0.96
	Prog Cost	% Annual growth	7	<0.4	<0.6	0.8	>1	0	0.6
		# APB breaches	2	1	2	3	>3	0	0
	Affordability	% Progs w/goals	4	>80	>70	60	<60	65	100
		% Progs exceeding goals	6	>10	>5	5	<5	5	21
	Schedule	# APB breaches	3	1	2	3	>3	0	0
	Performance	# APB breaches	6	<3	<4	4	>4 or KPP	2/KPP	3/1 KPP
	Risk	Risk Index	6	>.9	>.8	0.8	<.75	0.81	0.91
PROCESSES (25%)	Contracts	Current CPAR to total applicable contracts (>$5M)	5	>90	>75	50	<50	65	100
		Current IPAR to total applicable contracts	3	>75	>50	25	<25	30	80
		Ave PALT days past 12 mos	5	<180	<200	270	>270	230	165
	EVM	% applicable contracts	5	>85	>60	50	<50	65	100
		%Replan IBRs to replans	2	>75	>50	25	<25	60	80
		% Current EVMS MOAs	2	>80	>70	10	<10	75	85
	Requirements	% ORDs w/non- CAIV changes	1	<10	<15	18	>20	4	14
		Ave days pending ORD app	1	<180	<210	285	>285	200	200
		Ave days pending APB app	1	<100	<120	150	>150	160	115
	PPBS	% programs changed (excludes execution & taxes)	1	<25	<40	50	>50	0	20
STAKEHOLDERS (20%)	Fleet	Miss Cap Rate	5	>90	90	85	<85	90	92
		Fleet visit frequency	4	>1.5	1	0.8	<.8	0.3	2.1
	OPNAV/SECNAV	Establish Infrastructure plans/targets (%programs)	4	>75	>50	25	<25	35	80
		Actual Infrastructure savings/target (%)	4	>90	>80	70	<70	90	95
		Establish Human Sys Int plans/targets (% programs)	3	>75	>50	25	<25	35	80
LEARNING & GROWTH (15%)	Quality workforce	% DAWIA qualified	4	>80	>70	60	<60	65	85
		% meeting cont learning objective	4	>75	>50	20	<20	40	80
	Motivated workforce	% current performance plans & scheduled reviews	4	>95	>85	75	<75	75	100
		Award-reward rate (%)	3	>15	>10	10	<10	12	20
			Trend	QTR 1	QTR 2	QTR 3	QTR 4	SUMMARY	
	* Portfolio weighted average		YTD					2	3
	unless otherwise specified		YE						

Figure 22. Sample PEO Metrics. Source: Buss & Cooke (2005).

Buss and Cooke also developed sample metrics for the deputy assistant secretary of the Navy (DASN) for acquisitions and procurement shown in Figure 23. The DASN performance matrix exists at a higher level than those in the PEO performance matrix. The four categories are the same among all matrices throughout the organization, while the key areas may change depending on the level within the DoN (Buss & Cooke, 2005). Measures of key area performance typically vary from level to level since the higher up the pyramid the matrix is, the more span of control it encompasses, necessitating metrics that more accurately reflect the influence a leader asserts (Buss & Cooke, 2005).



DASN PERFORMANCE MATRIX	Key Area	Measure *	Weight (%)	4	3 Goal	2 Prior Year	1	YTD	YE
SYSTEMS (30%)	External Reports	#Nunn-McCurdy breaches	7	0	0	1	>1	0	0
		#Programs on DAES agenda	6	<3	<4	5	>5	3	3
	Prog Cost	% Annual growth	5	<0.4	<0.6	0.8	>1	0	0.5
		# APB breaches	4	1	2	3	>3	0	0
	Schedule	# APB breaches	4	1	2	3	>3	0	0
	Performance	# APB breaches	4	<3	<4	4	>4 or KPP	2/KPP	3/1 KPP
PROCESSES (40%)	Program Decision Meetings	% meetings delayed due to documentation	10	<3	3	4	>4	2	2
		% meetings delayed due to unresolved issues	10	1	2	3	>3	2	3
	Requirements	% ORDs w/non- CAIV charges	2	<10	<15	18	>20	4	14
		Ave days pending ORD app	2	<180	<210	285	>285	200	200
		Ave days pending APB app	2	<100	<120	150	>150	160	115
	PPBS	% programs changed (excludes execution & taxes)	6	<25	<40	50	>50	0	20
		% adverse issues favorably resolved	8	>50	>25	25	<25	100	30
STAKE-HOLDERS (15%)	Fleet	Fleet visit frequency	7	>1.5	1	0.8	<.8	0.3	2.1
	Congress	% late congressionals	8	<2	<5	5	>5	2	4
	OPNAV/SECNAV								
LEARNING & GROWTH (15%)	Quality workforce	% DAWIA qualified	4	>80	>70	60	<60	65	85
		% meeting cont learning objective	4	>75	>50	20	<20	40	80
	Motivated workforce	% current performance plans & scheduled reviews	4	>95	>85	75	<75	75	100
		Award-reward rate (%)	3	>15	>10	10	<10	12	20
			Trend	QTR 1	QTR 2	QTR 3	QTR 4	SUMMARY	
	* Portfolio weighted average		YTD					3	3
	unless otherwise specified		YE						

Figure 23. Sample DASN Metrics. Source: Buss & Cooke (2005).

Implementing BSC performance matrices, such as the two examples shown, throughout an organization helps ensure each division operates in a manner consistent with the core strategy and vision of its high-level leadership. It requires a commitment from leaders and managers on every level to develop SMART metrics within key areas that promote the achievement of the vision. While the process is relatively simple to explain in comparison to other methodologies in this study, applying the techniques in an effective manner that resonates with workers, managers, and leaders throughout the DoN is a thought-provoking task that must be continually evaluated for its success.

C. CRYPTOLOGIC CARRY-ON PROGRAM: KVA AND IRM

While not designed to be coupled together, the KVA and IRM methodologies work well in concert with each other. Most processes within the DoD do not have a readily identifiable, quantitative metric that can be used to demonstrate the value of the process output. KVA can develop that common-units metric for both the process as a whole and the individual sub-processes that comprise it. After developing these numbers, IRM can use simulation to determine statistical probabilities for various outcomes, frame real options for the acquisition program, and quantify these options using their present value.

The Cryptologic Carry-On Program (CCOP) is one example of these techniques used to assist decision-makers in determining the best solution for decisions in an acquisition program.

The CCOP is an IS-based Intelligence, Surveillance, and Reconnaissance (ISR) system for surface, subsurface, and airborne platforms in the U.S. Navy (Rios, 2005). There are numerous types of CCOP systems with different scope and functions (Rios, 2005). CCOP allows commercial off the shelf (COTS) and government off the shelf (GOTS) systems to augment systems currently on ships (Rios, 2005). COTS and GOTS systems usually require integration and modification for compatibility with the on-board ISR technology (Rios, 2005). The CCOP capability provides a more rapid transition of these tools (Rios, 2005). Approximately 100 surface ships were CCOP capable in 2005, representing a sizable portion of the Navy’s fleet (Rios, 2005). This case example focuses on the surface CCOP platforms.

During fiscal year 2005, the CCOP office was given a mandate to focus on three specific goals: efficiencies, metrics, and return on investment (Rios, Housel, & Mun, 2015). The CCOP PM was responsible for twelve CCOP systems and he needed to determine how to allocate resources amongst them (Rios et al., 2015). Following the guidance he received, he conducted an analysis on the programs based on the three goals for the program (Rios et al., 2015). As previously mentioned, the lack of revenue in the DoD makes return on investment difficult to calculate, so the PM turned to KVA to create a common-units approach when comparing the various systems (Rios, 2005).

This case vignette provides an example of how KVA can be applied to estimate the value added of systems that are, on the surface, amenable to the standard KVA learning time approach. KVA was similarly used in estimating the value added of advanced concept build improvements to the Aegis ship defense system (Mun, Housel, & Wessman, 2010).

The USS *Readiness* (the fictional name given to the real ship used for this analysis case), was equipped with four CCOP systems: A, B, C, and D (Rios et al., 2015). Each of these systems had different functions and scopes, although they all perform tasks within the Intelligence Collection Process (ICP) (Rios, 2005). Figure 24 shows the 10 sub-processes within the overall process of intelligence collection. Every sub-process can be further broken down into individual actions required to complete the sub-process with various degrees of automation depending on the task (Rios, Housel, & Mun, 2006). Figure 25 illustrates the four CCOP systems and the ICP sub-processes associated with them.

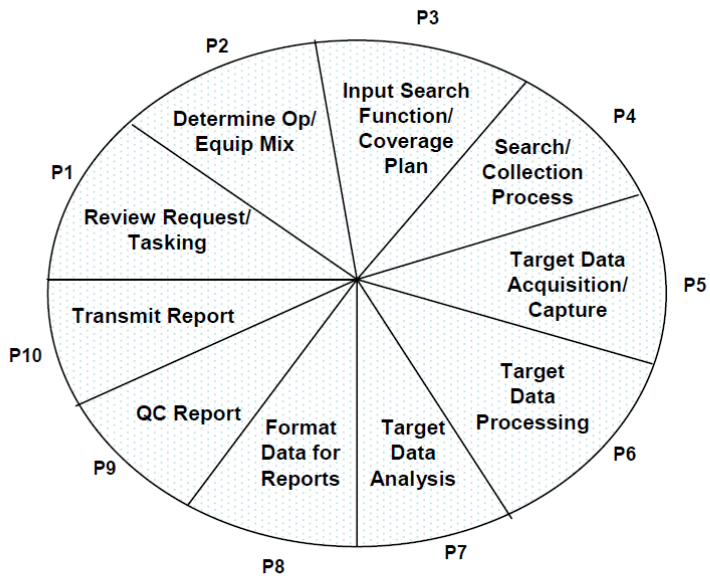


Figure 24. Intelligence Collection Process. Source: Rios et al. (2006).

	SUB-PROCESS NAME	CCOP A	CCOP B	CCOP C	CCOP D
P1	Review Request/Tasking	X			
P2	Determine Op/Equip Mix	X			
P3	Input Search Function/Coverage Plan	X			
P4	Search/Collection Process	X	X		
P5	Target Data Acquisition/Capture	X	X		
P6	Target Data Processing	X	X	X	X
P7	Target Data Analysis	X		X	X
P8	Format Data for Report Generation	X			
P9	QC Report	X			
P10	Transmit Report	X			

Figure 25. USS *Readiness* CCOP Systems. Source: Rios et al. (2006).

In his 2005 thesis, Cesar Rios discussed the data that was collected from a single ship's six-month deployment and adjusted to reflect annual cost. Rios explained how the PM used the learning time method and calculated the time to learn each sub-process for both automated and manned tasks. Learning time for automated tasks is the time an average user would take to learn how to produce the same output (Rios, 2005). He then multiplied the learning time and the number of times each process was executed to determine the output of each process in common units, referred to as K. Using market comparable prices for similar products, he assigned a notional price to assign revenue for the CCOP systems contributions to each sub-process. The author explained how costs were then assigned based on the human and IT assets that complete each task. The PM then determined the ROK and the Return on Knowledge Investment (ROKI), which is a surrogate for ROI (Rios, 2005). Figure 26 depicts the results for each sub-process and CCOP as well as for the aggregate.

Sub-Process		CCOP A	CCOP B	CCOP C	CCOP D	ROKI (ROI)
Review Request/Tasking	P1	68.54				22.11
Determine Op/Equip Mix	P2	66.86				20.89
Input Search Function/Coverage Plan	P3	52.91				-18.44
Search/Collection Process	P4	830.03	48.15			*239.01*
Target Data Acquisition/Capture	P5	190.15	47.71			47.28
Target Data Processing	P6	219.39	62.59	336.13	-71.82	36.67
Target Data Analysis	P7	49.98		434.76	-65.45	21.25
Format Data for Report Generation	P8	43.34				*-20.37*
QC Report	P9	215.88				79.19
Transmit Report	P10	48.75				-17.37
Metrics for Aggregated		178.59	52.81	385.44	68.63	109.9

Figure 26. Return on Knowledge Investment. Source: Rios et al. (2006).

