NPS-AM-20-002

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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

October 18, 2019

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The research presented in this report was supported by the Acquisition Research Program of the Graduate School of Defense Management at the Naval Postgraduate School.

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Abstract

This study examines five advanced decision support methodologies—Lean Six Sigma (LSS), Balanced Score Card (BSC), Integrated Risk Management (IRM), Knowledge Value Added (KVA), and Earned Value Management (EVM)—in terms of how each can support the information technology (IT) acquisition process. In addition, the study provides guidance on when each methodology should be applied during the acquisition life cycle of IT projects. This research includes an in-depth review of each methodology in the context of the acquisition life cycle. All acquisition projects within the Department of Defense must go through the acquisition life cycle. While each acquisition project is unique, all must pass a series of common hurdles to succeed. Understanding how and when the methodologies can be applied to an IT acquisition is fundamental to its success. The study concludes with a set of recommendations for the use of each methodology in the acquisition life cycle of IT projects.

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Problem Statement

A recurring problem at the U.S. Department of Defense (DoD) is that acquisitions of information technology (IT) have been fraught with schedule and cost overruns. High-profile programs such as the Joint Strike Fighter, Coast Guard Deepwater program, Army Comanche, and the Navy A-12 demonstrate the need for improvement within the acquisition process. The current suite of management tools does not seem to adequately provide sufficient early warning and high enough fidelity into the root causes of fiscal overruns in order to provide the program manager (PM) time to adequately respond to program issues. This is a problem because the capabilities promised to the warfighter are not provided in a timely manner and the over-budgeted resources used to provide the capabilities could be more efficiently allocated to other programs. A further problem is that the current methodologies do not include a defensible way to measure the value of the proposed acquisition of an IT system. Without a ratio level measure of value, using portfolio management to optimize IT investments is problematic. Several of the methodologies (i.e., Knowledge Value Added [KVA] and Integrated Risk Management [IRM]) do provide ratio scales for the value metrics they use.

There are a number of analytical and decision-support methods that can be used to improve the acquisition life cycle of IT investments. This study provides an approach that will aid practitioners in selecting the best decision support method for a given phase of the acquisition life cycle for IT systems. The methodologies that were reviewed for this study included Lean Six Sigma (LSS), Balanced Score Card (BSC), Integrated Risk Management (IRM: Risk Simulation), Knowledge Value Added (KVA), and Earned Value Management (EVM).

Research Questions and Objectives

The research questions are as follows:

1. When should the methodologies be used in the acquisition life cycle to ensure successful IT acquisitions?

2. How should the methodologies be used in the acquisition life cycle to ensure successful IT acquisitions?
3. What are the risks and limitations of using each of the methodologies for IT acquisitions?

The objective of the research is to provide a set of pragmatic recommendations, based on comparison of the proposed methodologies, that focuses on when and how each method can be applied to improve the acquisition life cycle of IT investments.

Overview

The authors have conducted numerous research studies on the effectiveness of IT acquisitions in, for example, the areas of signal intelligence, shipbuilding, and ship maintenance to name a few.[1] The prior studies focused on the return on investment of IT, valuation of IT real options, and IT investment portfolio optimization. For example, the shipbuilding and maintenance studies demonstrated the value added of acquiring additive manufacturing (AM), laser scanning technology (LST), and collaborative product life-cycle management tools (CPLM). This prior research revealed the need to understand how the IT acquisition life cycle should optimally be managed within the context of the DoD existing acquisition life-cycle frameworks that focus on the use of EVM.

The need for information technologies to improve productivity has been addressed in these prior studies using the KVA and IRM approach. For example, the KVA analysis of the "as-is" ship maintenance processes identified opportunities for improvement in process productivity. LSS has been used for process cost-reduction purposes in other studies. These methodologies identify opportunities for process productivity and efficiency improvement using IT. The strategic planning for the possible insertion of these technologies was further addressed in the current study by use of the BSC methodology. The standard means for managing and monitoring the progress of an IT acquisition in the DoD is generally approached using the EVM methodology.

Each methodology has its potential place in ensuring successful IT acquisition. In addition to these methodologies, past acquisition studies (e.g., signal intelligence, ship maintenance, and shipbuilding) have utilized the IRM methodology to forecast the future value of acquiring given information technologies as well as the risks involved in those acquisition approaches. The challenge for the current study was to identify and justify the application of each of the five methodologies in the IT

[1]Most of these studies can be found on the Naval Postgraduate School Acquisition Research Program website, https://my.nps.edu/web/acqnresearch.

acquisition life cycle. Each has its strengths and weaknesses, as prior research has pointed out.

This study examines the potential use of the five methodologies to improve the chances for successful IT acquisitions. The methodologies are examined within the context of the routine (e.g., the 5000 series) acquisition life cycle for IT. For the purposes of this study, the outputs from the Joint Capabilities Integration and Development System (JCIDS) and the Planning, Programming, and Budgeting Execution (PPBE) processes are assumed to be correct.

Literature Review

There are other management tools (aside from the five methodologies) that might be applied to the IT acquisition life cycle (e.g., activity-based costing and Total Quality Management [TQM], to name two). However, a review of the literature supported the focus on the five main analytical methodologies identified for this study. Expanding the potential scope of this research to include other methodologies was deemed to add minimal value given that these five approaches are in current use in acquisitions management and research. It was also assumed that starting with these five methodologies would provide a platform for inclusion of other approaches in future research.

Reviews of each of the methodologies follow, beginning with LSS followed in order by BSC, IRM, KVA, and ERM. The focus is on providing an overview of the methodologies as well as examples of and prior research on each methodology.

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, Lean Six Sigma (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 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). 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 1 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 1. 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 (Cudney et al., 2013). The stakeholder analysis provides an understanding of the roles and concerns of the various parties as well as their attitudes toward potential change (Cudney et al., 2013). Uncovering the initial voice of the customer gives insight to the needs and items that are critical to their satisfaction (Cudney et al., 2013). After determining this information, the leader must form a team consisting of individuals with the appropriate knowledge and commitment to advance the project (Cudney et al., 2013). Finally, the team must create 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 2) 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).

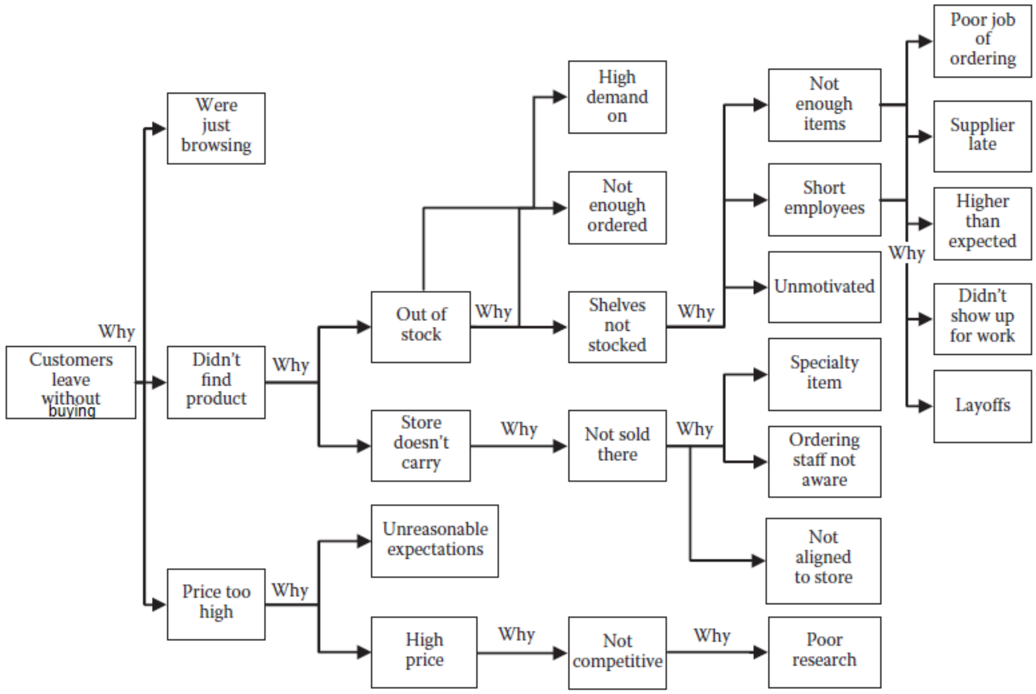


Figure 2. Five Whys Diagram.
Source: Cudney et al. (2013).

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 Ss, 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).

To effectively implement an LSS project, an organization must have the appropriate support structure. 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 (Desai, 2010). Consistent with the rest of the program, there is a regimented, prescriptive staffing structure within companies that utilize LSS (Desai, 2010). 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 (Desai, 2010). 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. Master black belts are experts within all aspects of LSS and have extensive academic training and field experience with the program (Desai, 2010). They serve as mentors and guides for the team leaders and as black belts within a company (Desai, 2010). Team leaders are black belts assigned to projects based on their training and experience (Desai, 2010). Black belts are the technical experts and change agents within a team and run the DMAIC process for a project (Desai, 2010). Typically, master black belts and black belts are full-time LSS employees within the organization, using their expertise to improve processes and maintain the improvements (Desai, 2010). Green belts are individuals that have received LSS training and have some real-world experience with LSS implementation (Desai, 2010). 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 (Desai, 2010). In addition to the belt holders, team members are individuals assisting with LSS projects in the DMAIC process (Desai, 2010). Teams often consist of three to ten members from various branches within a company relevant to the process being improved (Desai, 2010). Team members may or may not possess an LSS belt, but 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 stablished. Incrementally improving procedures during the operations and support phase may provide significant cost savings and improved performance over the life of an acquisition.

Balanced Score Card

A strategic planning and management methodology developed by Kaplan and Norton (1996), BSC includes financial metrics as well as nonfinancial performance measures, such as leadership, customer satisfaction, and employee satisfaction, to achieve a balanced view of an organization’s performance (Kaplan & Norton, 1996;

also see Niven, 2008). The BSC helps to strategically align an organization's actions to its vision and strategy, improve internal and external communications, and monitor organization performance against strategic goals.

BSC typically uses four or five critical perspectives—(1) organizational capacity; (2) customer/stakeholder satisfaction; (3) financial metrics; (4) leadership behaviour; and (5) internal process performance—to design a scorecard that reflects a company's vision and strategy. An organization can then develop strategic objectives, key performance indicators (KPIs), targets, and initiatives relative to each of the perspectives, so that progress based on the BSC can be measured and monitored (Balanced Scorecard Institute, n.d.).

Thereafter, the organization will need to convert the BSC into a strategy map, a basic graphic that shows a logical, cause-and-effect connection among the critical perspectives. This is an important step that leads to high-level vision and strategy statements that can be shared with the rest of the organization.

The organization should be able to measure the performance of its employees and management based on the targets set in the BSC, as well as incentivize them with recognition and rewards. One of the roles of leadership is to ensure that the strategy map, based on the BSC, is clearly communicated and shared throughout the organization, to avoid strategic misalignments. The goal is to ensure accountability and ownership at the management level when the BSC has been executed, and employees should know what their performance targets are and what they need to do to achieve them. The organization should also conduct regular performance reviews to update and share the short-term results with its employees and management so that changes can be made based on a review of the progress toward a completed BSC. The goal of the BSC is to improve strategic alignment of all elements of the organization to ensure the BSC targets are the focus of the organization. A regular performance review also can help to motivate an underperforming area of the organization to improve its performance (Kaplan & Norton, 1992).

