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SYSTEMS ENGINEERING CAPSTONE REPORT

**ANALYSIS OF PROCESS, PRODUCT, AND CONTEXT
IN MILITARY ACQUISITIONS**

by

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IN MILITARY ACQUISITIONS**

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ABSTRACT

The objective of this research is to identify key factors that impact the probability of success of a military material acquisition program. These key factors are intended to be incorporated in a wargaming-type acquisition game developed by the U.S. Army Engineer Research and Development Center. This project defines a successful military acquisition as a program that achieves a successful Milestone C decision and is not terminated or restructured. Measures of potential factors related to program cost, schedule, and performance were postulated and potential data sources identified. Data were drawn from Selected Acquisition Reports to Congress. Statistical analysis was conducted using data from 79 DOD ACAT I programs to determine correlations of initial program baseline cost, schedule, and performance data. Analysis determined that the percentage of a program's Key Performance Parameters that achieve their threshold values is the strongest indicator of a program achieving a successful Milestone C decision. The output of this capstone is a methodology that can be adapted for application in evaluating probability of successful military acquisitions in other countries or to incorporate stronger leading indicators of program success if data become available for analysis. Recommendations for further analysis and data collection efforts include categorizing programs based on the urgency of need, as well as the system's technology readiness levels at program initiation.

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LIST OF ACRONYMS AND ABBREVIATIONS

ACAT	Acquisition Category
ANOVA	Analysis of Variance
CADE	Cost Assessment Data Enterprise
DAMIR	Defense Acquisition Management Information Retrieval
DAVE	Defense Acquisition Visibility Environment
DOD	Department of Defense
ERDC	Engineer Research and Development Center
FCS	Future Combat Systems
GAO	Government Accountability Office
GMR	Ground Mobile Radio
JCIDS	Joint Capabilities Integration and Development System
JTRS	Joint Tactical Radio System
KPP	Key Performance Parameter
MA	military acquisition
MS	Milestone
MDAP	Major Defense Acquisition Program
MOE	measure(s) of effectiveness
NDS	National Defense Strategy
NSS	National Security Strategy
PPBE	Planning, Programing, Budgeting, and Execution
PPC	Process, Product, and Context
R&D	Research and Development
SAR	Selected Acquisition Report
TPM	Technical Performance Measurements
TRL	Technology Readiness Level

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EXECUTIVE SUMMARY

The process of acquiring equipment and services for military applications is a complex process that involves substantial risk for the service or country executing the acquisition. Variables such as available funding resources, personnel, time to acquire, technology advancements, and system performance can impact the success or failure of an acquisition program. The consequences of unsuccessful acquisitions include lost time, wasted money, and unachieved capability that can be costly or even catastrophic. The acquisition process follows a general order of events (identifying a need, determining a solution to address the need, and producing the solution that fulfills the need), one might hypothesize that there are certain conditions or variables that can indicate whether an acquisition will be successful or not.

The U.S. Army Engineering Research and Development Center (ERDC) undertook development of a table-top game to enable better understanding of the vulnerabilities of an acquisition by evaluating the impacts of human decision-making paired with the type of product acquired, the process in which the product is acquired, and the external context factors that are a result of the acquisition process. The use of a game as the medium allows for random variables, not chosen by the players, to be injected into the gameplay which forces a decision to be made, based on the situation. For variables in the game to have validity, however, ERDC needed to understand what variables impact the success of an acquisition as well as the magnitude of the impact of the chosen variables.

This capstone project analyzed data from historical, U.S. Department of Defense major acquisition programs with the objective of determining what variables should be gamified to influence the development of a potentially successful acquisition strategy and what metrics need to be achieved to increase the probability of achieving success. To accomplish this objective, the team first established a baseline definition of a successful program as one that received a favorable decision at Milestone (MS) C and was not terminated or transitioned. Program data from the Defense Acquisition Visibility Environment (DAVE), Cost Assessment Data Enterprise (CADE), and Defense Acquisition Management Information Retrieval (DAMIR) websites was used to conduct

quantitative analysis. Statistical methods including hypothesis testing, analysis of variance (ANOVA), and linear regression were applied to the data to determine the best leading indicators of program success. The interactions between these leading indicators were explored by conducting two-factor ANOVAs. The factors that were shown to be significant were then used to create a predictive model, which was tested by conducting cross validation using an 80/20 split.