Through his analysis, the PM learned that P4, the search/collection process, had the highest ROKI-ROI. Conversely, P8, the format data for report generation had the lowest ROKI. Using this data, the PM could use his breadth of knowledge to explore other questions that would help him make his funding determination. For instance, P4 was executed many more than twice as often as P8, leading to a higher total K and ultimately a higher return (Rios, 2005). Is P8 worth the investment in technology? Should it be more automated or less automated? Only one CCOP system, CCOP A, executes P8 (Rios, 2005). Would substituting a different system or changing a capability in a CCOP to include P8 improve the performance? When looking at the specific CCOP systems, CCOP D is the only system with a negative ROKI. It is a cost-heavy system that executes tasks a small number of times in comparison to the other systems (Rios, 2005). Is there a cheaper alternative to CCOP D? Are the operators trained properly? Should CCOP D even be on this platform or mission? The KVA analysis itself does not give the answers to these questions, although it does highlight their performance in an objective manner. The PM should have better and more thorough information about the different CCOP variants that will help him make the correct decision.

The KVA analysis also allows the PM use IRM techniques to conduct a statistical examination of the program since the ROKI, along with other metrics, gives the static financial model. In this instance, three real options were identified:

- Strategy A, Remote to Shore: Use the CCOP systems aboard deployed vessels and send the data to a remote location that will review the reports (Rios et al., 2015). This should reduce the number of intelligence personnel on each ship, consolidating them in a single location ashore (Rios et al., 2015).

- Strategy B, Direct Support: When a ship returns to port, the equipment and operators would move to another ship that is scheduled to deploy (Rios et al., 2015).

- Strategy B would also reduce the number of total CCOP systems and the number of intelligence personnel required fleet wide (Rios et al., 2015).

- Strategy C, Permanent Ships Signals Exploitation Space (SSES): CCOP systems and operators will be permanently assigned to a ship, regardless of its deployment status (Rios et al., 2015). While the total number of systems and personnel will be greater than those in Strategies A and B, commanders will have greater flexibility and control of each ship's intelligence collection capabilities (Rios et al., 2015).

A graphical depiction of these three options is shown in Figure 27, illustrating the various decision trees available to the PM. Each strategy also included the option to abandon a project after each phase, giving the PM the ability to reevaluate the progress of the program before committing additional resources to the next phase.

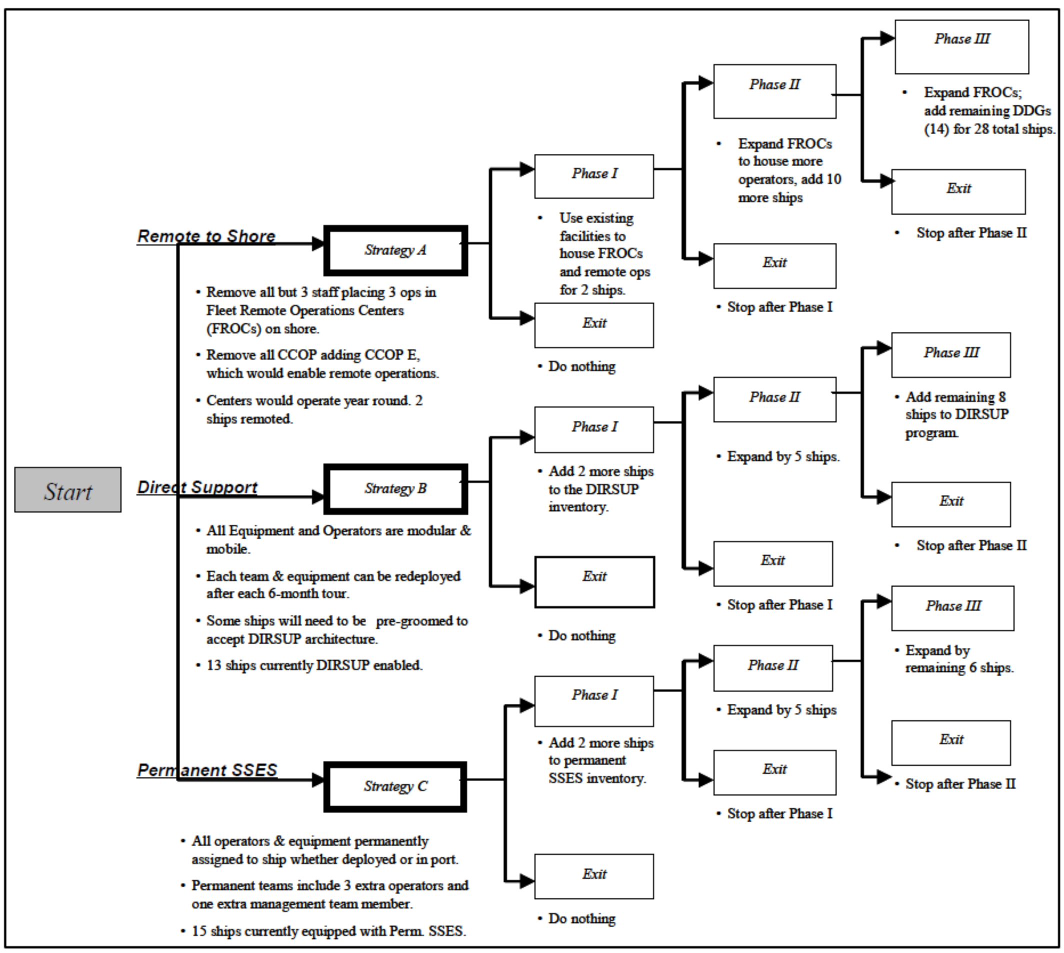


Figure 27. CCOPs Real Options Paths. Source: Rios et al. (2006).

The analysis produced present values for each of the different strategies, shown in Table 2. Commanders intuitively favored Strategy C because of the control it provided them over the makeup and operational capabilities of the units in their command (Rios et al., 2015). Strategies A and B both seemed likely to produce a greater present value due to perceived cost savings associated with reducing the number of systems and operators (Rios et al., 2015). However, the present value analysis indicates Strategy C is clearly the best option given the working conditions. As bandwidth limitations, processing power, and transmission speed improve, these options may change, necessitating a new look at the program, but in the current environment, the PM should choose Strategy C (Rios et al., 2015).

Table 2. Present Values of CCOPs Real Options Analysis. Source: Rios et al. (2005).

Summary Results	**Strategy A**	**Strategy B**	**Strategy C**
PV Option Cost (Year 1)	$348,533	$1,595,697	$1,613,029
PV Option Cost (Year 2)	$4,224,487	$3,043,358	$4,494,950
PV Option Cost (Year 3)	$3,688,994	$10,105,987	$8,806,643
PV Revenues	$24,416,017	$33,909,554	$38,820,096
PV Operating Costs	$16,220,188	$16,765,513	$9,951,833
PV Net Benefit	$8,195,829	$17,144,041	$28,868,264
PV Cost to Purchase Option	$425,000	$169,426	$72,611
Maturity in Years	3.00	3.00	3.00
Average Risk-Free Rate	3.54%	3.54%	3.54%
Dividend Opportunity Cost	0.00%	0.00%	0.00%
Volatility	26.49%	29.44%	15.04%
Total Strategic Value with Options	$1,386,355	$4,466,540	$15,231,813

The USS *Readiness* case example illustrates the potential use of the KVA and IRM methodologies within the Defense Acquisition System. A KVA review of the outputs of each system and its sub-processes produced a quantifiable, common-units metric the PM could use. The data could help determine which CCOP to funnel money towards, should it be decided to improve poor systems performance (or eliminate it altogether), make a good system even better, or elevate the performance of those systems performing at an average level. This information can also be used when determining a replacement for the CCOP program with a future system. The KVA metrics give a baseline ROKI detailing the output a future system should meet or exceed to be considered a viable alternative.

The IRM methodology helped frame the way forward by presenting real options for the PM to examine. Expounding the results via Monte Carlo simulation and developing a present value for the various strategies gave decision-makers a quantifiable and justifiable number on which to base their decision. This result could only be produced using the value of the output (rather than relying only on cost savings) through the KVA analysis conducted in earlier steps. Combining the KVA process to give a monetary value of a process's output gives IRM the ability to justify its results in a more universally understood metric: dollars. These traits suggest the methodologies should be considered for inclusion within the Defense Acquisition System.

D. SOFTWARE BUG FIX: LSS

LSS is a methodology designed to improve processes through incremental change. Following the steps in the DMAIC process allows project managers to determine where improvements can be made, how to measure them, and what changes to make to achieve better results. Numerous organizations within the DoD have had success using LSS to better their programs. The Letterkenny Army Depot reduced cost by $26.1 million per year for the PATRIOT missile program and increased their revenue from $123.3 million in 2002 to $456 million in 2006 (Harvey & Labedz, 2006). Like the examples just mentioned, LSS is often associated with manufacturing. However, the methodology can be employed with any process. The following vignette illustrates how LSS could be used in an IT setting.

The PM for a generic IT software program realized it was taking too long to remedy bugs within the program (Torres & Tighe, n.d.). He set a goal of reducing the average ticket time to fifteen days per request, which would improve the use of resources and reduce costs, ultimately increasing profit for the company (Torres & Tighe, n.d.). To accomplish this objective, he turned to the LSS methodology in order to reduce waste and variation within the process.

During the define phase, the PM formally stated his goal of reducing the mean service request time by ten days in the project charter (Torres & Tighe, n.d.). He also established the scope of the project to prevent any additional tasks from being added to the LSS improvement (Torres & Tighe, n.d.). This allows for incremental change and proper measurement of the changes the team implements to determine their effectiveness. He determined who the stakeholders were and what steps and inputs they held within the process. Then, he mapped out the As-Is system process, shown in Figure 28, to ensure every step was accounted for and to aid in analysis later in the LSS process (Torres & Tighe, n.d.).

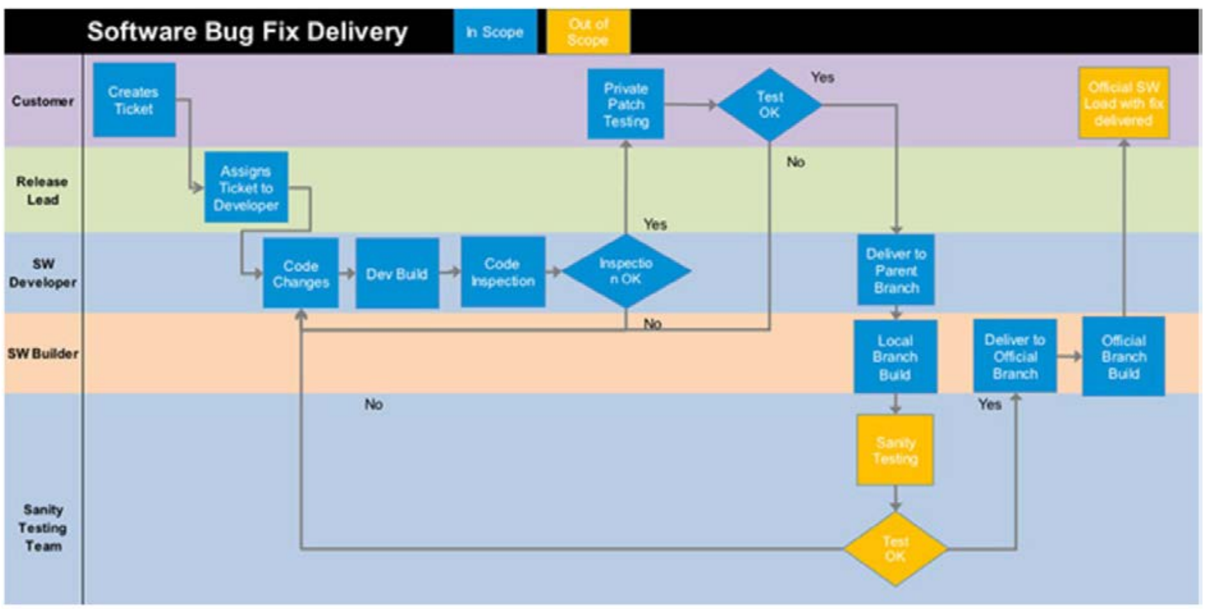


Figure 28. As-Is Software Fix Delivery. Source: Torres & Tighe (n.d.).