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). There are four categories within each scorecard that correspond with separate but related components of a business, each of which answer a basic, but crucial, question (Kaplan & Norton, 1992). Figure 3 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).

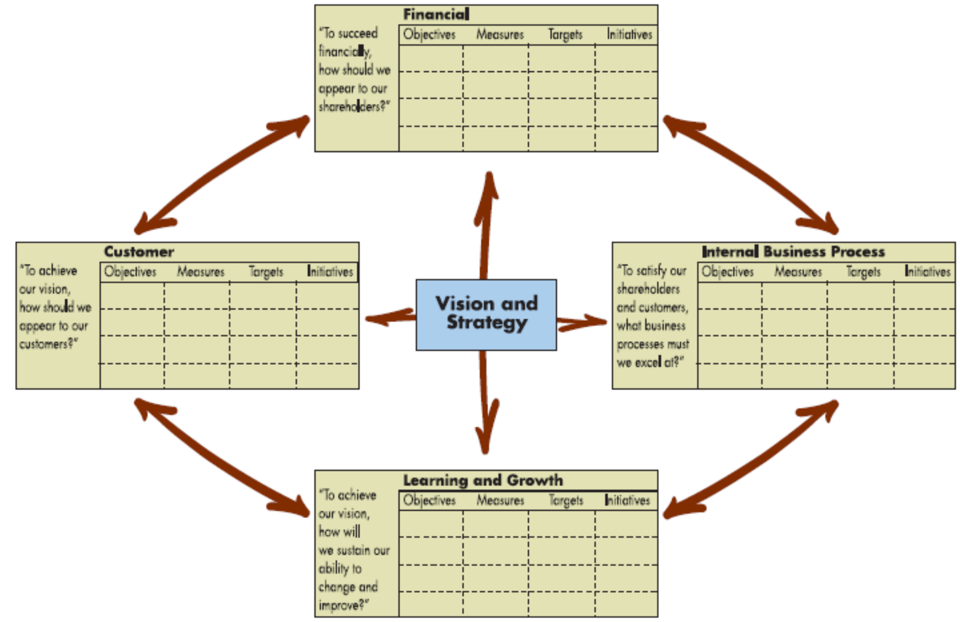


Figure 3. The Balanced Scorecard Framework.
Source: Kaplan & Norton (2007).

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). 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). 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). 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).

Leadership should use four management processes when implementing BSC (Kaplan & Norton, 2007). Figure 4 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 Information System (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.

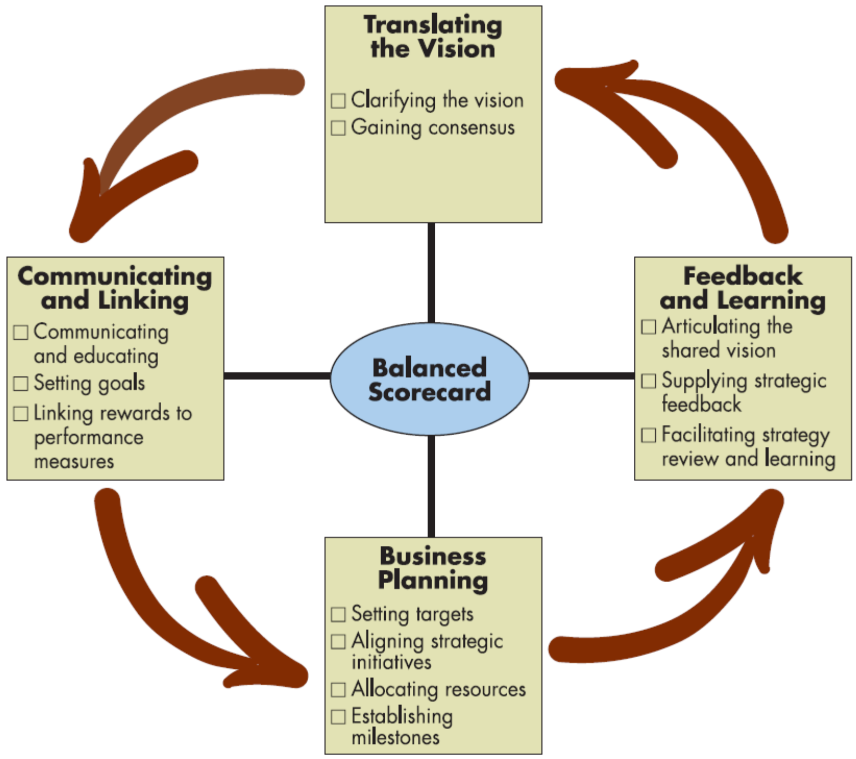


Figure 4. Managing Strategy.
Source: Kaplan & Norton (2007).

Integrated Risk Management

IRM is a comprehensive methodology that is a forward-looking risk-based decision support system incorporating various methods such as Monte Carlo Risk Simulation, Parametric Forecast Models, Portfolio Optimization, Strategic Flexibility, and Economic Business Case Modeling. Economic business cases using standard financial cash flows and cost estimates, as well as non-economic variables such as expected military value, strategic value, and other domain-specific Subject Matter Experts (SME) metrics (e.g., Innovation Index, Conversion Capability, Ability to Meet Future Threats, Force Structure, Modernization and Technical Sophistication, Combat Readiness, Sustainability, Future Readiness to Meet Threats) can be incorporated. These metrics can be forecasted as well as risk simulated to account for their uncertainties and modeled to determine their returns to acquisition cost (e.g., return on investment for innovation, or return on sustainability). Capital investment and acquisition decisions within IT portfolios can then be tentatively made, subject to any budgetary, manpower, and schedule constraints.

In the U.S. military context, risk analysis, real options analysis, and portfolio optimization techniques are enablers of a new way of approaching the problems of estimating ROI and estimating the risk value of various strategic real options. There are many new DoD requirements for using more advanced analytical techniques. For instance, the Clinger-Cohen Act of 1996 mandates the use of *portfolio management* for all federal agencies. The Government Accountability Office's (GAO) "Assessing Risks and Returns: A Guide for Evaluating Federal Agencies' IT Investment Decision-Making," Version 1, (1997) requires that IT investments apply ROI measures. DoD Directive 8115.01 issued October 2005 mandates the use of performance metrics based on outputs, with ROI analysis required for all current and planned IT investments. DoD Directive 8115.bb implements policy and assigns responsibilities for the management of DoD IT investments as portfolios within the DoD Enterprise where a portfolio is defined to include outcome performance measures and an expected return on investment. The DoD Risk Management Guidance Defense Acquisition guidebook requires that alternatives to the traditional cost estimation need to be considered because legacy cost models tend not to adequately address costs associated with information systems or the risks associated with them.

Projects can be broken down into their work breakdown structure (WBS) and tasks, where these tasks can be combined in complex systems dynamic structures. The cost and schedule elements for each task can be modeled and risk simulated within the system to determine the total cost and schedule risk of a certain program. Program management is often integrated with IRM methods to provide a more holistic view in terms of acquisitions of IT programs.

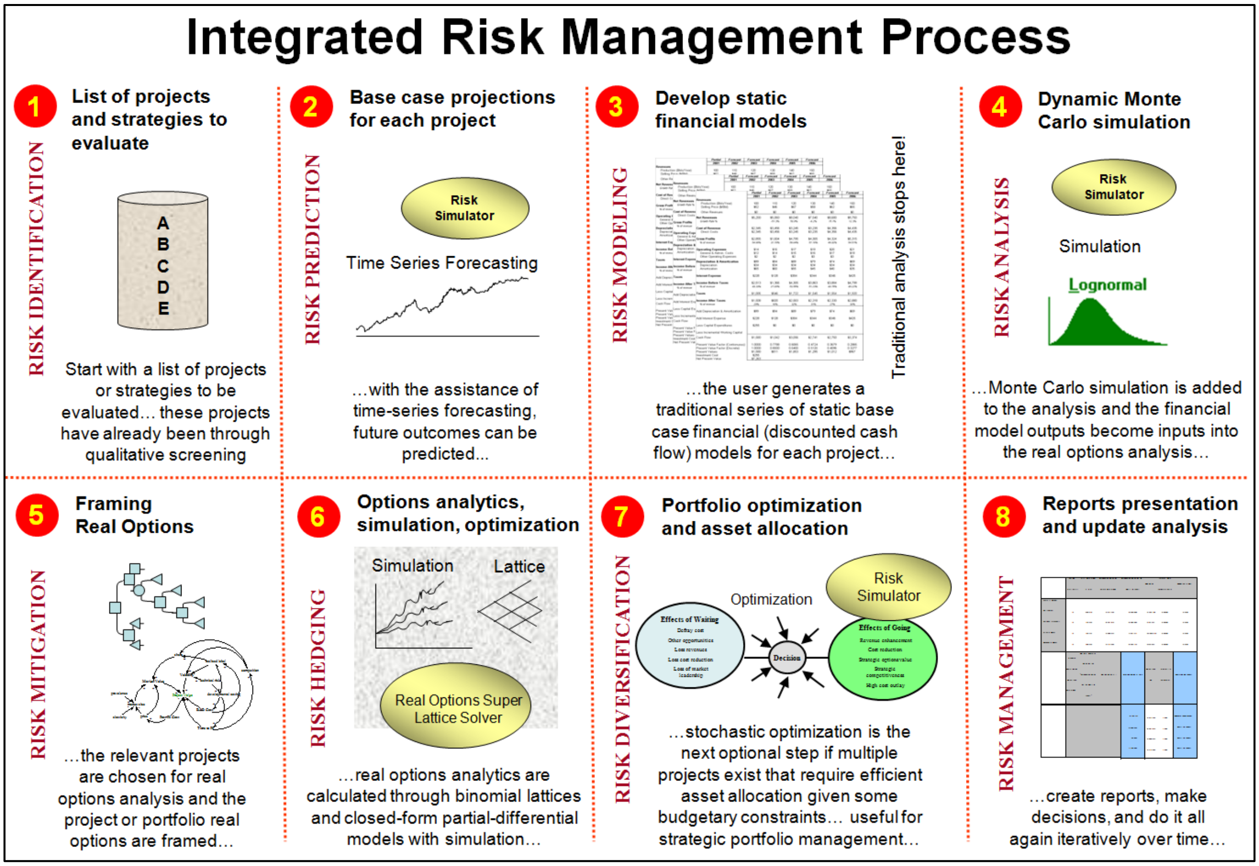


Figure 5. Integrated Risk Management Process.
Source: Mun & Housel (2010).

Figure 5 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.

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, or 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.). 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 6, 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).