The result of our analysis was the development of a useful measure of effectiveness (MOE) for program success, which was the ratio of Key Performance Parameters (KPP) that met their threshold values. Three significant factors were shown empirically to impact the MOE – whether a program was joint or not, the program’s lead service, and the system type that was being acquired. The MOE and its related factors were used to construct a baseline predictive model capable of estimating a program’s ratio of KPPs that will achieve the threshold value. This MOE was analytically shown throughout our research to be a statistically significant data point in a program’s success or failure. By building the predictive model, the team identified an eight-step methodology that can be used to study other potential factors that might be incorporated to improve on this initial model. The steps that have been documented in this analysis provide a map for incorporating new factors, new data sets, and new MOEs for success within military acquisitions.

While the capstone team accomplished our primary objectives for the project, the team also identified areas for future research and noted challenges associated with this project. Data collection represented the greatest challenge and will inevitably play a role in future research involving the acquisition process. Due to the limitations of the data available in CADE, DAVE and DAMIR, the team was unable to include factors that they anticipated to have a significant impact on a program’s success such as the initial technology readiness level (TRL) or urgency of need for the system. Future research could build upon this methodology to explore additional factors that could also influence success. A robust effort to collect relevant data will be required to support future research on this topic. Data collection could be significantly improved if additional information is categorized and included on the annual Selected Acquisition Reports to Congress.

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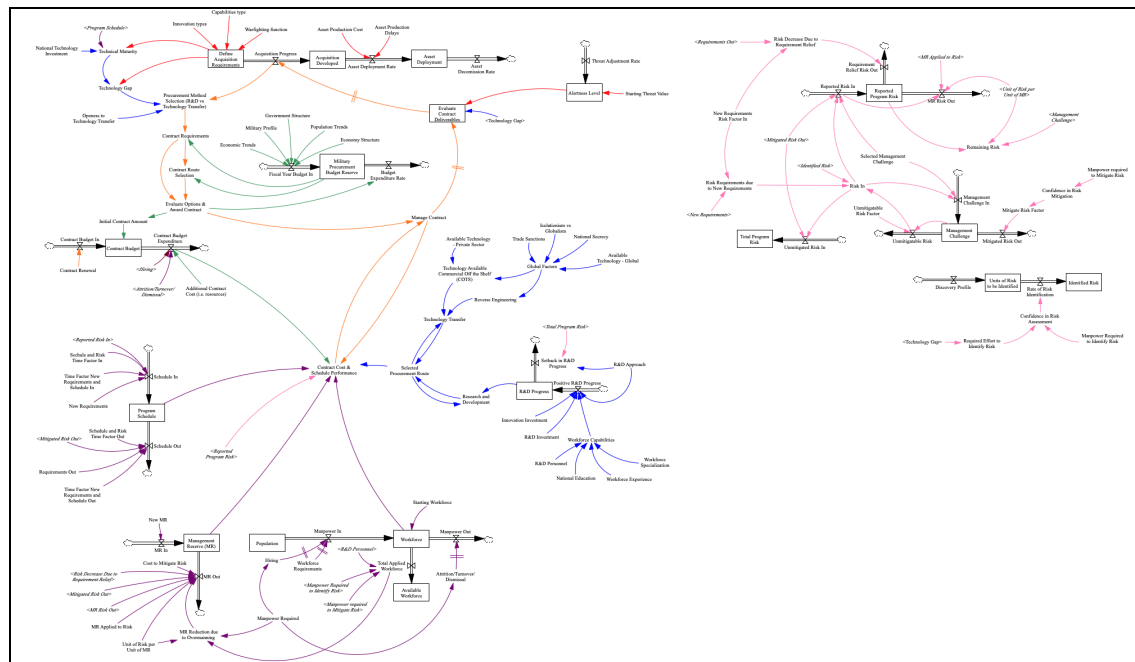
I. INTRODUCTION