After defining the current software fix process, the PM needed to measure the performance of the intermediate steps to establish a baseline (Torres & Tighe, n.d.). Prior to collecting the data, his team developed a plan to collect the data, shown in Figure 29 (Torres & Tighe, n.d.). This plan ensures the data in collected in a systematic, repeatable manner. It assigns a title, unit of measure, definition of the measurement, stratification factors, notes on sampling, and a responsible individual for each measurement. While reviewing the data, he discovered requests to update the code ranged from three days to 55 days before they were completed, with an average lead time of 25.8 days (Torres & Tighe, n.d.).

Measure Title	Data Type (Continuous or Discrete)	Operational Definition	Stratification Factors (By who/what/ where/when)	Sampling Notes (Time Frame, etc.)	Who and How (Person responsible and method - Check Sheet?)
SW Bug Fix Lead Time	Days - Continuous	The amount of time (in Days) it takes from the moment the customer creates a bug fix ticket (ticket state Created) to the moment the bug fix is built into the official SW branch (ticket state Ready For Testing 'RFT').	None	Sample every bug fix ticket for the next 6 weeks starting 8/1	Release Leader will check the date stamps on the bug tracking tool
Ticket Assigned Lead Time	Days - Continuous	The amount of time (in Days) it takes from the moment the customer creates a bug fix ticket (ticket state Created) to the moment the bug fix ticket is assigned to a SW developer (ticket state Assigned).	None	Sample every bug fix ticket for the next 6 weeks starting 8/1	Release Leader will check the date stamps on the bug tracking tool
Ticket Ready to Submit Lead Time	Days - Continuous	The amount of time (in Days) it takes from the moment the the bug fix ticket is assigned to a SW developer (ticket state Assigned) to the moment SW developer is ready to deliver the code (ticket state Ready to Submit). Development testing is done, and Code Inspection is approved in the Ready to Submit State.	None	Sample every bug fix ticket for the next 6 weeks starting 8/1	Release Leader will check the date stamps on the bug tracking tool
Ticket Code Commited Lead Time	Days - Continuous	The amount of time (in Days) it takes from the moment the SW developer is ready to deliver the code (ticket state Ready to Submit) to the moment SW developer delivered the code to parent branch (ticket state Code Committed). Development testing is done, and Code Inspection is approved in the Ready to Submit State.	None	Sample every bug fix ticket for the next 6 weeks starting 8/1	Release Leader will check the date stamps on the bug tracking tool
Ticket Ready for Testing Lead Time	Days - Continuous	The amount of time (in Days) it takes from the moment SW developer delivered the code to parent branch (ticket state Code Committed) to the moment bug fix is built into the official SW branch (ticket state Ready For Testing 'RFT').	None	Sample every bug fix ticket for the next 6 weeks starting 8/1	Release Leader will check the date stamps on the bug tracking tool
Code Inspections Lead Time	Days - Continuous	The amount of time (in Days) it takes from the moment code inspection is created to the moment the code inspection is approved.	None	Sample 20 Code Inspections per week for the next 6 weeks starting 8/1	Release Leader will check the number of comments on the code inspection tool
Comments per Code Inspections	Discrete	The ammount of Comments in a Code Inspections	By LOC (Lines of Code)	Sample 20 Code Inspections per week for the next 6 weeks starting 8/1	Release Leader will check the number of comments on the code inspection tool

Figure 29. Data Collection Plan. Source: Torres & Tighe (n.d.).

To reach the stated goal, the PM must analyze the collected data and discover why the process took so long before implementing changes that could reduce the time by an average of ten days. He began the analysis with a fishbone diagram to determine the root causes of the delays. The fishbone diagram looked at people, policies, the process itself, and the environment in which the process operated (Torres & Tighe, n.d.). From this assessment, he determined the areas that should most likely require further examination were the code inspections, delivering the fixes to the parent branches, and the bug fix ticket assignments (Torres & Tighe, n.d.). Reviewing the current process mapped out in Figure 28 showed possible sub-processes and stakeholders that may have extraneous steps or do not add the LSS definition of value (Torres & Tighe, n.d.). Figure 30 shows the total value added and non-value added time in days associated with each step in the overall process, which confirms the previous assessment of potential areas of improvement. Since the code inspection and delivery to parent branch steps add no value to the overall process, it is possible these steps may be eliminated entirely (Torres & Tighe, n.d.). Addressing the time required to "assign the ticket to the software developer" may also be an area of improvement, as it also does not add value to the final product (Torres & Tighe, n.d.). These hypotheses were evaluated and found to be partially true—code inspection was not needed for minor fixes, only for change that resulted in more than 250 lines of code (Torres & Tighe, n.d.).

#	Process Step	Step Label (VA, NVA, NVAr)	Value Added Time	NVA & NVA-Required Work Time	NVA - Wait Time
1	Assign Ticket to Software Developer	NVAr		2	
2	Software Code Changes	VA	10		
3	Development Build	VA	1		
4	Code Inspection	NVA		3	
5	Private Patch Testing	VA	1		
6	Deliver to Parent Branch	NVA		3	
7	Local Branch Build	NVA		1	
8	Sanity Testing	NVAr		2	
9	Deliver to Official Branch	NVAr		1	
10	Official Branch Build	VA	1		

	Time	% of total
Total Value-Added Work Time	13	52.00%
Total Non-Value-Added or NVA-r Work Time	12	48.00%
NVA - Wait Time	0	0.00%
Total Cycle Time	25	100.00%

Figure 30. Value Added Flow Analysis. Source: Torres & Tighe (n.d.).

The PM determined three root causes for the delays and now must improve the process based on the results from the analyze phase. He proposed four potential solutions to fix the root causes- remove code inspections when the total lines of code per fix are less than 250, cross train the software builders to perform other jobs, cross train the software developers to perform other jobs, and use the Kanban methodology (a scheduling system associated with lean manufacturing) when assigning tickets (Torres & Tighe, n.d.). These proposed solutions were graded on five weighted criteria- the potential to meet the goal, positive customer impact, cost to implement, stakeholder buy-in, and time to implement (Torres & Tighe, n.d.). While cross training the software builders was not determined to be an effective strategy, the PM decided to implement the other three solutions (Torres & Tighe, n.d.). He created a map of the To-Be process, shown in Figure 31. The unnecessary tasks were removed from the process and the changes to the process were utilized to reduce bottlenecks (Torres & Tighe, n.d.). Once the changes were initiated, the team measured the process again using the same measurement plan. The variability between tickets was cut in half while the mean lead time was reduced from 25.8 days to 15.6 (Torres & Tighe, n.d.).

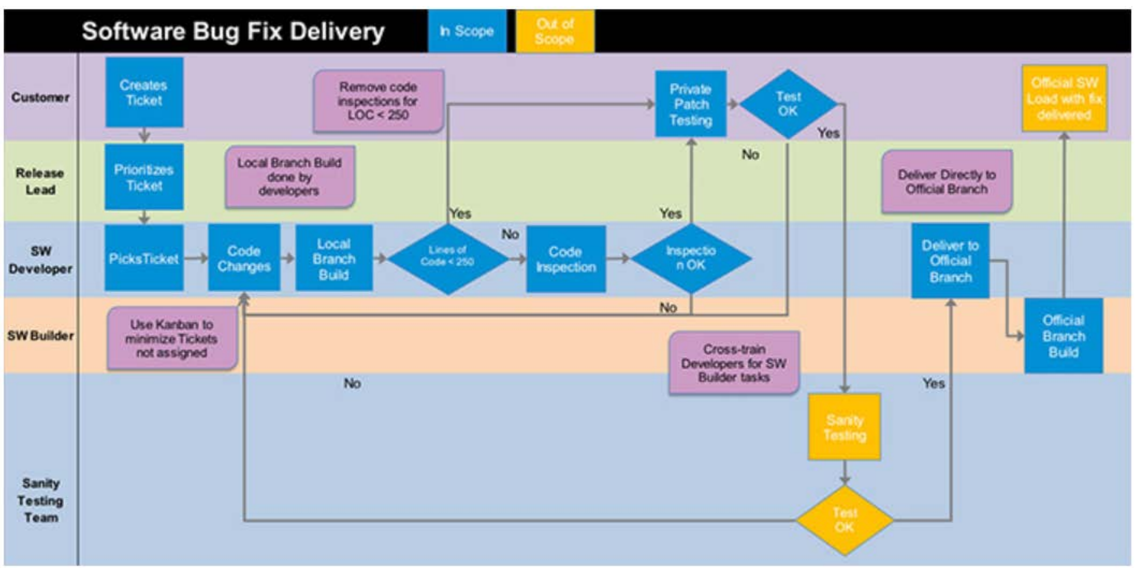


Figure 31. To-Be Software Fix Delivery. Source: Torres & Tighe (n.d.).

With the new process in place, the PM shifted to the control phase, documenting the lessons learned, impact on customers, and calculating the monetized results from the process improvement (Torres & Tighe, n.d.). He initiated a process control plan that allows the responsible individuals to track and measure the performance of the process now that the project has ended and normal operations have resumed (Torres & Tighe, n.d.). In a manner similar to the Data Collection Plan, Figure 32 lists the measures, method the data is collected, frequency of review, and responsible person for overseeing each process, as well as the trigger points and reaction plan should the process breach a trigger point (Torres & Tighe, n.d.).

Monitoring Plan						Response Plan		
Name of the Measure	Input, Process or Output?	What is the Target?	Method of Data Capture	Checking Frequency	Person Responsible	Upper/Lower Trigger Point	Who Will Respond?	Reaction Plan
Bug Fix Lead Time	Output	15 Days or Less	Date stamp when customer create a bug fix ticket to date stamp the fix is built in the official branch	Weekly	Release Lead	No greater than 17 Days Upper Control Limit	Release Lead	Observe the following Measurements to see why it's taking longer. Make corrections - Ticket Assigned Time - Ticket Ready to Submit Time - Ticket Code Commited Time - Ticket Ready For Testing Time
Ticket Assigned Lead Time	Process	1 Day or Less	Date stamp when customer create a bug fix ticket to date stamp when the ticket is assigned to a SW developer	Weekly	Release Lead	No greater than 2 Days Upper Control Limit	Release Lead	Make corrections - More resources needed? - Escalation Needed for more resources?
Ready to Submit Lead Time	Process	12 Days or Less	Date Stamp when the ticket is assigned to a developer to a sw developer is ready to submit to Official Branch.	Weekly	Release Lead	No greater than 15 Days Upper Control Limit	Release Lead	Make corrections - Fast response from the test team? - Architects or Subject Matter Experts need involvement? - Environment Issues?
Code Commited Lead Time	Process	1 Days or Less	Date Stamp when the ticket is delivered to Official Branch.	Weekly	Release Lead	No greater than 2 Days Upper Control Limit	Release Lead	Make corrections. Understand why we cannot deliver to Official Branch - Environment Issues? - Official Branch locked due to external issues?
Code Commited Lead Time	Process	1 Day	Date Stamp when the ticket is delivered to Official Branch.	Weekly	Release Lead	No greater than 2 Days Upper Control Limit	Release Lead	Make corrections. Understand why Official Branch is not doing software builds - Environment Issues? - Official Branch locked due to external issues?