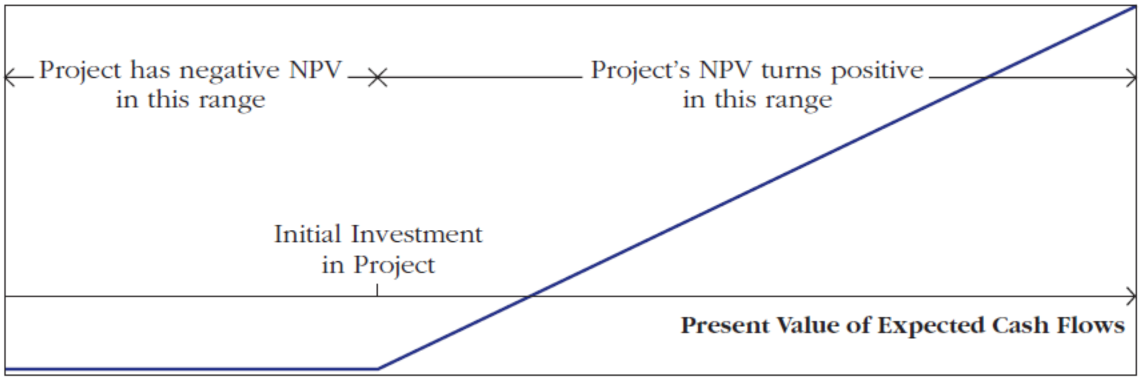


Figure 6. The Option to Delay.
Source: Damodaran (2000).

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 7 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).

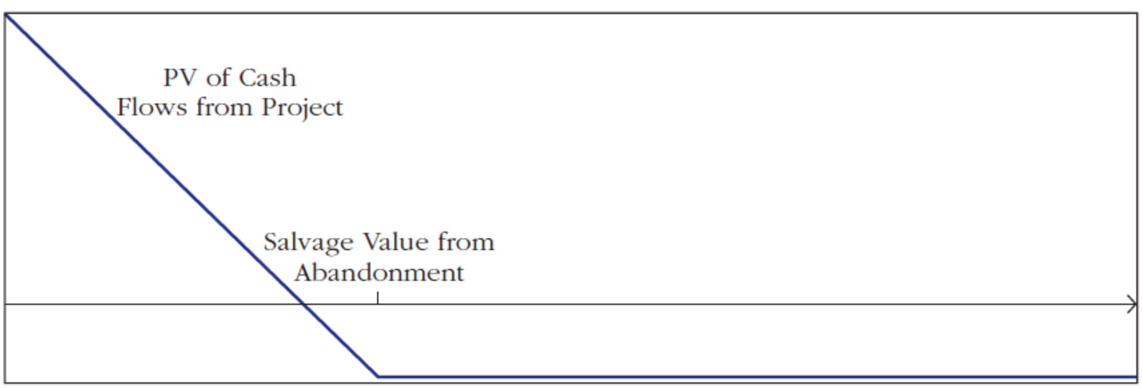


Figure 7. The Option to Abandon.
Source: Damodaran (2000).

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.

Knowledge Value Added

As the U.S. military is not in the business of making money, referring to revenues throughout this paper may appear to be a misnomer. For nonprofit organizations, especially in the military, we require the KVA methodology to provide the required "benefits" or "revenue" proxy estimates to run a true ROI analysis. ROI is a basic productivity ratio with revenue in the numerator and cost to generate the revenue in the denominator (i.e., ROI is revenue-cost/cost). KVA generates ROI estimates by developing a market comparable price per common unit of output multiplied by the number of outputs to achieve a total revenue estimate. The presumption is that the output of a process, at a given point in time, is by definition the thing of value because it was desired by the process owner regardless of how the process owner may decide to change the process at some future point in time.

In this way, KVA follows the general historical accounting model as a measure of cost (i.e., historical cost accounting model) per common unit of output. Standard accounting is based on historical measures of cost based on the cost to use resources (i.e., human, machine, raw, and infrastructural) to produce outputs. Generally accepted accounting practice (GAAP) does not provide any way to allocate revenue backward/historically within the enterprise. KVA goes a step further by adding a historical common unit measure of value (i.e., ratio level metric for common units of value via the KVA methodology). In a for-profit enterprise, this addition to GAAP allows for the allocation of revenue throughout the enterprise based on the outputs that core processes or functional areas produce at a given point in time providing an estimate for ROI. And, using KVA, it has been shown that internal ROIs are a defensible metric to use as a surrogate for capital asset price in estimating volatility over time (Housel, Little, & Rodgers, 2007). Armed with this new information, it is possible to use standard financial investment metrics that require measures of volatility (i.e., risk in financial terminology) over time.

In application to measuring the general productivity of organizational resources, KVA is a methodology whose primary purpose is to describe all organizational process outputs in common units. This provides a means to compare the current and potential future outputs of all assets (human, machine, information technology) regardless of the aggregated outputs produced. For example, the purpose of a military process may be to gather signal intelligence or plan for a ship alternation. KVA would describe the outputs of both processes in common units, thus making the ROI performance of any of the processes comparable.

KVA measures the value provided by human capital assets and IT assets by analyzing an organization, process, or function at the process level. It provides insights into each dollar of IT investment by monetizing the outputs of all assets, including intangible assets (such as that produced by IT and humans). By capturing the value of knowledge embedded in an organization's core processes (i.e., employees and IT), KVA identifies the actual cost and revenue of a process, product, or service. Because KVA identifies every process required to produce an aggregated output in terms of the historical prices and costs per common unit of output of those processes, unit costs and unit prices can be calculated. The methodology has been applied in 45 areas within the DoD, from flight scheduling applications to ship maintenance and modernization processes.

As a performance tool, the KVA methodology:

- Compares all processes in terms of relative productivity
- Allocates revenues and costs to common units of output
- Measures value added by IT by the outputs it produces
- Relates outputs to cost of producing those outputs in common units

Based on the tenets of complexity theory, KVA assumes that humans and technology in organizations add value by taking inputs and changing them (measured in units of complexity) into outputs through core processes. The amount of change an asset within a process produces can be a measure of value or benefit. The additional assumptions in KVA include:

- Describing all process outputs in common units (e.g., using a knowledge metaphor for the descriptive language in terms of the time it takes an average employee to learn how to produce the outputs) allows historical revenue and cost data to be assigned to those processes historically.
- All outputs can be described in terms of the time required to learn how to produce them.
- Learning Time, a surrogate for procedural knowledge required to produce process outputs, is measured in common units of time. Consequently, Units of Learning Time = Common Units of Output.
- Common units of output make it possible to compare all outputs in terms of cost per unit as well as price per unit, because revenue can now be assigned at the suborganizational level or at a DoD process level.
- Once cost and revenue streams have been assigned to suborganizational or DoD process outputs, normal accounting and financial performance and profitability metrics can be applied (Rodgers & Housel, 2006; Pavlou, Housel, Rodgers, & Jansen, 2005; Housel & Kanevsky, 1995).

KVA differs from other nonprofit ROI models because it allows for revenue estimates, enabling the use of traditional accounting, financial performance, and profitability measures at the suborganizational level. KVA can rank processes by the degree to which they add value to the organization or its outputs. This assists decision-makers in identifying how much processes add value. Value is quantified in two key metrics: Return on Knowledge (ROK: revenue/cost) and ROI (revenue-investment cost/investment cost). As previously noted, the KVA method has been applied to numerous military core processes across the services. It was originally developed to estimate the ROI on IT acquisitions in the telecommunications industry at the subcorporate level and has been used for the past 17 years in the DoD, with emphasis on the Navy, to assess the potential value added by IT acquisitions to core DoD processes.

With the KVA methodology, the value concept has a different meaning than it does for EVM or LSS. Using the KVA methodology, the value concept is based on complexity theory. This methodology values organizational processes in terms of their ability to change inputs into outputs using a given process. Thus, these changes are the units of value as shown in Figure 8 (Housel & Kanevsky, 1995). Elementary changes can be represented by common units of computational complexity (see Kolmogorov complexity theory explanation in Housel and Kanevsky's original 1995 treatise). These common units of complexity can be described in terms of the knowledge required to execute these units in a process. And, the amount of knowledge, i.e., computational complexity, can be described in terms of the learning time for a common reference point learner (i.e., common units of learning time is proportionate to the amount of knowledge contained in a process by the process change-making resources: people and machines).

The logic is as follows: process P changes the process input into the process output, and the changes represent the value added to the inputs (Housel & Kanevsky, 1995). If the process produced no changes, i.e., if input X is not changed by process P, then output Y is the same as input X, indicating no value was added by the process P (Housel & Kanevsky, 1995). The value generated through the process is proportional to the change in the state from X to Y, denoting the amount of knowledge created (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.

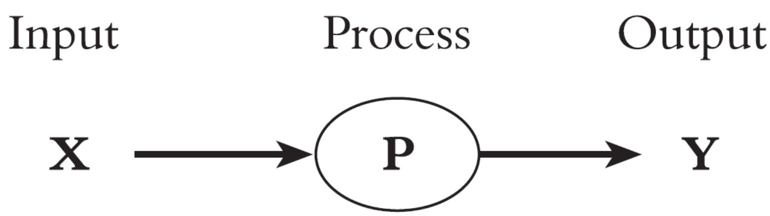


Figure 8. Value Added Process.
Source: Housel & Kanevsky (1995).

The KVA methodology is best completed by following the seven-step process shown in Figure 9. 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. (Housel & Bell, 2001). For ease of measurement, three measures are typically used within KVA to estimate the embedded knowledge within a process (Housel & Bell, 2001). Learning time, column two in Figure 9, measures the length of time it takes an average user to learn a process and correctly complete it (Housel & Bell, 2001). Process description, column two, is the number of instructions used to transform the given input into the desired output (Housel & Bell, 2001). The instructions must require an approximately equal amount of knowledge to complete a task (Housel & Bell, 2001). 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, any measure that satisfies the basic concepts of KVA can be used to create a common-units measure (Housel & Bell, 2001).

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 9. The KVA Approach.

Source: Housel & Bell (2001).

The first step, regardless of which metric an analyst employs, is identifying the core process and its subprocesses (Housel & Bell, 2001). To fully understand and accurately measure the knowledge inherent in a system, the entirety of the system must be mapped and understood. Next, analysts determine the measure that will be used in the analysis (Housel & Bell, 2001) Learning time or lines of code are more commonly used units as they can be measured with a higher degree of accuracy. Analysts must then calculate the number of units (i.e., learning time, tasks, or lines of code) within each subprocess (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, the unit of measure (i.e., learning time, tasks, or lines of code) is multiplied by number of times each subprocess is used during the sample period (Housel & Bell, 2001). Next, a proportion of revenue is allocated to each of the subprocesses relative to the results from the previous step and costs are calculated for each process (Housel & Bell, 2001). Finally, analysts should determine the ROK and interpret the results (Housel & Bell, 2001). Analysts should use two or more measures with a resulting high correlation to ensure the reliability of 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 an objective way to examine the benefit and value of a process compared to other processes, allowing leadership to determine which, if any, systems need improvement.

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 for 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, could provide beneficial information in the decision-making, budgeting, and planning processes.

Earned Value Management

EVM is used by the DoD and industry for the planning and management of projects and programs. It provides cost and schedule metrics to track performance in accordance with an acquisition project plan during the developmental phase of the acquisition life cycle after the Engineering Development contract is awarded. It uses a work breakdown structure (WBS) to try to measure the performance of a program based on the amount of planned work that is done at any point in the program management baseline (PMB). EVM uses cost and schedule metrics that aid in performance trend analysis with a focus on identifying any budget and schedule deviations from plan to allow the project team to take action as early as possible. It has been used for process improvements, but its strength is in providing a disciplined, structured, objective, and quantitative method to integrate performance, cost, and schedule objectives for tracking contract performance (DoD, 2015).