A. BACKGROUND

Military acquisition (MA) is a complex process, requiring a nation to balance their funding, security strategy, technology maturity, and other variables in pursuit of desired capabilities. The U.S. Army Engineer Research and Development Center (ERDC) is currently developing a table-top game to evaluate how process, product, and context (PPC) impact the success of MAs with respect to cost, schedule, and performance. The ERDC recognizes the difficulty in modeling and simulating complex systems in which humans play a role (Ruvinsky et al. 2021). They choose a game media, as games simplify these complex processes. ERDC defined process, product, and context as the following:

1. “The product dimension defines the object of interest that is desired from the acquisition process to include definitions of the functions the military system will perform”
2. “The process dimension serves to deliver the military system specified by the product dimension”
3. “The context dimension includes any factors external to the process and product dimensions that affect a nation’s ability to acquire a new military system. Factors from the context dimension act upon the process dimension, thus slowing or hastening a nation’s ability to acquire.”
(Ruvinsky et al. 2021)

An examination of specific country data by ERDC was used to extrapolate a framework for studying the effects of PPC on the success of MAs. To facilitate the transition from an understanding of a real-world acquisitions domain space to a gamified table-top simulation, ERDC required a model to facilitate the identification of (1) relevant objects, entities, and concepts, (2) the actions that may be taken, and (3) the impact of actions on the possibility space of the simulated game. ERDC also created a system dynamics model (Figure 1) depicting the interactions of context variables.



Additionally, ERDC created a framework of context variables (Figure 2) organized by three primary routes of acquisition—commercial off the shelf, research and development, and technology transfer.

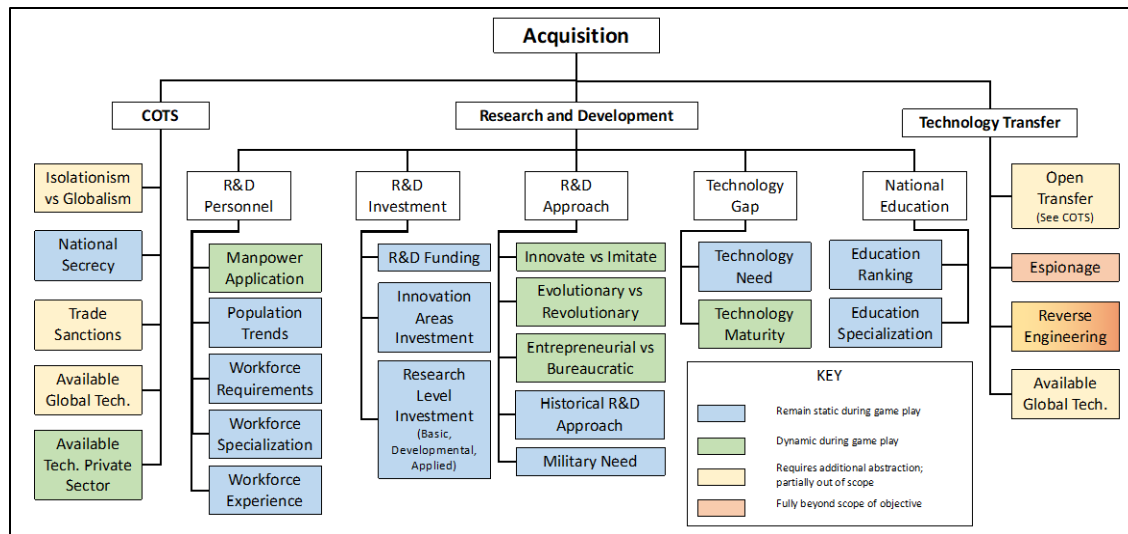


Figure 2. Detailed Framework of Acquisition Context Organized by the Three Primary Routes of Acquisition. Source: Ruvinsky et al. (2021).