Figure 32. Monitoring and Response Plan. Source: Torres & Tighe (n.d.).

As this case shows, LSS can be used in any type of repeatable procedure from traditional manufacturing applications to IT software fixes. The steps in the DMAIC process can offer substantial results when utilized correctly. Improving established processes can improve the speed of the process, improve its efficiency, reduce overall cost, or a combination of the three. However, there are limitations with LSS, which will be discussed in the following chapter.

E. SUMMARY

This chapter examined various cases—both historical and hypothetical—in which the five methodologies may be applied. Each vignette shows the different systems in circumstances that favor the use of the highlighted methodology. The following chapter will discuss some of the benefits and challenges that must be considered when choosing a system to employ.

IV. BENEFITS AND CHALLENGES

Parts of this chapter were previously published by the Naval Postgraduate School Acquisition Research Program (Housel, Mun, Jones, & Carlton, 2019).

The previous chapter examined the five methodologies in different real world or hypothetical cases, which illustrate strengths and weaknesses associated with each system. This chapter reviews the benefits and challenges with employing the various methodologies, using the vignettes discussed in Chapter III as context.

A. EVM

1. Benefits

EVM offers numerous advantages to PMs using the methodology to track the progress of a project. When properly implemented, it gives managers an early warning of potential issues within a program and a forecast of the total cost and schedule requirements (Fleming & Koppelman, 2010). Research has shown the CPI stabilizes within a ten percent range after a project reaches the twenty percent completion point (Christensen, 1998). The 20 percent stabilization holds true across various contract types, programs and services (Fleming & Koppelman, 2010). This early indication gives project managers a reliable prediction of the projects final costs (Fleming & Koppelman, 2010). The low range of the cost overrun is the current cost plus the remaining scheduled cost (Fleming & Koppelman, 2010). The high end of the costs is the budgeted cost divided by the CPI, which is a more accurate estimate unless extenuating circumstances caused the overrun (Fleming & Koppelman, 2010). SPI also gives an indication of future cost increases. An unfavorable SPI indicates spending will grow larger than initially planned to reduce the schedule variance (Christensen, 1998).

Each component has a cost and schedule associated with its completion which feed into the overall completion of the project. Since the baselines are established prior to work beginning on any subcomponents, management can create a detailed timeline with the expected cost necessary to achieve the tasks well in advance. Having such a thorough plan allows the PM to focus on the areas that are reporting discrepancies in their CPI and SPI rather than concentrating on all areas of the project. They can interact when there are issues with a component, trusting the aspects of a project that are on schedule and on budget to remain performing well. Instead of actively controlling all parts of the project, they can spend their limited time correcting issues with portions that have unfavorable SV and CV. The key metrics allow PMs to manage by exception.

Using a WBS to assign, track, and complete tasks facilitates the accurate and timely reporting of a project's performance. The use of a common system facilitates communication between the PM and the contractor. Since the individual components of a project are broken down into small subsections that must be completed, management can more easily communicate with contractors concerning discrepancies with subcomponents. This allows a PM to assign resources and facilitates subsequent tracking of a system's progress without creating additional reporting requirements. Given that reporting on the status of a program through EVM is required by law, managing with the same system reduces administrative requirements (Christensen, 1998). Managing from one methodology while reporting from a different system is a more difficult and costly way to conduct business (Christensen, 1998). EVM gives managers a single system to track cost, completion, and project performance, centralizing the control system while allowing lower level managers to oversee their sections with the same metrics.

Simplicity is a key attribute of the EVM methodology. The process is broken down into three main variables- money, time, and work completed. The key metrics managers use to assess a project are simple ratios derived from these three variables. Determining the performance of the project is as easy as determining how much money has been spent to complete the current amount of work at a given time. The methodology readily scales from the overall project to individual components without changing reporting requirements; managers simply compile the components reports into an aggregate report. However, in IS programs it can be more difficult to determine if the work is completed satisfactorily and in accordance with the stated requirements, as seen in the JTRS acquisition.

One of the most important attributes of EVM is the combination of schedule and fiscal performance. Traditional cost management approaches reflect a project's funding performance and not the true cost of the program (Fleming & Koppelman, 2010). Flexible budgets also give management the option to vary the budget for work based on the actual output level (Christensen, 1998). EVM differs from a flexible budget by including the time dimension in its calculations. EVM puts the schedule variance into a dollar amount, quantifying delays. The amount of money spent completing a project is important, but it does not show the complete picture. If an initiative is on or under budget yet is delivered seven years later than promised, it did not perform well despite the potential cost savings. Monetizing the scheduled time gives the PM the ability to determine how much a delay will cost, providing greater flexibility within management decisions.

2. Challenges

EVM has proven to be an effective management system in traditional manufacturing processes. However, in fiscal year 2008, the U.S. federal IT portfolio contained 346 major IT programs worth approximately $27 billion that received a rating of "unacceptable" or are on the "Management Watch List" (Kwak & Anbari, 2012). This suggests there is significant room for improvement within the current IS acquisition process. ISs are not developed in the same manner as projects that do not process information. When building a warehouse, a contractor uses the architect's blueprints to determine exactly how many bolts will be needed for each beam and how long it will take to install each item. Combining each sub-process, which consist of known values, the manager can establish a baseline with a high degree of accuracy. However, when a program involves writing code, the process is more complicated. Keeping with EVM principles, the desired outputs for a program are known before work begins and the plan to accomplish those steps can be created and mapped out prior to construction of the code. However, the time required to write, test, debug, and retest the computer code can vary significantly between projects and individuals. Using a system that measures the overall progress of a program using the completion of subcomponents compared to a baseline established well before work began is not an accurate assessment for projects that do not progress linearly, such as IS programs.

The requirements in large IS projects are often not well defined, leading to cost and schedule overruns. For instance, JTRS used LOCs to create the baseline. However, LOC can vary drastically from one programmer to another or between programming languages. While there are industry standards for estimating the number of LOCs, there is still variance between each individual creating a software program. In a traditional manufacturing application of EVM, a WBS containing the task 'turn on the light' would have schematics and plans associated with the task so that any qualified worker could complete the work. In an IS program, turning on the light via a software program could be completed in any number of ways and still meet the specifications. This simplistic example illustrates issues that will develop when using EVM to manage a more complicated IT based project, such as creating a software-defined waveform.

One of the core principles of EVM is maintaining the baseline of a program throughout the life of the project, allowing for consistent and accurate measurement of a project's progress. Adding additional requirements or changing the specifications of certain components can alter the trajectory of a program entirely. While any program will need to make adjustments when scope creep occurs, EVM is particularly ill-suited to make these modifications midstream. If new requirements are added to a program or existing requirements change after the baseline is established, especially after work commences, the baseline is no longer valid. More often than not, there will be additional costs and longer timelines required to fulfill the new specifications. This will change the ACWP while leaving the BCWS the same. As the actual costs increase and schedule expands compared to the baseline, all four performance metrics (CV, CPI, SV, and SPI) are negatively impacted, even if the newly added requirements are completed on time and on budget. EVM does not function well in projects with changing scope or requirements.

When developing JTRS, much of the software had never been written or created, calling on developers to estimate how the cost and schedule for the various components. To account for the possibility it may not be completed in time, the engineer or PM may add one week to something originally thought to take three weeks, accounting for some risk of the unknown. Should overruns occur in other areas, PMs often remove this risk factor from their calculations to improve their performance compared to the baseline. This eliminates much of the risk mitigation the program originally established, eventually leading to further CV and SV. However, when creating a complex product based on the assumption of future technological advancements, as in JTRS, there is a high degree of risk. Presuming all tasks will be completed on schedule without additional schedule risk mitigation is a poor assumption to make after previous components of the project have already fallen behind.

EVM functions well as a tool to monitor programs developed in waterfall or parallel design methods. In alternative design methodologies, such as agile or iterative designs, EVM does not provide the same level of usefulness to project managers. EVM does not require a particular development approach and can be used in any system that uses a baseline plan relating schedule and cost (DoD, 2018). Techniques such as agile EVM and scrum, attempt to use a more iterative approach typical of the software development process but are still using the same EVM concepts with tasks broken into various work packages. By assigning a budget and timeline to specific features within an IS initiative, PMs may use EVM to oversee progress. As each feature is completed, value is earned and the EVM metrics are updated. However, within the specific features and components of a program EVM is not as useful. As previously mentioned, the specifics of writing computer code are not as cut and dry as a physical project. If two capabilities written in parallel both work individually, it is still possible there are issues when combining the features in the final project. To reduce this risk, PMs must add additional time in their schedule. This can be done by scheduling multiple increments that are planned, designed, coded, tested, and demonstrated (DoD, 2018). While this is a viable method to use EVM in agile design, it is not as accurate or precise as an EVM program in a brick and mortar type project.

As discussed previously, the metrics within EVM are simple to understand and use to make management decisions. However, for the metrics to be accurate the cost and schedule must be accurate to a great level of detail. WBSs for multi-billion dollar programs often cover all items from the strategic overview down to small tasks within the project. Creating such a detailed list of requirements for each component within a system is both timely and costly. While the result may be a simple schedule with easily discernible metrics, the initial setup process to establish the baseline can be immense.

B. BSC

1. Benefits

The primary purpose of BSC is to align the efforts of every level of an organization to work towards the same strategic goals. In the example framework presented in Chapter III, the vision and goals are translated into key areas among the four categories that stem from the vision and strategy. The key areas remain the same through most levels within the DoN, keeping all the various units within the acquisition community aligned with the common strategy. The metrics and measures within each key area adjust based on a department’s span of control but the approach ensures the end state of every level is achieving the strategic vision. It is an excellent tool to ensure stakeholders at all levels review aspects of the acquisition structure other than the financial component. Learning and Growth, Internal Business Processes, Weapons Systems (finances), and the Warfighter are all important components of how the acquisition community operates and BSC ensures these categories are included in the decision making process.

The BSC methodology also provides additional structure throughout the organization. Stakeholders are able to view the performance of a department at any level through the chosen BSC lenses. For example, the ASN(RD&A) could look at a subordinate acquisition command or an individual acquisition program and view the same basic information. While the numbers and metrics will be different between the two, the basic concepts are related, allowing the stakeholders to make rough comparisons between the various divisions’ reports.

This structure can also improve communication up and down the organizational hierarchy. Since the key areas remain relatively constant and the four categories are strictly maintained in every level, stakeholders can easily discuss the performance of various units with respective to other internal agencies. Even if the metrics for an individual Marine Corps acquisition program and the command level of U.S. Navy Systems Command are vastly different, stakeholders can view the outcomes of the various categories and determine if the Weapon Systems or Internal Business Processes categories are performing as they should and determine where additional resources- be that manpower, money, or equipment- should be allocated.

Even though the BSC methodology makes measuring performance a common, systematic process across the organization, individual leaders are still able to determine their own metrics and performance criteria. The leaders at each unit should know their organization best and, as such, can set the measures that will best represent the overall execution of their tasks, provided they align with the strategic vision. Given a set of categories and key areas to focus mid-level management's mindset, they are then able to convert these into actionable items for the people within their span of control to push towards accomplishing the organization's overarching goals.

Using BSC within an organization ensures the strategy is kept at the forefront of all actions. Every performance review is conducted within the framework of the company's grand strategy. Monthly or quarterly reviews can determine how the unit is accomplishing the strategic goals. Yearly strategy reviews could ensure the strategy is relevant to the current operating conditions and updates are inserted into the measurement system. Should drastic changes occur in the internal or external environment, leadership can change the key areas to align with changes to the vision, helping lower levels adjust their techniques as needed to avoid the 'this is how we have always done it' mentality.