Given the propensity of IT acquisitions to be over budget and behind schedule, EVM metrics can help PMs identify and attempt to avoid overruns and schedule deviations. When variances in cost or schedule occur, EVM data can also be used to reforecast the budget and schedule with the focus of providing PMs with accurate performance information. It uses schedule and cost estimates to find the planned value (PV) of a given acquisition project. Cumulative PV provides the total value that should be achieved by a specified date (Reichel, 2006). Period PV can be calculated for a specified period of time, such as hour, day, week, and so on, to get the amount of work that is planned over the duration selected. The specific label for PV within the DoD acquisitions community is Budget Cost for Work Scheduled (BCWS). Actual Cost (AC) is the accumulated accrued costs of labor and materials. The label for AC within the DoD acquisitions community is Actual Cost of Work Performed (ACWP). Earned value (EV) measures the progress for a given plan. The DoD acquisitions label for EV is Budgeted Cost of Work Performed (BCWP; West, 2007). It may be possible to combine EVM with the IRM methodology to track IT acquisitions projects in a timelier manner leading to fewer cost and schedule overruns.

At its essence, EVM exists to provide an assessment of the actual, physical work a project has completed compared to a baseline plan (Fleming & Koppelman, 2010). 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 (Fleming & Koppelman, 2010). 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). 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 (Fleming & Koppelman, 2010).

Planned value, referred to within the DoD as 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 10) 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 than 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 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 9, 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 established during the Technology Maturation and Risk Reduction (TMRR) phase.

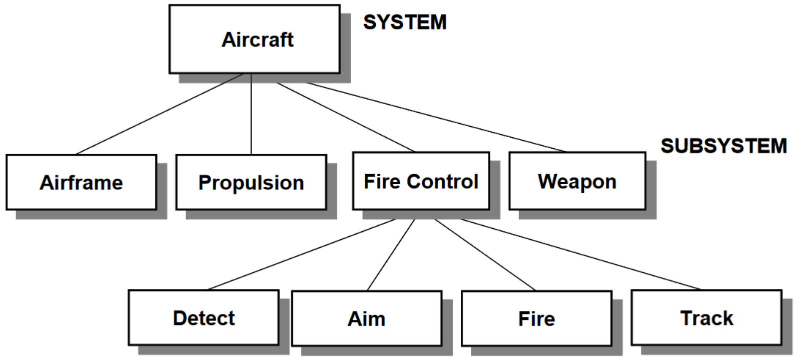


Figure 9. Sample WBS.
Source: Department of Defense (2005)

Earned value, 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, 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.

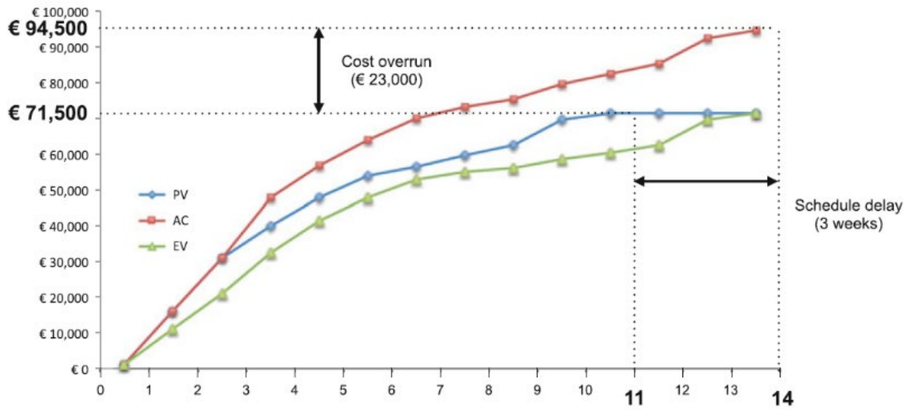
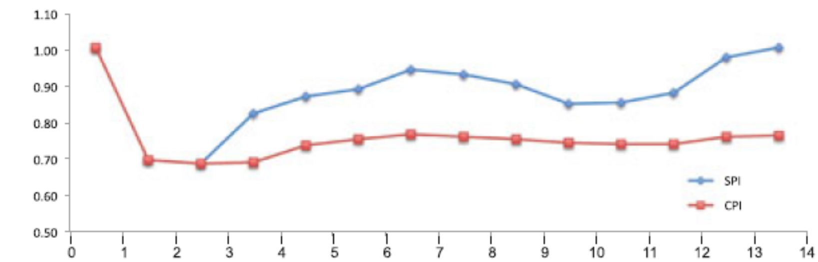


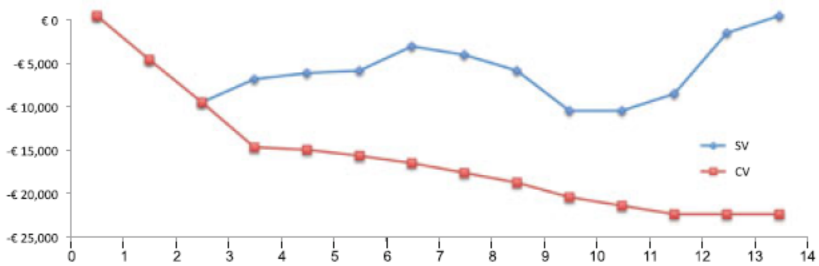
Figure 10. S Curve with the Three EVM Dimensions.
Source: Vanhoucke (2014)

Figure 10 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.

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 11 shows the performance metrics from the example project in Figure 10 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 11. 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 of 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 behind schedule, less than 1 is ahead of schedule, and if equal to 1 the project is on schedule (Vanhoucke, 2014). Once again, Figure 11 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 Knowledge Value Added. 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 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 subprocesses, the risk associated with developing subcomponents of a system, and incrementally improving a process may help improve the Defense Acquisition System as a whole.

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Research Methodology

A review of each of the methodologies was conducted as well as a high-level review of the current phases of the acquisition life cycle (i.e., DoDI 5000 series). The methodologies were evaluated in terms of each major phase of the acquisition life cycle to suggest how they might be used to enhance the likelihood of successful completion of the phase. Analysis included a review of how the general overall acquisition life cycle approach might be modified to incorporate the benefits from the methodologies, including the original motivations for the IT acquisition per the problems/challenges identified prior to the beginning of the acquisition process. It was presumed that it was possible that the acquisition life cycle should include a formal review of the need for the IT in the first place. It also was presumed that it was possible that the acquisition life cycle should not end when the IT is actually acquired. We examined how the methodologies might be used to monitor the ongoing return on the investments in the IT.

What follows are a review of the generic IT acquisition life cycle and the mapping of this generic life cycle to the existing DoD acquisitions framework; a review of the benefits and challenges of using each of the five methodologies with final recommendations about how to use each within the generic acquisition life cycle; a statement of the limitations of this study; and remarks on future research.

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Acquisition Life Cycle

This study developed a basic framework for placing the five methodologies within the generic IT acquisition life cycle as shown in Table 1, which can be mapped to the standard DoD Acquisition framework. Doing so allows a comparison of where the two general frameworks match up and provides some preliminary guidance for how the five methodologies might be used in the standard 5000 series acquisition framework.

Table 1. Five Approaches: When to Apply in the Methodologies in Tech Investment Life Cycle

Pre-Investment	Strategic Goal Alignment	Implementation	Post Implementation
KVA (As-Is)	BSC (Align strategy with performance metrics)	EMV (Monitor cost and schedule, adjust as needed)	KVA (Monitor ROI, ROK)
LSS (Identify waste, value added)	IRM (Identify the strategic options for IT investments)	KVA (To-Be, ROI, ROK)	LSS (Assess and monitor cost, waste reduction)
Other	Other	IRM (Use the project management tools within the IRM suite)	

As shown in Table 2, the Defense Acquisition life cycle framework mirrors the generic technology investment acquisition life cycle in that there exists a planning phase that includes activities consistent with pre-investment and strategic alignment, an execution or implementation phase, and an operations and support phase, generally considered the post-implementation phase of a program. The DoD defines these phases as the Materiel Solution Analysis phase, Technology Maturation and Risk Reduction phase, Engineering and Manufacturing Development phase, Production and Deployment, and the Operations and Support phase. Figure 12 is a visual representation of these phases as they are defined in DoDI 5000.02.

Table 2. Aligning the Generic and 5000 Series Life Cycles

Pre-Materiel Solutions Analysis	Materiel Solutions Analysis	Technology Maturation and Risk Reduction	Engineering and Manufacturing Development	Production and Deployment	Operations and Support
-Strategic goal alignment -Pre-investment	Pre-Investment	Pre-investment	Implementation	Implementation	Post-implementation

Materiel Solution Analysis Phase

The Materiel Solution Analysis (MSA) phase assesses potential solutions for a needed capability in an Initial Capabilities Document (ICD), which was developed during the defense requirements generation process known as the Joint Requirements Capability Determination System (JCIDS). The MSA phase is critical to program success and achieving materiel readiness because it is the first opportunity to influence systems supportability and affordability by balancing technology opportunities with operational and sustainment requirements. During this phase, various alternatives are analyzed to select the materiel solution and develop the Technology Development Strategy (TDS) that will be further assessed in the TMRR phase and eventually executed during Engineering and Manufacturing Development (EMD).

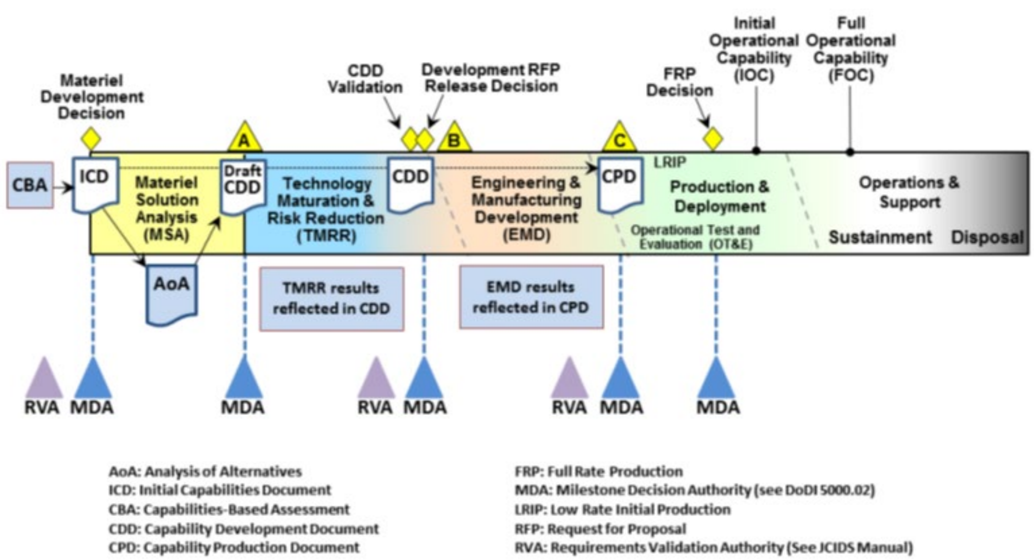


Figure 12. The 5000 Series Acquisition Life Cycle.
Source: DoD (2017).

