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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

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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

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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.

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. In essence, the learning time that traditionally is found in production does not exist in DoD acquisitions. Thus, the “Job Shop” size for many of these major acquisition procurements becomes a lot size of “one” due to the fact that each version of the new production is a unique procurement with customized outputs and places a higher premium on each reoccurring item. 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.

The problem is that current analysis and management tools based on continuous production are not adequate to address the evolving requirements of complex IT systems. This is a problem because acquisitions of increasingly complex IT systems require a broader set of management and analysis tools to ensure successful acquisitions in a Job Shop production context. The purpose of this study was to suggest a set of criteria for selecting management and analysis tools that could help acquisition professionals successfully navigate the acquisition life cycle of Job Shop products. This research is important because acquisition managers need a wider variety of tools to help them optimally analyze and manage their increasingly complex acquisition of IT-based portfolios.

There are several 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.

The Five Methodologies

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 on this paper is providing a brief introduction of the methodologies. For a more thorough discussion, see the full report of this research that provides a detailed explanation as well as examples of and prior research on each methodology (see Housel et al., 2019).

Lean Six Sigma

Currently employed 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 et al., 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 goal of a continuous process flow via a cycle of iterative improvement.

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 into 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; see also 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 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.

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.

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 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 et al., 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 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 (Housel & Kanevsky, 1995). Elementary changes can be represented by common units of computational complexity; see Kolmogorov complexity theory explanation in Housel and Kanevsky's (1995) original 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).

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 that 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 the 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). 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.

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 acquired. 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.

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 1 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).

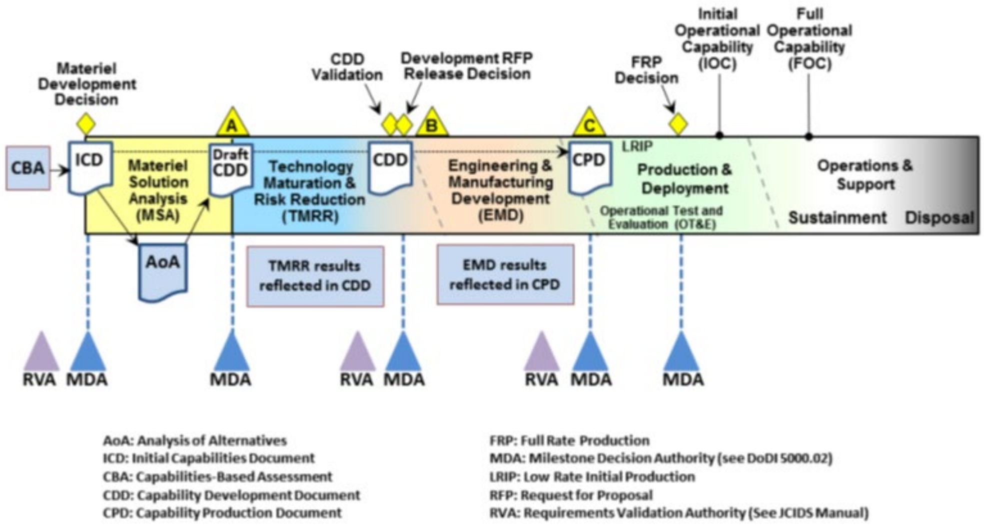

Figure 1. The 5000 Series Acquisition Life Cycle (DoD, 2017)

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 principal 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 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 2 shows the seven steps that comprise the RMF, repeating in a cyclical pattern—prepare, categorize, select, implement, assess, authorize, and monitor.

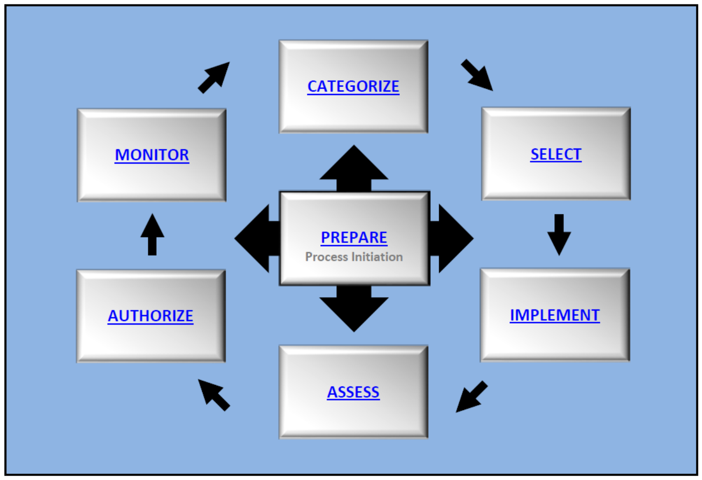

Figure 2. Seven Steps in the Risk Management Framework (Joint Task Force Transformation Initiative, 2018)

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 (see 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 et al., 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.

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 Present Value 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 information systems. 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 improve the system holistically.

Research Discussion, Recommendations, and Conclusion

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 military program managers 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 the 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 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.

In conclusion, PMs should use the approach that fits with the selection criteria and point in the acquisition life cycle (constrained by time and cost). Thus, they should use continuous production economics for mature, simple products. Furthermore, in the case of the job shop and lot size of one, economics for complex products that can be "intelligensized."[1] In the era of Great Power Competition and the race with rising powers, there is a need for a new common unit of value to track upside of value of intelligensizing military products to stay ahead, because no current methodology in use provides adequate program value to risk-based forecasting. Therefore, this study seeks to address that gap in methodology.

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)

[1] This is an operational term that the authors use to describe the processes laid out in this work.

[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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