2. Challenges

Even though BSC can offer benefits to the acquisition community, it also presents unique challenges that must be overcome for its success. Despite its name, Balanced Scorecard is not a balanced system. The four categories are measured separately with different key areas and metrics within each category. If a program is performing well above expectations in two areas, at the expected level in one category, but well below average in the other last aspect, how should the PM categorize its performance? BSC does not provide a proverbial dial in the middle of the four categories to tie them together into a comprehensive measurement. While there may always be balancing issues between various performance metrics, such as cost, schedule, and quality, these outputs typically have common-units of measurement to determine their interaction. The lack of a model to tie the categories together makes it difficult to determine if corrective action should be taken in the above example or which area should receive more attention in the event of two categories underperforming. The framework discussed in Chapter III addresses this issue by assigning weights to each category, which assigns the importance of each metric but also raises the next challenge within BSC.

Comparing different types of measurements that do not have common units is not done easily, especially when they use different types of data. There are four levels of measurement, listed here with increasing level of precision: nominal, ordinal, interval, and ratio (Statistic Solutions, n.d.). Nominal data is name only, such as the red, yellow, or green often seen on scorecard sheets (Statistic Solutions, n.d.). Ordinal data depicts the order relationship within a set, such as small, medium, or large (Statistic Solutions, n.d.). Interval measurements have the same distance between each unit, such as measuring temperature in Fahrenheit, where the change in heat associated with one degree is the same no matter if it is hot or cold (Statistic Solutions, n.d.). Finally, ratio data has equal intervals but can also include zero within the scale, such as financial data (Statistic Solutions, n.d.). Interval and ratio data are much more precise than nominal and ordinal data and are used to measure different things. Moving data from a higher level to lower level is acceptable (i.e., calling a 20 oz. cup a large), but moving from lower level to higher is not (i.e., assuming a large contains 20 oz.). However, within BSC practitioners often move back and forth between the various scales, convoluting the data and compromising the integrity of the measurements. While the examples in Chapter III have well defined metrics that do not violate the principles discussed, it can be problematic if leaders at different levels use metrics with inappropriate scales, especially if that information is then aggregated and used at higher levels.

The underlying concepts of BSC are not overly complex and they average user can likely grasp them within a short amount of time. However, implementing BSC into an organization, especially an organization as large as the acquisition community, can be a massive feat. Using BSC as it is designed requires a complete overhaul to the organization. Categories, key areas, and metrics must be determined and assigned at each individual level within the community. The metrics must be validated to ensure measurement errors are avoided and the complete picture is captured through the chosen measures. Due to the hierarchical structure, lower level managers cannot create their metrics without knowing the specific measures required by the level above their unit. It would be difficult for PMs to develop metrics to meet strategic goals without appropriate context.

Since the premise behind the methodology is "what you measure is what you get" (Kaplan & Norton, 1992, p. 71), performance evaluations for programs and individuals must be tailored to include the new BSC metrics. To prevent issues with data accuracy, formatting, version control, and other complexities, the measurement reporting system must be tailored for each unit and program using BSC. As each metric within key areas may be specific to an individual program, this must be created for the organization, reducing flexibility. The vision and strategy may change with time, indicating BSC projects do not have a defined end date. As leadership changes, goals may change, necessitating updated key areas and metrics.

C. KVA

1. Benefits

KVA is an objective, quantifiable method to measure the value associated with a system and the sub-processes within the system. The value measurements of each process are ratio scale numbers, allowing analysts to compare them with the values from other sub-processes to determine their relative effectiveness. PMs can determine the value generated from the human component against the value added by IT processes. Because of the scales, PMs can use these measurements to develop useful ratios in their analysis of the program's performance. Productivity ratios such as ROK, output of a process divided by the process cost, and ROI, output minus cost divided by cost. The ROKs and ROIs, which are always 100% correlated, give managers information about the amount of value a process generates compared to the amount of money spent to create the value. Unlike any other methodology, KVA assigns these figures to both the process and sub-processes rather than only the process as a whole. The CCOP case shows that an increase in the amount of automation within a process does not necessitate an increase in value, which is often assumed when acquiring ISs.

Conducting an analysis of a program using KVA will give a PM a clearer picture of the operational components of the program. While organizations likely have metrics used to determine the performance of a project or operation, ROK will give them additional information to improve their management decisions. PMs can determine the relative value of the components that comprise the program. Knowing a particular job or sub-process gives the same output value as a different process but at a different cost may provide context for the performance of the system. This, in turn, gives experienced managers the information needed to allocate resources to specific components of a program that need improvement or should be utilized more frequently. As seen in the CCOP example, the PM learned which CCOPs and processes had a high or low ROK. He could then use his expertise to determine the most beneficial use of his limited resources.

While a KVA analysis can provide information that will change the course of a program or project, it does not require significant changes to organizational structure or reporting processes to do so. The evaluation can be conducted during normal operating conditions without introducing complicated new metrics into the system. Learning time, process description, or the binary query method are all based on information that should be available within the organization. A small amount of 'hands on' measurement may be required to verify the accuracy of the given data. As such, the analysis can be done quicker than the other methodologies, giving PMs access to actionable information more rapidly than previous methods.

2. Challenges

KVA will give analysts a quantifiable, ratio-scale number for the value of the sub-processes. However, it does this only with processes that consist of known a priori outputs. The intangible items, such as creativity and imagination, that occur within the human brain cannot be quantified with this method (or any other method so far). In fact, no current system is able to accurately quantify these creative types of intangibles within a process because there is no algorithm for creativity. These factors are not common to the average user and as such, cannot be defined via any of the KVA methods- learning time, binary query, or process description- because the creativity process cannot be learned or described. The CCOP case shows how one can use KVA to measure complicated tasks that humans cannot perform by quantifying the knowledge embedded within the signal intelligence systems. However, this was only possible after the system was completed and described. KVA will assign the value of process but it cannot predict the value of potential outputs, only those that are specified a priori.

While KVA provides the PM with an objective measurement of the ROK, the ROK itself does not provide recommendations for future actions. Knowing CCOP A has a good ROKI and CCOP D has a much lower ROKI does not tell the PM what to do with his resources. He must decide if the limited resources in his program should be allocated to CCOP A to leverage its excellent performance or if they would be best used improving CCOP D to increase the ROKI for future iterations. The analysis provides leaders with useful data when comparing the sub-processes and programs within their control, but it does not give definitive answers on what to do with those processes. Instead, leaders must utilize their knowledge and expertise of the program to decide the best course of action. This is why the CCOP example used IRM to compare possible solutions once the ROKIs were established.

Although KVA will provide ratio-scale numbers to aid in evaluating processes within a program, the ratios are often only valid for comparisons within the same analysis. Benchmarking the raw numbers with other organizations or with different divisions in the same organization may not provide a usable assessment depending on the techniques used when determining the ROK. For instance, the CCOP method used learning time to establish the ROK for the different systems. However, another analyst may have used the binary query or process description methods to describe the outputs in an equally defensible evaluation. These numbers will not be comparable to the numbers from the learning time method unless they are normalized, even though the final analysis will result in the same relative quantitative comparisons of productivity. Other variances may cause the same issues, such as if an analyst includes the underlying infrastructure or common training for all personnel. Because these can be treated as constants across all processes, they can be excluded without skewing the final results. Nevertheless, the final results of any properly conducted analysis will return the same ROKs, which is the ultimate goal of KVA.

D. IRM

1. Benefits

The combination of several proven techniques makes IRM a valuable tool to improve the quality of information available when making decisions. Introducing dynamic Monte Carlo simulation to analysis of potential initiatives and investments illustrates the risks associated with the projects in a more realistic manner than traditional approaches. Static forecasting based on assumptions and historical performance offers a limited view of the range of a project's possible outcomes. Running thousands of simulations (or more) while adjusting the variables within realistic possibilities allows decision makers to obtain a more complete picture of the uncertainty inherent within the project. Increasing the amount of relevant and accurate information managers can access will improve the quality of decisions made by the leadership team.

IRM provides a systematic approach to addressing IT investments. Following the eight steps is a straightforward process that facilitates a quantitative decision making process. While the functions within each step are sometimes complicated and require additional training to complete, the process as a whole is clear-cut and easy to follow. Since the IRM method is well defined, it can be implemented into established procedures without a complete reengineering of established processes. Data used in traditional methods will be used in IRM and expanded to improve the scope of a project's evaluation. The present value analysis on the three CCOP real options paths used data that was already available to the PM. The real options were quantified and resulted in an output that differed from expectations. The systemic nature of IRM allows the process to be completed by different members or different teams without recollecting data and starting from the beginning. After analysts have completed training in IRM, they should be able to continue the process from any point within the method.

Armed with the probability of certain outputs from the project, real options analysis allows managers to determine the best method to proceed with a project. The CCOP case demonstrated multiple ways real options can be included in program management. Real options were presented not only at the beginning of the program with three different directions for the program to head, but also after each different phases of the chosen strategy. By writing a contract that lets an organization adjust their chosen course of action as more information becomes available, the company can minimize losses for failing programs and capitalize on initiatives that are performing well or show promise. Fortunately, within DoD acquisitions, many real options are already commonplace. The government regularly cancels contracts due to a change in fiscal policy, failure to meet specifications, or other reasons. Adding other real options to contracts would not be a completely foreign concept.

A key strength of the IRM methodology is the use of common units to make strategic decisions relate to the value of a system. By implementing KVA measurements into the static and dynamic IRM models, leadership can see a statistical range depicting the potential value of a project. In the CCOPs example, the IRM metrics stemmed directly from the KVA methodology. The market comparable prices generated from the value analysis were used to determine the present values of the real option strategies. Most other methods only use the cost of the program to determine its effectiveness, assuming the value is inherent due to the requirements that were generated. IRM can inform decision makers about both the costs associated with a potential investment into an initiative and the value of the said initiative in units that can be directly compared.

2. Challenges

While IRM is an extremely useful analytical tool, there are drawbacks to the process as well. The various techniques within the method can be difficult to master (Housel et al., 2019). It is a complicated process that requires a detailed understanding of both finance and statistics to complete a thorough analysis. While there are software tools to assist in conducting the analysis, the inputs are more complicated than simply inserting a few numbers into a program and reading an output. However, with an understanding of the basic concepts, sufficient training, and the correct tools, an analyst can generate the necessary information to allow decision makers access to the appropriate comparative material to make an informed decision (Housel et al., 2019). The information congregated during the statistical analysis can appear daunting. For those without a strong statistics background, the simulations and their outputs seemingly come from a quantitative black-box (Mun, 2016). If decision makers do not understand why an analyst makes a recommendation, it can be easy to disregard the suggestions and rely on familiar techniques. Creating comprehensive and thorough reports for management review combined with informed presentations to alleviate concerns with the unaccustomed procedures will combat this potential issue.

To take advantage of real options, these options must be considered in advance of the decision to enact any of the options. Leadership must recognize the future option when writing contracts to ensure certain options remain available. Some options, such as the option to expand, can be enacted relatively simply by developing another project based on the success of the initial investment. However, the option to abandon may not be as readily available to project managers if the contract did not include appropriate clauses. Vendors must be willing to accept potential cancellation of sub-contracts when they are not at fault, which may increase the price they charge to complete a task. Due to the potential increased cost associated with contracting real options, managers must conduct a detailed analysis of which potential options may be exercised in the future. The CCOPs example shows a good method of ascertaining the real options prior to execution. This allowed the PM to conduct a sound analysis of the different options prior to signing contracts with vendors.