The MSA phase also includes identifying and evaluating affordable product support alternatives with their associated requirements to meet the operational requirements and associated risks. Consequently, in describing the desired performance to meet mission requirements, sustainment metrics are defined that will impact the overall system design strategy. One of the principle tasks that must be completed during this phase is the Analysis of Alternatives (AoA), suggesting that tools that offer robust trade-off analysis might be better suited for this phase.

Significant events within the MSA and other phases of the acquisition life cycle are listed in Table 3. While this is not an all-inclusive list of events during each phase, important steps within a program's development are incorporated.

Technology Maturation and Risk Reduction Phase

The Technology Maturation and Risk Reduction (TMRR) phase is designed to reduce technology risk, engineering integration risk, life cycle cost risk and to determine the appropriate set of technologies to be integrated into a full system. The objective of the TMRR phase is to develop a sufficient understanding of a solution in order to make sound business decisions on initiating a formal acquisition program in the EMD phase. This phase lends itself well to management tools that provide all the program manager (PM) needs to conduct technical and business process trade-off analysis studies relative to cost and schedule.

Table 3. Key Events within the Phases of the 5000 Series

MSA	TMRR	EMD	P&D	O&S
Analysis of Alternatives	Preliminary Design Review	Complete detailed design	Low rate initial production	Lifecycle Sustainment Plan (LCSP)
Initial funding estimates	Capability Development Document	System-level Critical Design Review (CDR)	Initial Operational Test & Evaluation (IOT&E)	System Modifications
Technology Development Strategy	Competitive prototyping	Establish project baseline with Performance Measurement Baseline (PMB)	Full rate production decision	Sustainment
	Acquisition Program Baseline (APB) established		Initial and Full Operational Capability (IOC and FOC)	Disposal

Engineering and Manufacturing Development Phase

The Engineering and Manufacturing Development (EMD) phase is where a system is developed and designed before going into production. The EMD phases is considered the formal start of any program and the point at which a development contract is awarded based on a specific statement of work (SOW). The goal of this phase is to complete the development of a system or increment of capability and evaluate the system for technical maturity before proceeding into the Production and Deployment (PD) phase. This is the phase in which cost and schedule variance models that help the PM to better understand technical issues are best employed since requirements are fundamentally solidified and represented in the SOW. If requirements are shown to be less than optimal or there are other mitigating issues during this phase that impact cost and schedule, then decision support tools to facilitate trade-offs may be used to help the PM maintain the program baseline and deliver user-defined capability.

Production and Deployment and Operations and Support Phases

These two phases (PD and Operations and Support [OS]) are necessary for the PM to ensure that the product being manufactured meets the operational effectiveness and suitability requirements for the user or customer. While the design is pretty well set at this point in the program, there may still be some trade-offs that take place prior to the full rate production decision and fielding of the system. The PM is less concerned with managing cost and schedule variance at this point since the contract types typically revert to a fixed price strategy. The biggest concern for the PM at this point is correcting any final deficiencies in the system and establishing a stable manufacturing and sustainment process.

The four generic phases listed in Table 1 align with the current DoD structure, as shown in Table 2. As the scope of this research is limited to the 5000 series, the pre-materiel solutions analysis column is for informational purposes only. The JCIDS process accomplishes strategic goal alignment, determining the necessary additions to the DoD's capabilities portfolio prior to the 5000 series. The ICD generated in the JCIDS process describe the high-level needs that the user requires, and these needs are assessed in the AoA process during the MSA phase. Within the scope of this paper, the DoD acquisition life cycle and generic IT acquisition life cycle begin with pre-investment during MSA.

Risk Management Framework

If one discounts basic scheduling and cost management practices, the primary tools to monitor progress of an acquisition program during the MSA and EMD phases are EVM and the Risk Management Framework (RMF). Figure 13 shows the seven steps that comprise the RMF, repeating in a cyclical pattern—prepare, categorize, select, implement, assess, authorize, and monitor.

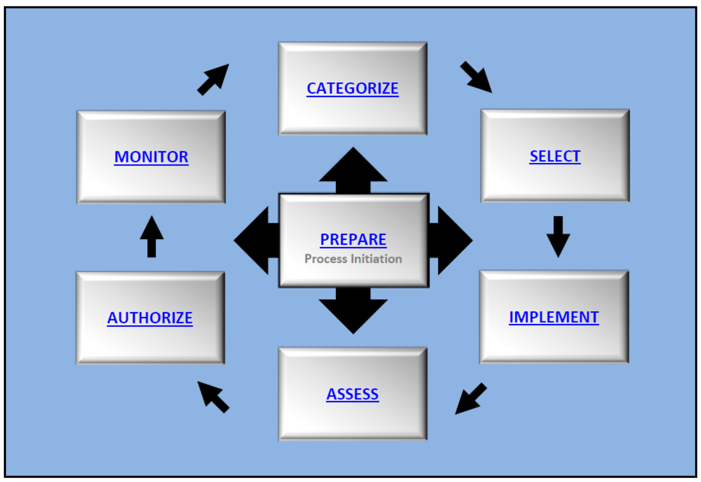


Figure 13. Seven Steps in the Risk Management Framework. Source: Joint Task Force Transformation Initiative (2018).

Preparation initiates the process, ensuring organizations are ready to execute RMF and giving context and priorities for managing risk (Joint Task Force Transformation Initiative, 2018). Categorization consists of organizing the system and the information used by the system based on an impact analysis (Joint Task Force Transformation Initiative, 2018). The risk manager then selects the appropriate security controls, tailoring them as necessary (Joint Task Force Transformation Initiative, 2018). The controls must then be implemented into the system and its operating environment before assessing the controls' effectiveness and authorizing the use of the information system (Joint Task Force Transformation Initiative, 2018).

Finally, the manager must monitor the security controls on a continual basis, repeating the cycle as necessary when deficiencies are discovered (Joint Task Force Transformation Initiative, 2018). EMD is the first point at which PMs use EVM in an official capacity. The appropriate decision-makers approved a schedule and budget for the program creating the Acquisition Program Baseline. Future progress is now measured against this benchmark. Even using these proven tools, cost and schedule overruns occur regularly, illustrating the need for a different approach.

The RMF is a broad analysis that covers multiple types of risk and is used throughout the entire life cycle of a new development system. Implementing other tools into the process could help PMs better understand the risk involved at various points throughout the program. Within an acquisition there is an interdependence of risk. As the program progresses (and using the EVM methodology) and the ACWP increases, there are increasing levels of aggregation and abstraction of risk. For instance, to award an EMD contract, the technology involved must be at a Technology Readiness Level (TRL) of 6, indicating the technology performed adequately in a relevant test environment (Assistant Secretary of Defense for Research and Engineering [ASD(R&E)], 2011). However, the technology is not yet completed and requires significant improvement before production. The current risk assessment program does not account for the possibility that this categorization is incorrect and may not lead to a fully operational system. As a result, PMs proceed with the assumption the technology will continue development as planned. Any lack of progress will not become apparent until the ACWP begins to vary from the BCWP. It is often too late to make the appropriate corrections to the program in order to remain on budget by the time the discrepancy is discovered using EVM metrics.

Early risk management that focuses on the validity of the decision-making process using the RMF framework might introduce a higher level of understanding of the subordinate processes. For example, if at a particular milestone, the technology is not at the level of readiness it is being portrayed, then the consequences are x, y, and z. The results of each statement can be expressed in terms of time and money, or, keeping with the already established EVM terminology, potential CV. A PM can then assign a probability of success estimate to the state of the program that might drive a deeper understanding of the various interdependent program management processes.

Generic Framework and 5000 Series Integration

Table 4 shows when each methodology might be used in the 5000 series phases. This table reflects the reality that there are multiple tools for the various phases that should be used in concert and that certain tools are more appropriate for a particular phase than others. It is incumbent on the PM to use the tools appropriately in that they provide more information for a complex environment. The tools themselves do not provide the solutions to potential problems; they are simply indicators of underlying performance issues and, as such, are tools that can provide better insight into the life cycle of a program.

Table 4. Methodologies within the 5000 Series

Materiel Solutions Analysis	Technology Maturation and Risk Reduction	Engineering and Manufacturing Development	Production and Development	Operations and Support
BSC	IRM	EVM	EVM	KVA
IRM	KVA	IRM	IRM	LSS
KVA	LSS	KVA	KVA	
LSS				

Understanding the extent to which a particular tool might provide greater insight into program performance across the life cycle, one should consider the level of analysis required and the viability of a particular tool to provide sufficient insight at that level of analysis. Three levels of analysis were considered for this initial survey: Organizational, Business Process, and Task Analysis (Table 5).

Table 5. Management Tool Selection Criteria Based on Level of Analysis, Focus of Analysis, and Acquisition Phase

Level of Analysis	Focus of Analysis	Time Horizon	Acquisition Phase
Organization	-Strategic competitive advantages: BSC, IRM -Value=Revenue: BSC, IRM strategic options	LSS: 3+ months (depends on level of process complexity)	MSA/TMRR/P&D/O&S
Business Process	-Cost savings: LSS, EVM, BSC, IRM -Schedule: EVM Value: KVA outputs	-EVM: 5+ months set up time (depends on requirements) -KVA: 2 days – 1 month (depends on level of analysis)	MSA/TMRR/P&D/O&S
Task Analysis	-Cost savings: LSS, IRM -Value=Cost+schedule cycle time: LSS, BSC	-BSC, IRM: 3-6 months	TMRR/EMD/P&D

It is clear from Table 4, that a variety of tools are required across the life cycle for the PM to gain a more robust view of the program performance. As shown in Table 5, the selection of the tool will depend on the particular focus and time horizon with which the tool is able to provide relevant information about the program. Table 6 illustrates different benefits and challenges of each methodology. Simply relying on one tool will not allow the PM to adequately manage the program. Planning for the type and depth of the management tool is started early in the life cycle and should be part of the overall acquisition strategy. Additionally, selecting contractors that are able to implement and manage these tools is critical in the decision-making process.

BSC is an excellent tool when viewing a system holistically. It provides a way for managers to examine a project from a systems-thinking approach. It may be most useful when strategizing about the potential use of an IT acquisition and how it might fit into the DoD's higher-level strategic goals prior to developing a requirements document. The statements derived from the BSC for general dissemination among all levels of the organizational structure must be translated into a simpler form presented in set of objectives and targets that are clear for all levels within the organization. It is also important to understand that leadership is central to ensuring any IT acquisition will support the organization's overall strategy enumerated in the BSC. This is true in the DoD as well as in any organization's implementation of a BSC (Llach, Bagur, Perramon, & Marimon, 2017). Without leadership support and guidance, the BSC is unlikely to succeed, and the organization will not be able to generate acceptable returns on its IT investments.