Ultimately, the developed framework will be used with game theory to create and play acquisition games under instances of PPC, thus allowing for the creation of data points beyond historical cases. The game and results will be used by acquisitions research analysts to better understand and explore acquisition capabilities of various nation-states. This capstone project required the team conduct research on historical MAs, analyze factors concerning PPC, conduct a quantitative analysis of variables, and provide ERDC with an improved success-failure framework to augment future gameplay scenarios in follow on iterations of the game.

B. PROJECT PURPOSE

The purpose of this research project is not to create game elements for ERDC's effort, but to investigate the influence of PPC on historical MA initiatives to assist ERDC in development of their gaming process. The capstone project will accomplish the following objectives to meet the purpose:

1. Define program success and develop measures of effectiveness for our definition.
2. Identify common PPC factors impacting MA.

3. Conduct a quantitative analysis of the data elicited from historical MAs.
4. Identify the factors that contribute to successful or unsuccessful MAs.
5. Construct a predictive model for incorporation in ERDC's game.

C. PROJECT APPROACH

The ERDC's system of interest is a table-top game, with the goal of evaluating how aspects of PPC impact the success of MAs. ERDC provided products defining PPC and a framework of their defined variables. The scope of this capstone project included an analysis of historical MAs in the United States military to provide increased realism for ERDC's game by quantifying their steps to a successful acquisition process. Our capstone team developed a definition for a successful acquisition, developed useful measures of effectiveness (MOEs) tied to our definition of success, conducted an analysis of factors concerning PPC, conducted research on historical MA's, conducted quantitative analysis of context variables, and identified a methodology for further study of PPC that will enhance ERDC's gamification efforts and improve their framework for gameplay scenarios. The process carried out here also provides a format for analyzing other nations' acquisition processes and will provide for expansion of ERDC's table-top game.

D. RESEARCH QUESTIONS

Our primary research question was: What measurable factors in MAs can be used to quantify the probability of a successful acquisition strategy and then be used as an input to ERDC's gamification efforts?

In addition, the team identified three supplementary research questions:

1. How is MA success defined in terms of cost, schedule, and performance?
2. How can context be used as a gamification input in MAs?
3. How do context variables correlate with MA success measures?

II. LITERATURE REVIEW

A. GAMIFICATION

1. What is Gamification?

The use of games and gameful experiences in everyday situations has risen tremendously over the last few decades. Video games can be found in many facets of our lives, from Xbox and PlayStation consoles in living rooms and bedrooms to game applications on our cell phones. Our youth are exposed to gaming environments almost as soon as they can focus on a screen with educational programs taking advantage of the medium. Games provide a user engagement experience that other sectors, such as education and industry, can employ to engage students and workers more deeply in other life activities, thus “gamifying” ideas and technology was born.

The terms “gamification” or “gamifying” have definitions that vary widely amongst scholarly articles and various works, with disagreements over the interpretations and oversimplification of the meanings and context of the terms. In fact, there have been at least three published works (Deterding 2011; Werbach 2014; Huotari and Hamari 2017) dedicated solely to defining the term(s) alone from 2011–2017. Deterding et al. surveyed existing published research on the subject to produce an accepted definition of “gamification” and produced the following: “the use of design elements characteristic for games in non-game contexts” (Deterding et al. 2011). Werbach more simply defined gamification as “the process of making activities more game-like” (Werbach 2014). Huotari and Hamari (2017) defined the term through the lens of service marketing as “a process of enhancing a service with affordances for gameful experiences in order to support users’ overall value creation.” The definition produced by Deterding et al. best fit our sponsor’s objectives of and framed the way our team approached this capstone project.

2. Where is Gamification Most Commonly Used?

A 2014 review by Hamari, Koivisto, and Sarsa of 24 empirical studies showed that 9 of the 24 gamification contexts were geared towards education or learning. The second and third most common contexts were Intra-Organizational Systems and Work, each with

four studies (Hamari, Koivisto, and Sarsa 2014). An example of this type of educational context would be the ABCMouse application that is designed to teach educational foundations to children between the ages of two and eight years old. Kids earn tickets by completing activities such as tracing letters or counting and can then buy items in the game such as pets or accessories for their avatar. This application aligns with Kapp's statements (2014) that educational gamification differs from learning games that have a defined start and finish. Educational gamification is delivered in short increments to a learner's mobile device and uses game elements as rewards for completing lessons.