Like all financial forecasting, IRM relies on historical data to make predictions. Predictions that incorporate current information in their analysis rather than relying purely on historical trends can provide more insight to decision makers. For example, sophisticated meteorologists create weather predictions from multiple sources. Doppler radar, satellites, radiosondes (i.e. weather balloons), automated surface-observing systems observe the current weather conditions (National Oceanic and Atmospheric Administration (NOAA), 2017). Using numerical weather prediction, the data from the various sources is run in models based on known historical patterns for the region (NOAA, n.d.). For the meteorologist, knowing the current conditions is just as important as knowing the historical models (NOAA, n.d.). Similarly, if the project analyst had the ability to incorporate relevant information that is current to the minute (or to the required fidelity) the models would provide even more accurate information. The CCOPs case is an example of a project comparing known historical options. Outsourcing, reducing manning, and maintaining the current structure all had statistics that could be used in simulations because of similar projects with historical data. Although this drawback is not unique to the IRM methodology, leaders should be aware of this flaw in any financial prediction.

Finally, the DoD does not currently incentivize project managers reaping the positive benefits of risk. The risk framework within DoD acquisitions is designed to minimize cost and schedule overruns during a project. The structure of DoD contracts does not encourage increased capability or performance from vendors or the project as a whole. Where a for-profit business may invest in an endeavor that may fail, they do so because they believe the upside reward is greater than the potential cost of failure. For instance, if a design objective for an aircraft is to reach 250 knots and the design threshold is 200 knots, the budget will be for the threshold vice the objective. There will not be enough funding for the program to reach the objective unless the PM is able to reallocate resources internally. The acquisitions process looks at the cost to reach the objective rather the value of the objective. For-profit companies reward for performance, which is measured by revenue. The DoD's unspoken surrogate for revenue is cost savings, which promotes a different value than increasing the value of a project. Conversely, DoD acquisitions only proceed once the negative consequences are mitigated to the greatest extent possible. The upside risk is of minimal importance to the project managers; the program simply needs to be completed on time and on budget. Although it is still vital to examine how potential projects it into the overall collection of acquisitions and current assets in the DoD, the contract structure limits some of the portfolio optimization aspects of IRM.

E. LSS

1. Benefits

LSS allows PMs to increase the value within their program by improving the product quality or reducing the overall cost. It can optimize processes already in place, allowing for incremental improvements without the need for expensive redesigns. Using LSS techniques will help PMs determine the root cause of any problems to enact the appropriate changes rather than simply addressing symptoms of the problem, which may allow them to recur. The software fix case study shows how the LSS principles helped create a more efficient system by identifying where the bottlenecks and waste were in the process. Determining the source of issues within the IS or the processes that support the IS will improve either the final product or the steps that lead to the creation and support of the IS.

Identifying waste within the system lowers the cost, which can lead to significant savings when applied to the lifecycle of a program. A large portion of the total cost of a program can occur after the product is initially fielded, especially with programs that are intended to have a long service life. For example, the service life of the B-52 will likely last over eighty years, with 90% of the lifecycle cost incurring during the Operations and Support phase (Apte & Kang, 2006). While IS programs will likely not have as lengthy a lifecycle as the B-52, improvements to established processes can result in significant cost savings, especially when the refinements are discovered early in the lifecycle. The case study demonstrates how waste may be encountered and reduced in an IS program through analysis.

LSS is already widely used within the DoD, making the implementation process easier due to the relative familiarity of the methodology. The Red River Army Depot implemented LSS in their recapitalization efforts, increasing High Mobility Multipurpose Wheeled Vehicle (HMMWV) output from 1 vehicle every 2 days to 32 vehicles a day, improving the Heavy Expanded Mobility Tactical Truck (HEMITT) delivery time from 120 days per vehicle to 30 days per vehicle, and producing 16 Small Emplacement Excavators (SEEs) a month compared to 5 a month before the LSS initiative (Tonkin, 2007). The Letterkenny Army Depot improved the PATRIOT missile recapitalization program using LSS, saving over $26.1 million a year and improving turnaround time by 2.5 months (Harvey & Labedz, 2006). Some Marine Aviation Logistics Squadrons have LSS black belts that train both the intermediate and organizational level maintainers in the basic techniques of LSS. Since there are numerous examples of LSS use within the military, the lessons learned and procedures that were developed during this extensive use in the DoD can be translated into the acquisition process.

2. Challenges

LSS works best when examining an established process to determine the waste, inefficiencies, and discrepancies within the system. It does not perform as well when developing a new process. LSS is designed to create incremental improvements in the system, not to create innovative solutions or new designs. In the software case study, the to-be system the PM created came from the careful analysis of the flaws in the as-is system rather than an entirely new idea or design. While PMs should keep LSS components—such as the elements of waste, mistake proofing, etc.—in mind when developing their processes since they are important principles to any procedure, LSS itself is best used to improve the procedure once it is in place.

LSS can be costly to implement on a large scale. While the various certification agencies charge different amounts for different training levels, each belt level requires an employee to attend courses to complete the training, which can range from as little as one day for white or yellow belt courses or as long as four weeks for black belt certification. The employer must pay for the training and compensate employees for their time. While any new technique will require training, LSS emphasizes training a large portion of your workforce on at least the basics of the methodology. This can result in significant costs depending on the size of the company and number of trainees.

The principles of LSS can lead to an overly enthusiastic approach to cost savings. Creating a process that conforms to six sigma of variance (1 defect in every 3.4 million items) is often a time consuming and costly endeavor and an organization may not recuperate money made improving the product if customers do not demand the higher quality item. Depending on the product and customers' preferences, a cheaper method with a slightly higher defect rate may be preferable to a more expensive method with a lower defect rate. Eliminating waste is fine as long as the product remains the same and keeps the same value for the customer. However, it is easy for managers to view portions of a product that add value to a product or service as unnecessary, removing these sections while eliminating waste. Reducing waste within a process and variance in a product are important intermediate steps as long as they are accomplished with the ultimate goal of reducing cost for the organization and not simply a form of extreme quality control.

F. COMPARISON OF KEY ATTRIBUTES

Choosing a methodology should depend on the nature of the project under consideration, specifically, the commitment needed from the organization, the organization's desire to align strategic goals with the project, the predictive capability of the methodology, the flexibility required, and the time available. Table 3 compares these categories across the five methodologies. While others in the organization need to understand the concepts to comprehend status reports, EVM only needs the management team to track the cost and schedule of the project compared to the baseline as there is no goal alignment with the organization. While the CPI and SPI can help estimate the final cost and schedule, there is no true predictive ability associated with EVM since the assumption is that the schedule will proceed according to the baseline, regardless of previous performance. Adherence to the baseline is essential in EVM, and changing requirements can drastically alter a baseline, reducing the effectiveness of the methodology. Setting up, monitoring, and reporting the performance of each work package within the WBS can be a time-consuming and expensive task.

Based on the strategic goal alignment and the department-specific metrics, the entire organization is committed to any BSC efforts. The underlying assumption within BSC is that measuring something will improve its performance. As such, leaders are predicting improvement in the areas being measured, although BSC does not give a numerical estimate of the improvement. BSC is flexible in that the same key areas can lead to different metrics depending on the specific department's tasks. These tasks and metrics can also change as the organization shifts its vision or strategy. However, doing so can take a significant amount of time as every level must adjust its metrics and can do so only after the immediate superior has updated the metrics for that level.

KVA needs only the analyst and the process owner as the subject matter expert to determine the value of a process's output, eliminating the need to align the project with an organization's goals. Using this analysis, they can establish the current as-is process and compare it with the to-be process in development, predicting the improvement between systems. Since KVA can be used with any language of description to define the process, analysts can choose whichever method is most beneficial for the particular system in question, providing flexibility. This analysis can be completed quickly, potentially providing a rough-cut assessment within a few days.

Table 3. Comparison of Key Attributes

	EVM	BSC	KVA	IRM	LSS
Organizational Commitment Required	Management team	Entire organization	Analyst and process owner	Analyst, project and portfolio manager, and leadership	Leadership, champion, project manager, process managers, LSS team members
Organizational Goal Alignment	None: Tracks completed work vs baseline	Every level to organizational goals	None: Objective measurement of output	Portfolio management	Requires commitment to techniques but not an overall shift in organizational strategy
Predictive Capability	Limited: CPI and SPI can be used to estimate final cost and timeline	Limited: Assumes high marks in chosen metrics indicates positive future performance	As-Is to To-Be predictive improvements	High: Probabilities based on historical data	Limited: Incremental improvement predictions
Flexibility	Not flexible after baseline established. Requirements ideally remain constant	Can develop different metrics for each department	Can be adapt language of description used for common units of output	Real Options provide flexibility after learning and implementation	Creates iterative changes to processes
Time Requirement	Time consuming	Time consuming	Rough cut analysis done quickly	Relatively quickly, depending on data collection for first steps	Time consuming

IRM requires the organizational leadership, portfolio and project managers, and the analyst to determine how a project fits within an organization's portfolio, the PV of the project, and potential real options. By analyzing and simulating various scenarios, IRM provides a prediction of a project's likely performance, which allows managers to build in flexibility via real options at the appropriate locations. Assuming the data necessary for the analysis is available, the process can be completed in a relatively quick manner.

Leadership, project and process managers, a project champion, and LSS team members must all be involved for an LSS initiative to have success. Leadership is needed to provide funding for black and green belt training to ensure improvements made to processes remain in place and additional areas with potential enhancements are identified. While the overarching goals of the company will not change because of LSS, some business practices will be adjusted to make iterative improvements. There is limited predictive capability within the methodology other than that the areas from which waste and variation are removed will produce a more efficient product. LSS makes numerous incremental changes that can be time consuming before a process is optimized.

G. METHODOLOGIES IN IS ACQUISITION

As previously discussed, the five methodologies all have strengths and weaknesses, making them more suitable in certain applications than others. Table 4 depicts some of these considerations when conducting an acquisition of a software-intensive system, hardware-intensive system, upgrade to a legacy system, or a complete, organic build. The biggest challenge in using EVM when acquiring ISs is the iterative nature of software development. EVM needs clearly stated, detailed requirements for intermediate steps to be most effective. While the outputs of software programs are defined well, the steps required to build the software are not, leading to issues when developing cost and schedule estimates. If the software is not complex or consists of known processes, EVM can sufficiently monitor the progress. Integrating software and hardware is also complicated with EVM since there are numerous pieces of the program that must be combined to meet the goals, resulting in additional debugging and recoding. EVM is more efficient when used to manage the physical creation of systems or infrastructure. It can monitor the progress of software work packages but is not as useful at estimating the earned value of those programs until the requirements have been delivered.

BSC can assist mangers in aligning the goals of the organization with those of their individual program, whether they are dominated by hardware or software. This is especially true during an organic build, ensuring the entire IS under development is created with the strategy and vision of the acquisition community in mind. However, it can be difficult to change the vision when implementing updates to existing hardware and software systems already in use if the original strategy differs greatly from the strategy already in place. For example, if the Littoral Combat Ship (LCS) needs future updates through acquisition programs and the future vision of the DoN focuses on redundancy for combat operations versus the current vision of IS replacing manpower, it will be difficult, if not impossible, to redesign the ship with the necessary modifications.