Table 6. Benefits and Challenges of the Five Methodologies

	Extensible, Quantitative Value Measurement	Time to Perform	Cost	Bottleneck Analysis
BSC	No, subjective measurement (revenue is exception)	3-6 months (depends on level of analysis)	Accounting-based financial metrics only	None
EVM	No, cost measurement only	5+ months setup time (depends on requirements)	Cost of resources and time	No, linear tracking only
LSS	No, nominal value only	3+ months (depends on level of process complexity)	Activity-based costing approach	Direct bottleneck analysis
KVA	Yes	2 days – 1 month (depends on level of analysis)	Common units of cost	Elapsed time versus work time
IRM	Yes, KVA	3-6 months (relatively quick once initial steps completed)	Cost accounting and KVA cost metrics	Monte Carlo simulation

The use of BSC can result in a cursory review of KPIs during the traditional acquisition life-cycle management process. BSC also avoids overreliance on financial KPIs by viewing the effects of each KPI on the other parts of the scorecard. While financial KPIs are reviewed with BSC, the other segments are separated from a purely financial analysis, allowing managers to use their judgement in determining how the proposed solution will affect the scorecard as a whole. The problem is that without a quantifiable common-units performance metric that allows the practitioner to determine the relative value between the different scorecards, it is difficult to determine which course of action would be optimal. There is no performance ratio that tells the manager that by performing a given action, the financial KPIs will improve by a given amount, the stakeholder engagement will decrease by this amount, and the internal process will change by this amount. Instead, it is more of a conceptual thought exercise to ensure managers consider the effects of their decisions on the entire range of KPIs. Because of this, BSC works best during the strategic goal alignment phase of the generic IT acquisition life cycle and the pre-MSA portion of the DoD acquisition life cycle. The MSA phase also includes aligning the stated requirements with the possible solutions to the capability gap during the AoA. An all-inclusive view of the effects of the various IT solutions that are being considered will assist in the selection of the most appropriate option to continue towards acquisition. BSC is recommended for implementation during the MSA phase.

EVM provides users with an easily understandable report of a project's advancement towards completion. Comparing the BCWP and the ACWP gives a clear view of how a system is progressing within the anticipated budget. The metrics used for cost and time are also clearly delineated. This delineation allows managers to compare the performance at different points throughout the project, which can assist in determining where a project has changed trajectories. There are numerous challenges when using EVM as well. While cost is measured and tracked regularly, the value of the project is not monitored as closely. Despite the name, the amount of work performed does not tell a manager the actual quantifiable value (in a common-units measurement) the project has accrued at a given point. There is no quantifiable measure of value within the methodology. The only quantitative measures of performance are measures of cost and time.

The ACWP assumes the outputs from all work were perfect on completion. If there are issues with the results from earlier efforts, they must be reworked, changing the ACWP calculation. If the technology does not improve as expected because the TRL was not accurately portrayed, a PM will believe the project is on schedule despite the "earned value" lagging behind what the numbers are projecting. Additionally, and in some instances because of this assumption, EVM outputs are not timely. Conducting an accurate analysis of a program is time consuming and does not provide useful predictive information. By the time EVM alerts a PM to a variance, the variance has already occurred. All corrections are reactive to bring the ACWP back to the baseline, which has proven to be a nearly impossible task in practice. EVM will only be effective when the baseline plan is well researched and accurate. Otherwise, the ACWP is compared against flawed data. EVM does provide valuable information to project managers during the EMD phase but should be supplemented with some of the other methodologies (LSS, KVA, IRM) throughout the project management cycle.

Successfully implementing LSS into a process will lower the cost of the project by reducing the variation in a product run and the waste associated with its production. When additional steps or unnecessary waste is reduced, additional resources become available for use in other processes. In identifying a bottleneck, LSS can address multiple problems simultaneously depending on how the project is defined. By creating improvement in one area and freeing resources, other areas may benefit from an improved process workflow. However, LSS can be costly to implement. The analysis requires a great deal of time and information to develop meaningful understanding of any problems. LSS's definition of value is at the nominal scale level: an item either adds value to a project or it does not. Reality is not often as black or white. There are required steps that must be conducted that do not necessarily add value to a product from the user's standpoint. For instance, accounting departments do not attempt to directly add value to a final product, but any organization recognizes the need for accounting, suggesting the accounting department does add value. LSS is time-consuming when applied on a large scale, as would be the case in a DoD acquisition. Defining the problem and determining appropriate measurements in a step-by-step manner is a major undertaking. However, acquisition professionals can use it to ensure the project is defined and measured appropriately.

The greatest benefit from KVA is a quantifiable (common units) value metric that can be compared across various aspects of a project (Housel & Bell, 2001). If the value of an intermediate step is quantified, managers can compare the outputs of a component instead of simply the effort measured by time and cost that were inputs. KVA provides a value measurement for both tangible and intangible assets, making it especially well-suited for use with IT. A KVA analysis can be accomplished in a relatively short period of time in comparison with the other methodologies. A quick, rough-cut KVA analysis can provide rapid guidance for the project before sinking valuable time and resources into a more comprehensive examination. KVA is primarily a measurement tool that provides performance information to decision-makers. It is not a system that will drive an acquisition project towards the goal on its own. As in the other methodologies mentioned thus far, KVA has limited value in making predictions for future value, focusing instead on the current value of systems in development. There must be another methodology employed with KVA to ensure a project's success.

IRM provides a foundation to incorporate the risk associated with a decision into a quantitative decision process. IRM's core premise maintains there is a probability for success and failure with every decision option during a project's life cycle. Using statistical simulations, real options, and optimization will improve the quality of information a PM has to determine the course of a project. Real options analysis can be used to frame strategies to mitigate risk, to value and find the optimal strategic pathway to pursue, and to generate options to enhance the value of the project while managing risks. IRM's drawback is that the analytical methods can sometimes be difficult to master. But with the requisite knowledge and training, coupled with the correct tools, the IRM methodology can provide a plethora of value-added information for making strategic and tactical decisions under uncertainty.

Case Study Vignettes

In what follows, we review a number of case vignettes of the use of the five methodologies in the DoD context. Some of the vignettes are more detailed than others. For example, the use of KVA and IRM is very well documented across a number of contexts that can be found in prior Acquisition Research Program reports. Others, such as BSC, are not as well documented.

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).

Software-defined radios, such as JTRS, use software to control the operation of a radio rather than hardware as used in traditional radio operation (Francis, 2006). Waveforms are the software applications the radio uses to transmit messages, including the frequency, modulation, message format, and/or transmission system (Francis, 2006). 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 (Francis, 2006). 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 14 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). The success of the program relied on the development of the various waveforms and their ability to operate on the different JTRS radios (Francis, 2006).

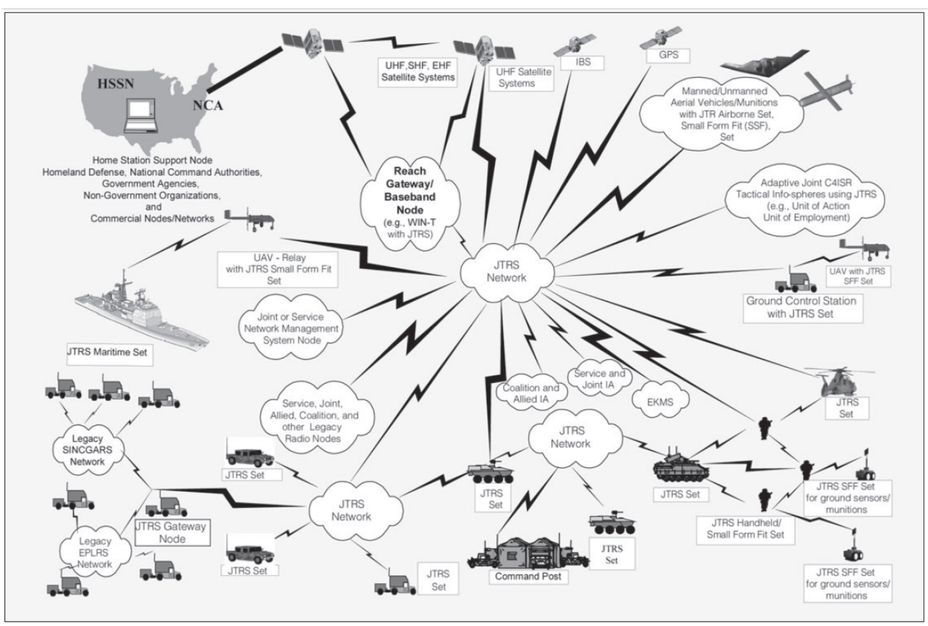


Figure 14. JTRS Operational Overview.

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. Figure 15 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).

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

Figure 15. JTRS Clusters.
Source: Feickert (2005).

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 Acquisitions Category (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 16. 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.

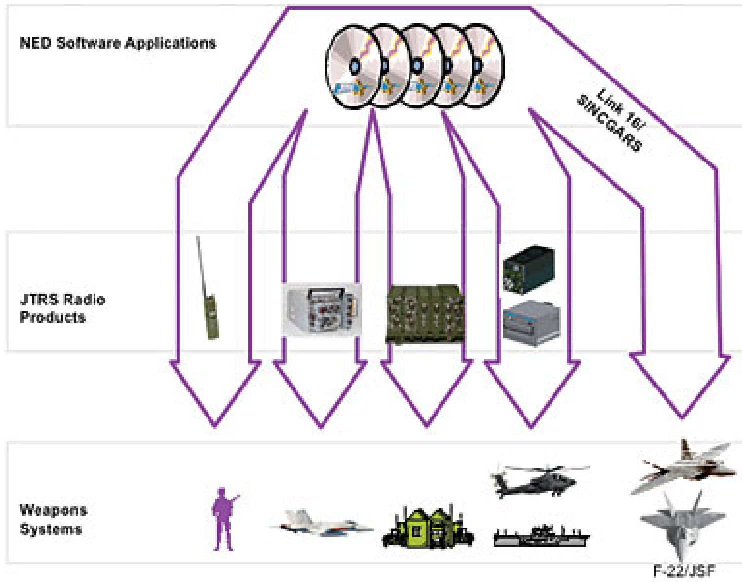


Figure 16. JTRS Program Structure

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 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 vs. 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 impacted 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" (Powner, 2009). Figure 17 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 17. GAO Review of JTRS HMS Key EVM Practices.
Source: Powner (2009).

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 subprocesses 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 PV. 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 18 shows the 10 subprocesses within the overall process of intelligence collection. Every subprocess can be further broken down into individual actions required to complete the subprocess with various degrees of automation depending on the task (Rios, Housel, & Mun, 2006). Figure 19 illustrates the four CCOP systems and the ICP subprocesses associated with them.

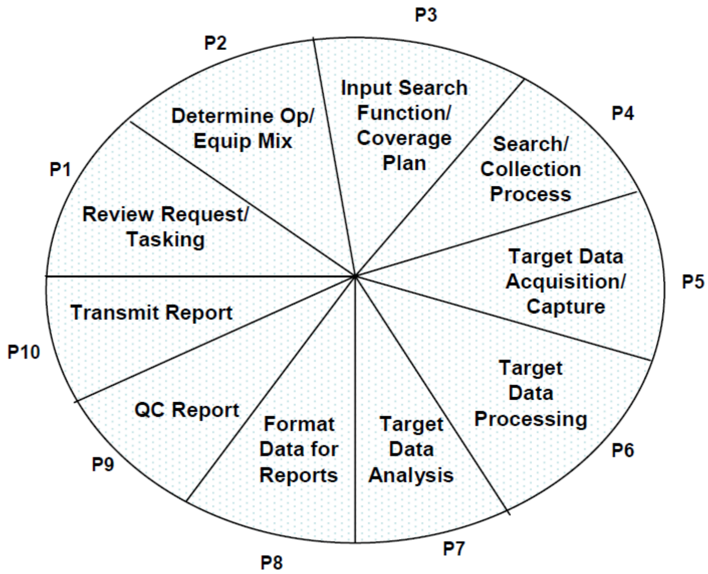


Figure 18. Intelligence Collection Process.

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 19. USS *Readiness* CCOP Systems.

Source: Rios et al. (2006).

Data was collected from a single ship's six-month deployment and adjusted to reflect annual cost (Rios, 2005). Using the learning time method, the PM calculated the time to learn each subprocess for both automated and manned tasks (Rios, 2005). 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 (Rios, 2005). Using market comparable prices for similar products, he assigned a notional price to assign revenue for the CCOP systems contributions to each subprocess (Rios, 2005). Costs were then assigned based on the human and IT assets that complete each task (Rios, 2005). The PM then determined the ROK and the Return on Knowledge Investment (ROKI), which is a surrogate for ROI (Rios, 2005). Figure 20 depicts the results for each subprocess and CCOP as well as for the aggregate (Rios et al., 2006).

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	-137.27	109.9

Figure 20. 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 21, 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.

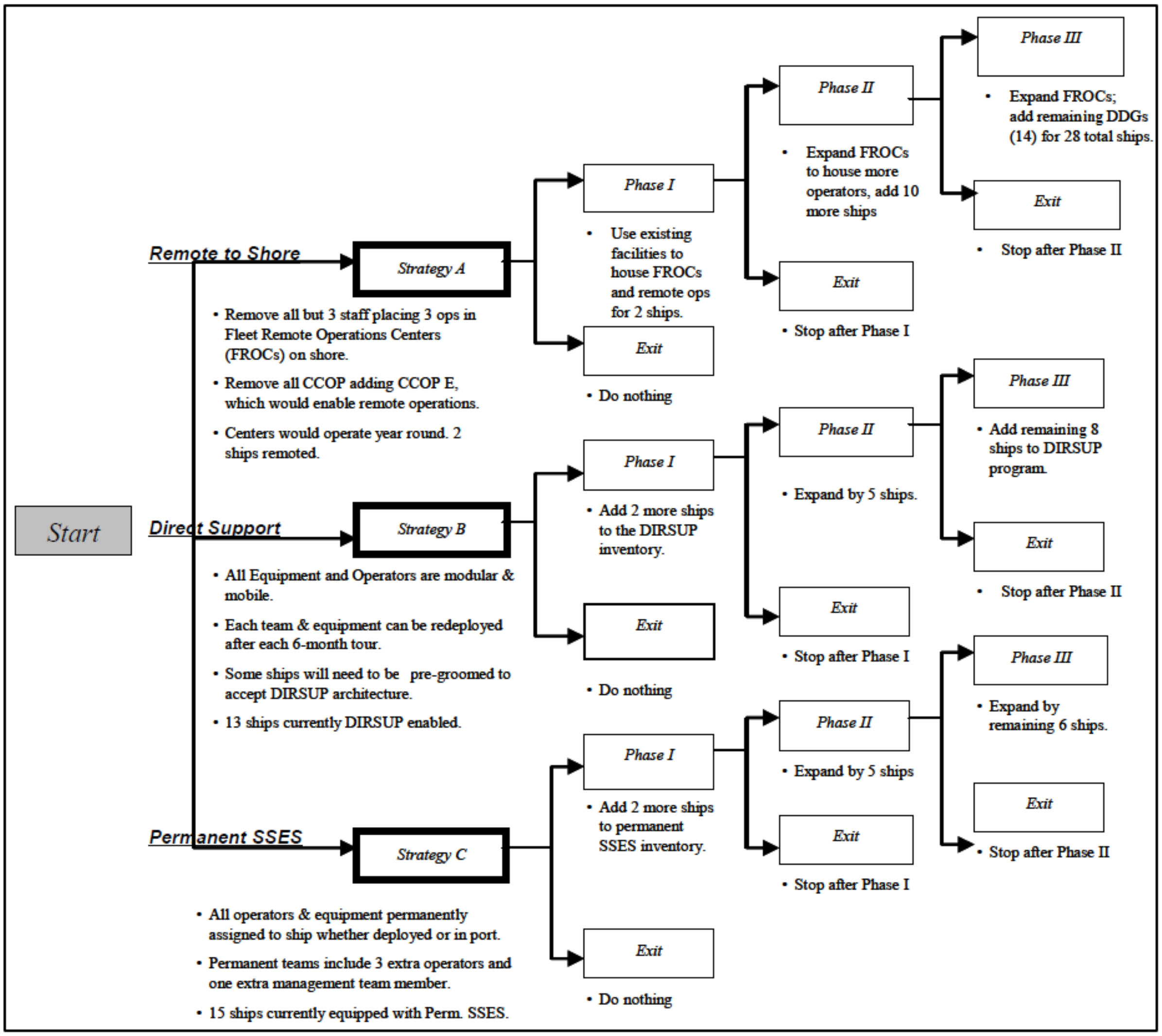


Figure 21. CCOPs Real Options Paths.
Source: Rios et al. (2006).

The analysis produced present values for each of the different strategies, shown in Figure 22. 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 PV due to perceived cost savings associated with reducing the number of systems and operators (Rios et al., 2015). However, the PV 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).

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

Figure 22. PVs of CCOPs Real Options Analysis.
Source: Rios et al. (2005).

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 subprocesses 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 PV 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.

Letterkenny Army Depot: Lean Six Sigma

Lean Six Sigma (LSS) was used to successfully rehabilitate a struggling U.S. Army Materiel Command's (AMC) facility at the Letterkenny Army Depot (LEAD). LEAD was a Depot-level repair facility that performed recapitalization of the U.S. Army's Patriot missiles and power generators (Harvey & Lapedz, 2006). In 1995, LEAD was downsized under the Base Realignment and Closures (BRAC) initiative, which caused the loss of 1,200 jobs and the ceding of 1,450 acres of land to the regional civil authority. In 2002, the new commander assigned to LEAD assessed that the organization was suffering from dysfunctional workflow, high hourly wages compared to the going labor rate, and infrastructure shortfalls. LEAD was recognized as a likely candidate for further cuts in the imminent 2005 BRAC cycle, threatening a further 1,800 jobs and the existence of the facility. The AMC commanding general advised the LEAD commander to apply LSS methods as part of the management strategy.

The LEAD commander and a selected executive team of LSS "believers" commenced the LSS approach with a focus on Lean (process efficiency) over Six Sigma (quality) approaches after their initial assessment of the greatest opportunities for improvement. The commander also elected to focus on the highest profile and most expensive product line, the Patriot missile, in order to demonstrate the value of LSS at scale. The LEAD LSS team applied a phased approach using Readiness Assessment, Engagement, Mobilization, and Performance and Control.

The LSS Readiness Assessment revealed that LEAD lacked formal process flows and performance benchmarks. The AMC-wide use of Balanced Score Card methodology was based on low performance standards and failed to create a climate of growth or improvement. The LEAD processes and products also lacked reasonable performance benchmarks that could be used to generate targets for process improvement.

The LSS executive team used the Engagement phase to communicate strategy, prepare the management and line workers, and build consensus around the need for improvement and the path forward. The looming BRAC created a sense of urgency, and the global context of the early days of the Global War on Terror was a motivating force for the team to pull together in the process of changing many long-held practices and expectations.

During the Mobilization phase, the LSS executive began a series of Value Stream Analysis (VSA) and Rapid Improvement Events (RIE). The VSA analyzed the work processed and identified bottlenecks, inefficiencies, waste, and other areas for improvement. It included a detailed accounting of time, material, and the cost of the LSS analytic process overhead in order to benchmark the current state for comparison against future improvements. The RIE followed the VSA with actions that addressed the VSA shortfalls. VSA efforts included participation from leadership, middle management, and line workers, as well as interdependent functions at the facility to guarantee buy-in and mitigate adverse unintended consequences in other processes.

The Performance and Control phase was the culmination of the LSS process. With established benchmarks and detailed reports on the labor hour savings, process time efficiencies, facility space usage, and the cost of the LSS process, the team could see and communicate the gains achieved by each LSS project.

LEAD’s LSS efforts from 2002 to 2005 successfully turned around the beleaguered facility. In 2005, LEAD was awarded the Shingo Prize for Excellence in the Manufacturing Industry. The 2005 BRAC cycle did not close LEAD and actually moved 200 jobs from other sites to the now thriving organization. The freed space and work capacity gained in LSS were applied to new service offerings as LEAD took on “new business lines” repairing HMMWVs, generators, mobile kitchens, and more.

The success at LEAD is echoed in many other DoD activities. The Army’s Red River Texas High Mobility Multipurpose Wheeled Vehicle (HMMWV) repair site reported $30 million in savings after LSS. The Air Force HH-60 maintenance facility in

Corpus Christi, TX, improved its aircraft rebuild time by 50%. An Army command demonstrated the value of LSS by reducing its Awards paperwork process times from 90 to 21 days.

Defense Acquisition System: Balanced Score Card

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). This vision was supported by three concepts: strategic vision to think globally; strategic awareness to collect, analyze, and communicate information; and strategic resilience (Young, 2004). Additionally, three principles along with specific goals guided the organization towards 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 23. 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).