Table 4. Methodology Performance in Different IS Acquisition Cases

	EVM	BSC	KVA	IRM	LSS
Software Intensive Systems	Not well adapted to iterative system development lifecycle	Aligns organizational goals with system development given appropriate metrics	Provides value and cost estimate enabling productivity and ROI on IT estimates	Includes KVA capabilities. Allows iteration of the value of real system options	Can be used in software fixes or improvements after system is operational
Hardware Intensive Systems	Useful provided the IT component is relatively non-complex	Aligns organizational goals with system development given appropriate metrics	Provides value and cost estimate enabling productivity and ROI on IT estimates	Includes KVA capabilities. Allows iteration of the value of real system options	Can improve hardware manufacturing and sustainment processes
Legacy System Upgrades	Useful for manufacturing based updates of programs	Difficult to adapt changes in vision/strategy to existing hardware and software	Determine value of components. Helps manager decide how to use resources to improve system	Includes KVA capabilities. Allows iteration of the value of real system options	Can improve sustainment process and determine system bottlenecks for future upgrades
Organic Builds	Useful for manufacturing based acquisitions not involving complex software development	Helps ensure new system alignment with strategic goals	Can help manager estimate future value of the system	Quantifies risk and assigns probabilities of success, allowing for real options analysis	Useful after system is operational

KVA can provide an objective, ratio scale measure of value and cost for each sub-process within any of the IS systems. Using the two measurements, managers can then analyze productivity ratios, such as ROI, to determine the effectiveness of a process compared to the resources used to achieve the output. This can help the manager decide how to use resources to update systems or estimate the future value of a system being acquired. Combining the KVA results with IRM allows managers to iterate the value of real options analysis through simulation and other techniques. IRM can also quantify risks and assign probabilities of success for programs and components of programs using historical data. It is a tool to assist with the investment strategy, making it useful when acquiring all types of ISs. However, it is not designed to help manage the actual acquisition of a program or determine how to meet its detailed requirements.

LSS is best used after a process has reached its steady-state operational capability. Then it can be used to analyze any of the systems to reduce waste and variation within the processes. The corrections made to the sustainment process are done incrementally, gradually improving the efficiency of the program over time. While elements of LSS, such as mistake proofing, may be beneficial during the acquisition process, LSS as a whole works better after the program is operational and can make adjustments to improve the system as a whole.

H. SUMMARY

Examining the benefits and challenges of the five proposed methodologies demonstrates the scope, capabilities, and limitations of the various systems. It also helps inform which areas and phases of the Defense Acquisition System may be appropriate to include the methodologies or portions of the methodologies within the system. The next chapter provides recommendations based on these findings.

V. CONCLUSIONS

Parts of this chapter were previously published by the Naval Postgraduate School Acquisition Research Program (Housel, Mun, Jones, & Carlton, 2019).

A. RESEARCH FINDINGS AND RECOMMENDATIONS

The central question of this research was, “how should the methodologies be used in the acquisition life cycle to help ensure successful acquisition of IS technologies?”

It should be noted that EVM is required for all programs with a contract value greater than $20 million. Regardless of this requirement, EVM offers a structured approach to the acquisition of IT via program management processes that track schedule and cost. While there are some significant limitations when using EVM for IS acquisitions, this was the only program management methodology required by the government and can be useful in ensuring that an acquisition stay on schedule and within cost estimates.

The major weakness of EVM for IT acquisition is that it was not designed for managing IT acquisitions that follow a very iterative pathway. Organic IT acquisitions require a given level of flexibility to deal with the unknowns that arise during the development process. In addition, EVM does not provide a common unit of value metric to enable standard productivity metrics, such as ROI. When value is inferred by how consistent a program is with original baseline cost and schedule estimates, the performance of the program may sacrifice on the quality of the outputs when planned program activities become iterative, as in the development of many IT programs. For example, if an IT program is trending toward cost and schedule overruns, but the resulting value added of the modifications to the original requirements provides disproportionate increases in value, EVM is not designed to recognize this increase in value.

To remedy these shortcomings of EVM in IT acquisitions, the methodology should be combined with VA and IRM. KVA can be useful during the requirements phase of EVM by ensuring that a given IT acquisition is aligned with organizational strategy and that a baseline process model has been developed for establishing current performance before acquisition of the supporting IT. A future process model that estimates the value added of the incorporation of the IT can also set expectations that can be measured against the baseline model after the IT has been acquired. IRM can be used to value the real options that an acquired IT may provide so that leadership can select the option that best fits their desired goals for the IT inclusion. This kind of information can help guide the requirements analysis based on expected value added by the IT over time.

BSC is not recommended for use within the Defense Acquisition System as a means to ensure an IT acquisition aligns with the overall defense strategy for any given area or military service. The primary purpose of BSC is to ensure all levels of the organization are aligned to the organizational strategy and vision. The requirements process already produces outputs aligned with the strategic goals. PMs must oversee their programs in accordance with the given requirements, which should force them to automatically align with the vision of the DoD. The "what you measure is what you get" theory is accounted for in the Defense Acquisition System. The specifications, cost, and schedule are the desired measurements that must be followed. While BSC might provide some benefit in aligning goals throughout the DoD or the entire acquisition process (i.e., using BSC to align requirements, budgeting, and acquisition together), using BSC exclusively within the Defense Acquisition System is not recommended.

KVA should be used in the acquisition of IT. Having an objective, quantifiable measure of value in common units will allow decision-makers to better understand and compare different options based on their value and the cost. Obtaining a return on investment of IT systems can only be done when using KVA to determine the value embedded in the system. This information provides insight to PMs and gives them a more complete perspective regarding the performance of both the current and the to-be systems.

Likewise, using IRM is recommended when acquiring IS through the Defense Acquisition System. Applying static and dynamic modeling techniques to predict likely outcomes can improve the risk estimates associated with the components and sub-components of a program. Analyzing various real options within the context of the models' outputs will help PMs make the most advantageous choices when determining a program's future.

LSS should also be used when acquiring IT. The incremental advancements LSS principles can discover may result in significant improvements in efficiencies and cost saving measures over the life of a program. Using the DMAIC process to eliminate waste and reduce variation will enhance program performance. The techniques can be applied to all types of processes, including both hardware and software-based systems. Improvements may be made to aspects of programs ranging from the software repair process to the depot level repair of the hardware in an IS. The military already has extensive experience with LSS, including education teams and a belt training system. This familiarity will make the introduction of the formal LSS methodology into the Defense Acquisition System easier than other options.

A secondary research question was, “how should the methodologies be used in the acquisition life cycle to ensure successful acquisition of IS technologies?

PMs should use EVM only in EMD phase, as is currently done. EVM will work best in hardware manufacturing solutions with technology that is fully mature prior to the program beginning. Since many IS acquisition programs consist of advancing the current technology and developing new software solutions to meet requirements, EVM is not perfectly suited for IS development. Nevertheless, PMs can use various agile EVM techniques to complete projects on baseline provided the appropriate steps are taken when establishing the baseline. Requirements must be broken into small, easily definable tasks with suitable risk and uncertainty factors accounted for within the schedule. Other methodologies should be used with EVM to ensure these factors are based on defendable metrics rather than simply guessing how much additional time, money, and value may be necessary to complete complex tasks.

During the MSA phase, KVA will help determine the value of the different options considered in the AoA. KVA can objectively measure the value of the current, as-is system and the potential to-be systems under consideration. Using other factors such as cost, complexity, timeline, etc., the PM can then select an appropriate alternative. As the chosen solutions mature during the TMRR phase, an updated KVA analysis will reassess initial estimates and provide a projected return on investment for the IT solution prior to entering the EMD phase. In the OS phase, KVA will help decision-makers establish how a program is performing and use that information to make any adjustments or corrections that may be needed. KVA has limited prediction capabilities, so it should be used in conjunction with other methodologies, particularly IRM, to obtain the most benefit.

IRM techniques should be implemented during most of the acquisition phases. Ideally, portfolio management decisions were made during the requirements development process, although they should also be considered during MSA. Financial and value analysis derived from KVA, as well as simulation of possible outcomes should occur during the MSA, TMRR, and EMD phases. The results of these simulations should be fed into the EVM baselines to account for risk across the program. Real options should be developed during the TMRR phase prior to awarding contracts and the real options should be executed during the EMD and PD phases as appropriate.

LSS will best serve IS acquisitions after the product is implemented in the operational forces during the OS phase, which overlaps with PD. While individual manufacturers may use LSS in their manufacturing processes, PMs will not see the full benefits of this methodology until the program is in its steady state operation and the incremental improvements can have the greatest effect on process improvement and cost savings. LSS will help PMs evaluate the system through in depth analysis of updates, upgrades, repairs, and other services that occur during OS. Elements of LSS may be useful in other phases of the Defense Acquisition System as most processes can be improved in some manner. However, formal LSS procedures should not be established until the system is in use, regardless of whether it is a hardware or software-based system.

The final research question asked, "what are the risks and limitations of using each of the methodologies for IS acquisition?" The risks and limitations of each methodology were reviewed in detail in Chapter IV. This analysis led to the recommendations listed above.

B. FUTURE RESEARCH

This thesis examined if five methodologies— EVM, BSC, KVA, IRM, and LSS— could be used within the Defense Acquisition System to improve the acquisition of ISs. Future research should examine how these methodologies may interact with or improve other components of the acquisition system. This includes the JCIDS and PPBE components as individual processes and the interaction of JCIDS, PPBE, and the Defense Acquisition System as a whole. Certain methodologies, specifically BSC, may be more beneficial when used throughout the entire acquisition process instead of within a portion of the system. Additionally, future research could examine how these different methods may be used in the acquisition of products outside the IS or IT realm.

The research conducted for this thesis looked at ISs as a whole and not specific types of ISs or IT. Future studies should examine if acquisition methods, strategies, and methodologies should change based on the category of IS being acquired. This is of specific interest when considering artificial intelligence and its subsets. Machine learning, intelligence with a specific focus or field of expertise, and general or universal intelligence would likely have different methods used in the acquisition process based on their complexity, complicated nature, undeveloped technology, and level of risk.

The applicability of these methodologies within commercial acquisition of ISs is another area of potential research. This thesis focused exclusively on the application of the respective techniques within the DoD acquisition process. However, commercial entities also struggle when acquiring complex or complicated IS and IT systems, particularly when the systems operate at the enterprise level. Further research may indicate if these same methodologies could provide value to decision makers in the private sector during the creation, adoption, or customization of commercial ISs.

Finally, this thesis examined only five methodologies out of numerous different possibilities. Future research could examine other program management tools, management philosophies, analytic tools, or other methodologies and their benefit when acquiring ISs. While the examined methodologies were chosen because they would likely benefit the process, other systems may be more appropriate in certain phases or may offer additional benefits not seen in this research.

THIS PAGE INTENTIONALLY LEFT BLANK

LIST OF REFERENCES

Apte, U., & Kang, K. (2006). *Lean Six Sigma for reduced life cycle costs and improved readiness*. Monterey, CA: Naval Postgraduate School.

Brandimarte, P. (2014). *Handbook in Monte Carlo simulation: Applications in financial engineering, risk management, and economics*. Hoboken, NJ: John Wiley & Sons, Inc.

Buss, T. F., & Cooke, D. (2005, May). Performance measurement in defense acquisitions: A case study of the Navy. Paper presented at the Acquisition Research Symposium, Naval Postgraduate School, Monterey, CA.

Carlton, B., Ellis, K., Jones, J., & Schofield, B. *Marine Corps transport corrective maintenance process optimization and knowledge value analysis*. Unpublished manuscript.

Christensen, D. (1994). An analysis of cost overruns on defense acquisition contracts. Readings in Program Control. Retrieved from https://ntrs.nasa.gov/search.jsp?R=19950014332

Christensen, D. S. (1998). The costs and benefits of the Earned Value Management process. *Journal of Parametrics 18*(2), 1-16. https://doi.org/10.1080/10157891.1998.10462568

Cudney, E. A., Furterer, S., & Dietrich, D. (2013). *Lean systems: Applications and case studies in manufacturing, service, and healthcare* (1st ed.). Boca Raton, FL: CRC Press.

Cudney, E. A., & Kestle, R. (2011). *Implementing Lean Six Sigma throughout the supply chain: The comprehensive and transparent case study*. Boca Raton, FL: CRC Press.