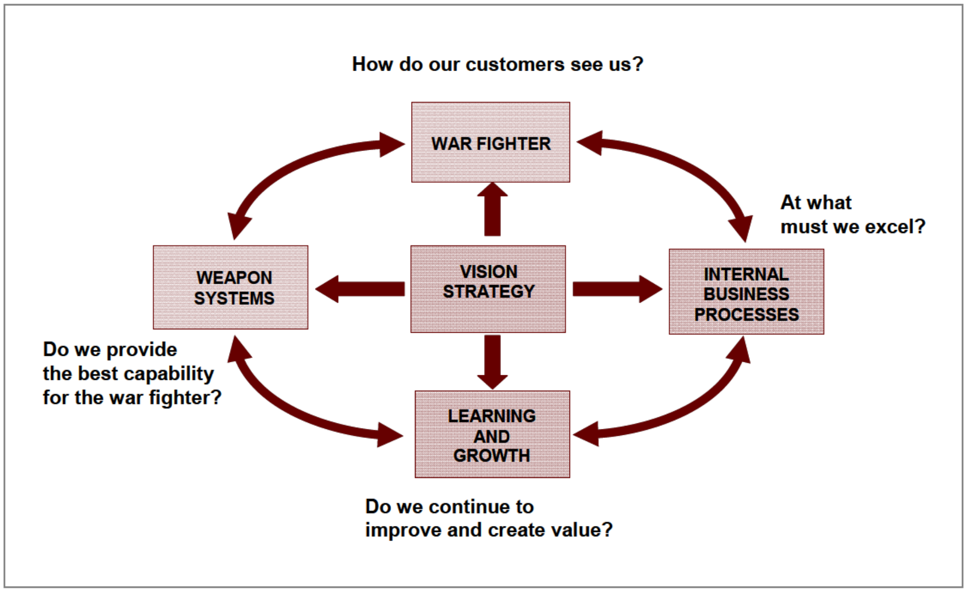


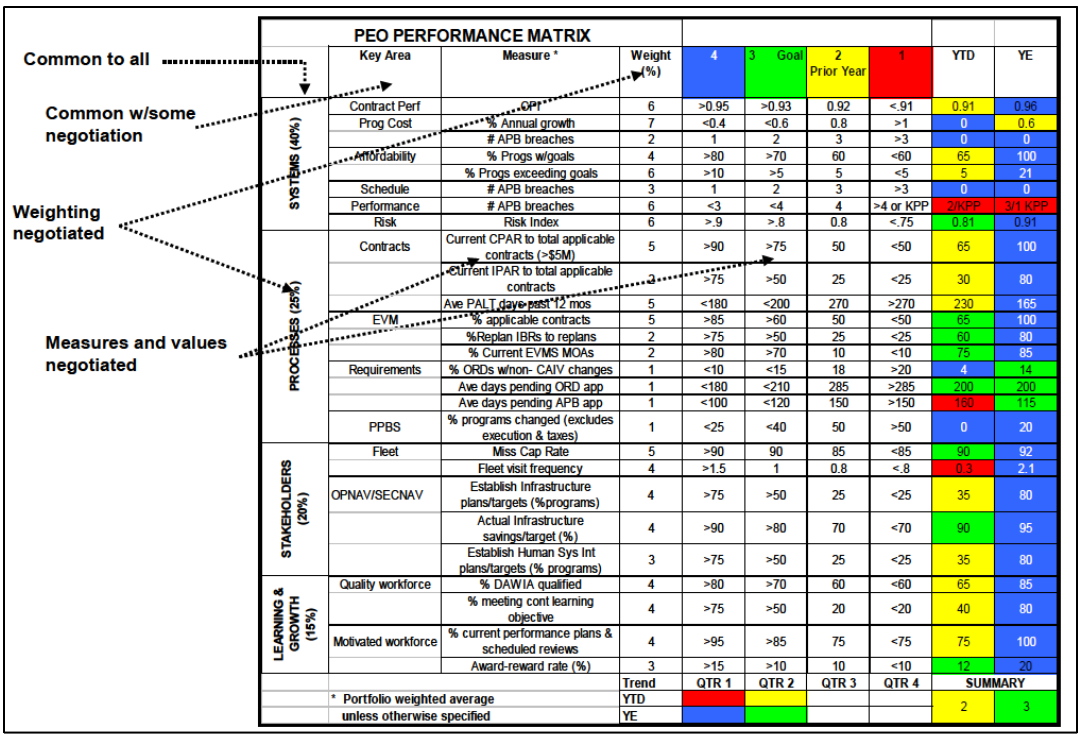
Figure 23. Four BSC Perspectives of the ASN.
Source: Buss & Cooke (2005).

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 24 provides an example BSC for a program executive officer (PEO). The BSC contains the same four categories from the higher scorecard in Figure 25. 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 towards 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.

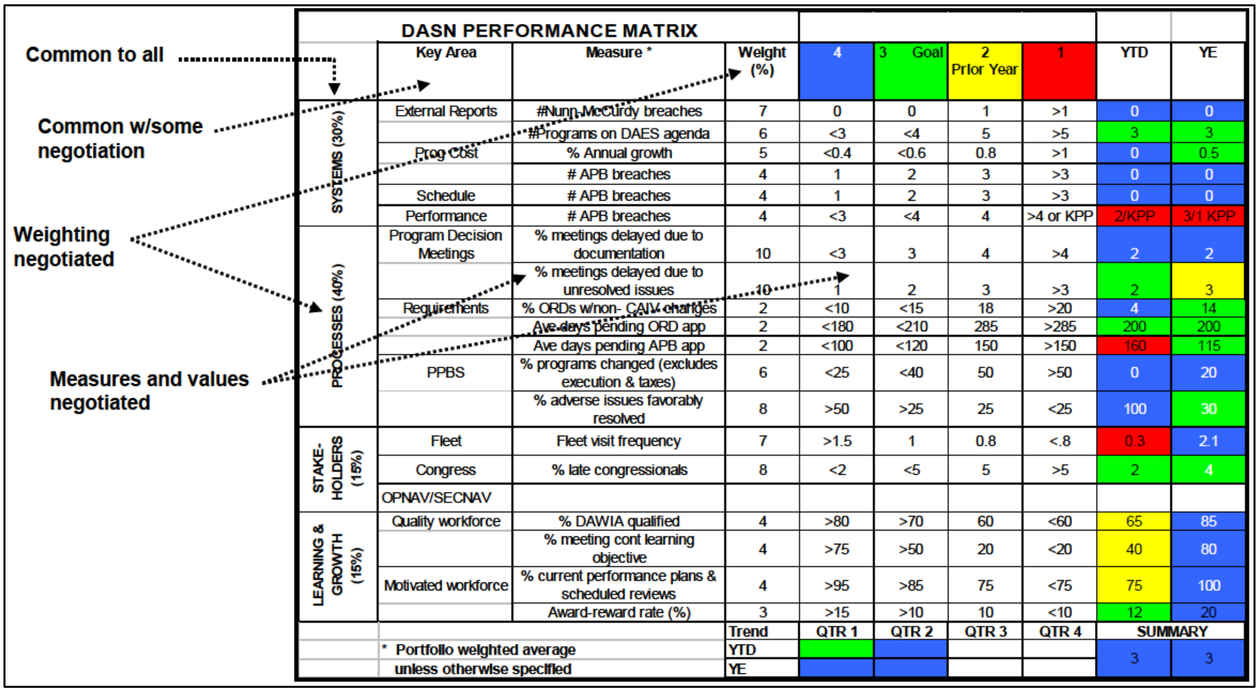


PEO PERFORMANCE MATRIX									
	Key Area	Measure *	Weight (%)	4	3 Goal	2 Prior Year	1	YTD	YE
SYSTEMS (40%)	Contract Perf	CPI	6	>0.95	>0.93	0.92	<.91	0.91	0.96
	Prog Cost	% Annual growth	7	<0.4	<0.6	0.8	>1	0	0.6
		# APB breaches	2	1	2	3	>3	0	0
	Affordability	% Progs w/goals	4	>80	>70	60	<60	65	100
		% 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 24. 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 25. 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 changes	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 25. 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.

BSC has been implemented in military organizations with success, including the U.S. Army, British Ministry of Defense, and the Canadian Department of National

Defense. The U.S. Army successfully used BSC to determine if troops were sufficiently prepared to deploy to global conflict areas. The British Ministry of Defense conducts its annual performance review from a BSC perspective (Balanced Scorecard Review, n.d.). Each section of its review is based on one of its four BSC categories: purpose, resources, enabling process, and future (Balanced Scorecard Review, n.d.). The Canadian Department of National Defence uses the four key areas listed below (Balanced Scorecard Review, n.d.):

- Shape future defense security outputs
- Deliver defense outputs
- Manage program resources
- Professional, effective, and sustainable team defense

From these categories, it created a strategy map, similar to the one shown in Figure 26, to illustrate the effects key areas have on one another and how they could link items with their strategic goals.

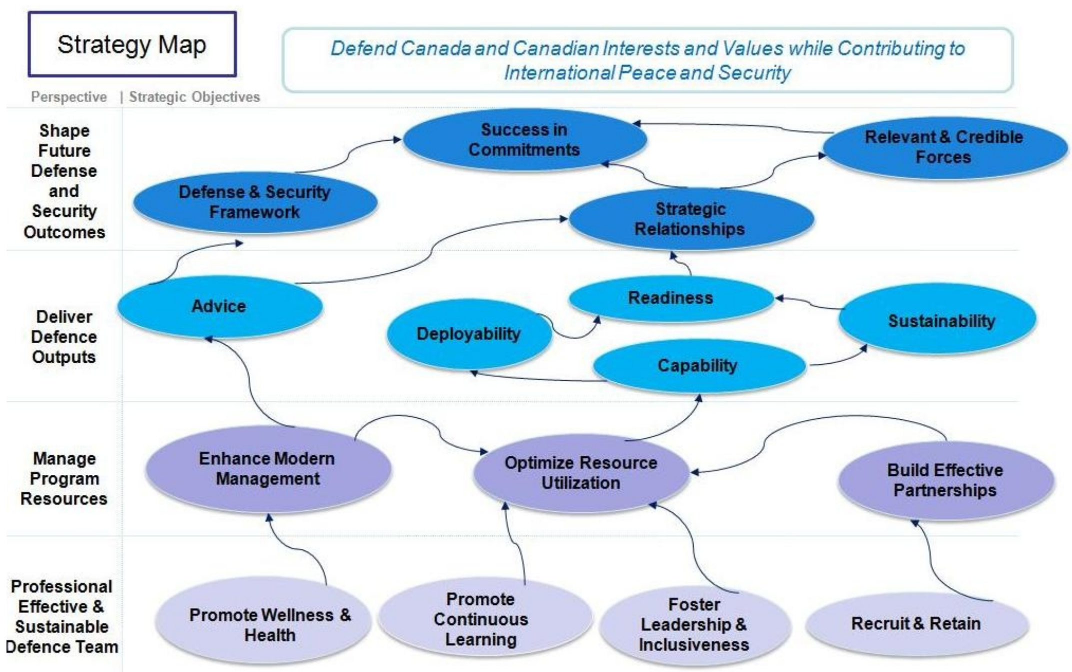


Figure 26. Strategy Map Adapted From Gillis, 2004.
Source: Balanced Scorecard Review (n.d.).

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 7 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.

Table 7. 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

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.

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.

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 8 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 IS 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.

Table 8. 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

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 updates in the future 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.

KVA can provide an objective, ratio scale measure of value and cost for each subprocess 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 ISes. 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.

Research Discussion 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 BSC, KVA and IRM. BSC and 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. Program managers 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.

- How should the methodologies be used in the acquisition life cycle to ensure successful acquisition of IS technologies?

Program managers 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 and money that 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.

Limitations and Future Research

This research examined only the 5000 series acquisition life cycle.[2] It is probable both the JCIDS and PPBE processes could benefit from the calculated implementation of some or all of the methodologies discussed. Improving one component of the Defense Acquisition Decision Support System will likely improve the outputs of the other two systems. Additional research into creating a quantifiable measure of risk will provide beneficial information that allows decision-makers to understand the probability of success for subcomponents within a project.

Future research in how the five methodologies might be useful for other areas of investment in IT and DoD acquisitions of IT might be beneficial in extending the current research study. The proposed five methodologies may be useful for researchers who are also interested in focusing on the following topics of acquisition research interest:

- Innovative Contracting Strategies—contracting at the speed of relevance (BSC, IRM)
- Breaking down silos, enterprise management (LSS, KVA)
- Rapid Acquisition and Decision Support (IRM, KVA)
- Effects of Risk-Tolerant and Risk-Averse Behavior on Cost, Schedule, and Performance (IRM, EVM)
- The Role of Innovation in Improving Defense Acquisition Outcomes (BSC, IRM, EVM)
- Applying Model-Based Systems Engineering to Defense Acquisition (IRM, KVA)
- Augmenting the Acquisition Decision Processes with Data Analytics (IRM)

[2]Given that the case studies of IT acquisitions exist in various existing data sources and written case studies, there is very little risk associated compared to the normal generation of new data sets that were required in the prior studies performed by the authors for the ARP. Access to acquisition subject matter experts (SME) at NPS reduced the risk associated in seeking other SMEs to discuss IT acquisitions and the use of the methodologies within the IT acquisition life cycle.

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