Damodaran, A. (2000). The promise of real options. *Journal of Applied Corporate Finance, 13*(2), 29-44. htttps://doi.org/10.1111/j.1745-6622.2000.tb00052.x

Department of Defense. (2003, May 12). *The Defense Acquisition System* (change 2) (DoD Directive 5000.01). Retrieved from https://www.esd.whs.mil/Directives/issuances/dodd/

Department of Defense. (2005). *Work breakdown structures for defense materiel items* (MIL-HDBK-881A). Retrieved from http://www.acqnotes.com/Attachments/MIL-Hand%20Book-881.pdf

Department of Defense. (2011, Apr). Technology Readiness Assessment (TRA) guidance. Retrieved from https://apps.dtic.mil/dtic/tr/fulltext/u2/a554900.pdf

Department of Defense. (2014, March 12). *Risk Management Framework (RMF) for DoD information technology (IT)* (change 2) (DoD Instruction 8510.01). Retrieved from https://www.esd.whs.mil/Directives/issuances/dodi/

Department of Defense. (2015a, January 7). *Operation of the Defense Acquisition System* (change 4) (DoD Instruction 5000.02). Retrieved from https://www.esd.whs.mil/Directives/issuances/dodi/

Department of Defense. (2015b, September). *DoD program manager's guide for integrating the cybersecurity Risk Management Framework (RMF) into the system acquisition lifecycle*. Retrieved from www.acqnotes.com/wp-content/uploads/2014/09/PM-Guidebook-for-Integrating-Cybersecurity-RMF-into-System-Acquisition-Lifecycle-Sep-2015.pdf

Department of Defense. (2017, Feb 26). Defense acquisition guidebook. Retrieved from https://www.dau.mil/tools/dag

Department of Defense. (2018, April 16). *Agile and Earned Value Management: A program manager's Desk Guide*. Retrieved from https://www.acq.osd.mil/evm/assets/docs/PARCA_Agile_and_EVM_PM_Desk_Guide.pdf

Department of Defense. (2019, January 18). *Earned Value Management implementation guide (EVMIG)*. Retrieved from https://www.acq.osd.mil/evm/assets/docs/DOD%20EVMIG-01-18-2019.pdf

Desai, D. (2010). *Six sigma* (1st ed.). Mumbai, India: Himalaya Publishing House.

Dixit, A. K., & Pindyck, R. S. (1995). The options approach to capital investment. *Harvard Business Review 73*(3). Retrieved from https://hbr.org/1995/05/the-options-approach-to-capital-investment

Dodaro, G. L. (2019). *Weapons systems annual assessment: Limited use of knowledge-based practices continues to undercut DoD's investment* (GAO-19-336SP). Washington, DC: Government Accountability Office.

Edwards, C. & Kaeding, N. (2015) Federal government cost overruns. *Tax & Budget Bulletin, 72*. Retrieved from https://object.cato.org/sites/cato.org/files/pubs/pdf/tbb-72.pdf

Electronic Industries Alliance. (1998). *Earned Value Management Systems.* Arlington, VA: Electronic Industries Alliance.

Feickert, A. (2005). *The Joint Tactical Radio System (JTRS) and the Army's future combat system (FCS): Issues for Congress* (CRS Report No. RL33161). Retrieved from https://digital.library.unt.edu/ark:/67531/metacrs7941/

Francis, P. L. (2006). *Defense acquisition: Restructured JTRS program reduces risk, but significant challenges remain* (GAO-06-955). Washington, DC: Government Accountability Office.

Francis, P. L. (2008). *Defense of Defense needs framework for balancing investments in tactical radios* (GAO-08-877). Washington, DC: Government Accountability Office.

Fleming, Q. W., & Koppelman, J. M. (2010). *Earned value project management (4th Edition)*. Newtown Square, PA: Project Management Institute.

Gallagher, S. (2012, June 18). How to blow $6 billion on a tech project. Retrieved from https://arstechnica.com/information-technology/2012/06/how-to-blow-6-billion-on-a-tech-project/

Harvey, R. K., & Labedz, C. S. (2006). *Letterkenny Army Depot: The Army teaches business a lesson in Lean Six Sigma*. Retrieved from http://hdl.handle.net/1721.1/82005

Housel, T., & Bell, A. H. (2001). *Measuring and managing knowledge*. New York, NY: McGraw Hill.

Housel, T., & Kanevsky, V. A. (1995). Reengineering business processes: A complexity theory approach to value added. *Infor*, *33*(4), 248-262. https://doi.org/10.1080/03155986.1995.11732285

Housel, T., & Kanevsky, V. (2006). *Measuring the value added of management: a Knowledge Value Added approach*. Monterey, California. Naval Postgraduate School.

Housel, T. J., Mun J., Jones, R. & Carlton, B. (2019, May). A comparative analysis of advanced methodologies to improve the acquisition of information technology in the Department of Defense for optimal risk mitigation and decision support systems to avoid cost and schedule overruns. Paper presented at Acquisition Research Symposium, Monterey, CA.

Jones, R., & Housel, T. (2018, May 9). *Extending an Econophysics Value Model for early developmental program performance prediction and assessment.* Presented at Acquisition Research Symposium, Monterey, CA.

Kaplan, R. S., & Norton, D. P. (1992). The Balanced Scorecard: Measures that drive performance. *Harvard Business Review 70*(1), 71–79.

Kaplan, R. S., & Norton, D. P. (1993). Putting the Balanced Scorecard to work. *Harvard Business Review*, *71*(5), 134. Retrieved from https://doi.org/10.1016/B978-0-7506-7009-8.50023-9

Kaplan, R. S., & Norton, D. P. (2007, July–August). Using the Balanced Scorecard as a strategic management system. *Harvard Business Review, 85*(7, 8), 150–161. Retrieved from https://search.proquest.com/docview/227841808/

Kendall, F. (2011, October 13). Letter to the Honorable Howard K. "Buck" McKeon. Retrieved from https://www.govexec.com/pdfs/101411bb1.pdf

Kefe, I. (2019). The determination of performance measures by using a Balanced Scorecard framework. *Foundations of Management, 11*(1), 43–56. Retrieved from https://doi.org/10.2478/fman-2019-0004

Keyes, J. (2011). *Implementing the project management Balanced Scorecard*. Boca Raton, FL: CRC Press.

Kwak, Y., & Anbari, F. (2011). History, practices, and future of Earned Value Management in government: Perspectives from NASA. *Project Management Journal, 43*(1), 77–90. doi:10.1002/pmj.20272

Mun, J. (2015). *Readings in Certified Quantitative Risk Management (CQRM)* (3rd ed.). Dublin, CA: Thompson-Shore and ROV Press.

Mun, J. (2016). *Real options analysis* (3rd ed.). Dublin, CA: Thompson-Shore and ROV Press.

Mun, J., & Housel, T. (2010). A primer on applying Monte Carlo simulation, real options analysis, Knowledge Value Added, forecasting, and portfolio optimization. Monterey, CA: Calhoun.

Mun, J., Housel, T., & Wessman, M. D. (2010). PEO-IWS ACB insertion portfolio optimization. In *Proceedings of the Seventh Annual Acquisition Research Symposium*, Volume 2*)* (No. NPS-AM-10-069-VOL-2). Monterey, CA: Naval Postgraduate School. Retrieved from https://my.nps.edu/documents/105938399/108624025/NPS-AM-10-069.pdf/c71c6830-853a-448b-beac-242bea4cba8b?version=1.0

National Oceanic and Atmospheric Administration. (n.d.) Numerical weather prediction. Retrieved April 17 2019, from https://www.ncdc.noaa.gov/data- access/model-data/model-datasets/numerical-weather-prediction

National Oceanic and Atmospheric Administration. (2017, August 14). 6 tools our meteorologists use to forecast the weather. Retrieved from https://www.noaa.gov/stories/6-tools-our-meteorologists-use-to-forecast-weather

Norreklit, H. (2000). The balance on the Balanced Scorecard: A critical analysis of some of its assumptions. *Management Accounting Research, 11*, 65-88. https://doi.org/10.1006/mare.1999.0121

Pepper, M. P. J., & Spedding, T. A. (2009). The evolution of lean and six sigma. *International Journal of Quality & Reliability Management, 27*(2), 138-155. https://doi.org/10.1108/02656711011014276

Powner, D. A. (2009). *Information technology: Agencies need to approve the implementation and use of Earned Value Management techniques to help manage major system acquisitions* (GAO-10-2). Washington, DC: Government Accountability Office.

Rios, C. (2005). *Return on investment analysis of information warfare systems* (Master's thesis). Retrieved from https://calhoun.nps.edu/handle/10945/2068

Rios, C., Housel, J., & Mun, J. (2006). Integrated portfolio analysis on investment and real options analysis of intelligence information systems (Cryptological Carry On Program). Paper presented at the Acquisition Research Symposium, Monterey, CA. Retrieved from https://calhoun.nps.edu/handle/10945/33143

Rios, C., Housel, J., & Mun, J. (2015). Case study 11: Real options and KVA in military strategy at the United States Navy. In J. Mun (Ed.), *Case studies in certified quantitative risk management (CQRM)* (pp. 145-154). Dublin, CA: Thompson-Shore and ROV Press.

Risk Amp. (n.d.). What is Monte Carlo simulation? Retrieved April 23, 2019, from http://riskamp.com/files/RiskAMP%20-%20Monte%20Carlo%20Simulation.pdf

Robinson, B. (2008). DoD spotlight: DoD rallies around Lean Six Sigma *Federal Computer Week*, *22*(5), 32-34, 36. Retrieved from http://libproxy.nps.edu/login?url=https://search.proquest.com/docview/218882555?accountid=12702

Roosevelt, A. (2012, October 2). Joint Tactical Networking Center opens, JPEO JTRS officially closed. Retrieved from https://www.defensedaily.com/joint-tactical-networking-center-opens-jpeojtrsofficially-closed/navy-usmc/

Salah, S., Rahim, A., & Carretero, J.A. (2010). The integration of Six Sigma and lean management. *International Journal of Lean Six Sigma, 1*(3), 249-274. https://doi.org/ 10.1108/20401461011075035

Schmidt, E. (n.d.). 64 fold increase in productivity at Army repair depot. Retrieved from https://www.isixsigma.com/industries/government-non-profit/64-fold-increase-productivity-army-repair-depot/

Statistic Solutions. (n.d.). Data levels of measurement. Retrieved September 9, 2019 from https://www.statisticssolutions.com/data-levels-of-measurement/

Tonkin, L. A. P. (2007). The real power of lean military transformation: Aligning today's lean initiatives for long-term, collaborative improvements. *Target, 23*(3), 6-19. Retrieved from https://www.ame.org/sites/default/files/target_articles/07-23-3-Lean_Military.pdf

Torres, E., & Tighe, S. (n.d.). Project storyboard: Reducing software bug fix lead time from 25 to 15 days. Retrieved from https://goleansixsigma.com/project-storyboard-reducing-software-bug-fix-lead-time-from-25-to-15-days/

Tsai, A. (2014). An empirical model of four processes for sharing organisational knowledge. *Online Information Review*, *38*(2), 305–320. https://doi.org/10.1108/OIR-03-2013-0059

Vanhoucke, M. (2014). *Integrated project management and control*. Switzerland: Springer International Publishing.

Under Secretary of Defense, Acquisition, Technology, and Logistics. (2016). *Performance of the Defense Acquisition System: 2016 Annual Report.* Washington, DC: Department of Defense.

Young, J. J., Jr., (ASN (RD&A)). (November 30, 2004). *Blueprint for the future, Naval Research and Acquisition Team 1999–2004 Strategic Plan* [Memorandum]. Washington, DC: Department of Defense Retrieved from https://www.secnav.navy.mil/rda/Pages/ViewPolicy.aspx

Yu, W., Chang, P., Yao, S., & Liu, S. (2009). KVAM: model for measuring knowledge management performance of engineering community of practice. *Construction Management and Economics*, *27*(8), 733–747. https://doi.org/10.1080/01446190903074978

INITIAL DISTRIBUTION LIST

1. Defense Technical Information Center
   Ft. Belvoir, Virginia

2. Dudley Knox Library
   Naval Postgraduate School
   Monterey, California