In a work setting, gamification has been used in Information Systems development to motivate the users, or employees of companies. Fernandez et al. (2012) discusses a web-based program for conducting collaborative requirements elicitation that is called "iThink." The program presents the requirement generation process as a game in which players are rewarded for generating and analyzing new and existing requirements. iThink engages its users by awarding points for various aspects of the requirements generation process, with the hardest tasks being awarded the most points. All the requirements generation team members can see their ranking amongst their contemporaries to generate a competitive environment.

Games can help simplify complex systems, such as system acquisition, for analyses. "Beer Game," developed at the Massachusetts's Institute of Technology's Sloan School of Business in the 1960s, simplified the management of a beer supply chain by identifying significant variables and ignoring the rest for gameplay (Sterman 1992). Significant variables are elements of the system that have the greatest impact on success or failure. We will follow a similar process in support of the acquisition game for ERDC.

3. Why is Gamification Effective for Motivation?

The source of the effectiveness of gamification is another broadly defined and often debated topic. What motivates one person is often vastly different from the next, but there are common psychological factors that motivate most humans. Research into motivation (Astleitner 2000) has identified six principal perspectives that are "relevant in the context of gamification: the trait perspective, the behaviorist learning perspective, the cognitive

perspective, the perspective of self-determination, the perspective of interest, and the perspective of emotion.” Of these perspectives, the self-determination perspective encompasses a broad range of motivational mechanisms that have already been successfully applied in the context of games (Sailer et al. 2017). “Within self-determination theory, three basic psychological and intrinsic needs are postulated: the need for competence, the need for autonomy, and the need for social relatedness” (Ryan and Deci 2002). According to Sailer et al. (2017):

1. The need for competence refers to the desire to gain skills and master tasks that are relevant to a person’s environment. When people feel they have achieved a mastery of their required skills, they are more likely to set out and achieve their goals.
2. The need for autonomy refers to doing something not because you are told to do it, but because you want to do it. This allows for the sense of choice and when the choice belongs to the person executing, they have more “buy in” to the decision.
3. The need for social relatedness refers to a person’s need to have a sense of belonging to or contributing to a group.

When gamifying something, a process, operation, or activity for example, Sailer et al. (2017) identified seven typical game design elements that can be related to the psychological needs above: (1) points, (2) badges, (3) leader boards, (4) performance graphs, (5) meaningful stories, (6) avatars and (7) teammates (Sailer et al. 2017). Sailer et al. (2013) and Hence et al. (2014) found the “need for competence can be addressed by points, performance graphs, badges, or leaderboards.” Points provide feedback to the player that lets them know their actions were correct; performance graphs provide feedback over a period of time; badges and/or leaderboards let the player know how their progress compares to others (Rigby and Ryan 2011). The feedback function of these game design elements makes the player feel competent, as they let the player know if their actions were successful or not.

Meaningful stories and avatars are game design elements that address the need for autonomy. Whether a game is a first-person shooter, an action-adventure, or a sandbox genre, a meaningful story helps players experience their decisions and the actions that result from those choices. In some games, the player can choose an avatar or character to represent themselves however they like. This freedom of choice fulfills another aspect of the need for autonomy.

The elements of teammates and meaningful stories address the need for social relatedness. “Together with teammates, who can be real co-players or nonplayer characters, a sense of relevance can be evoked by emphasizing the importance of the players’ actions for the group’s performance. A shared goal, which can be conveyed within a meaningful story, can also foster experiences of social relatedness” (Sailer et al. 2017).

B. ACQUISITION CHARACTERISTICS

1. Characteristics of Terminated Acquisition Programs

To effectively identify the critical factors that impact Major Defense Acquisition Programs (MDAP), it is important to conduct a retrospective review of failed programs in addition to identifying the characteristics of successful programs. Many researchers have attempted to identify factors that contribute to failed programs. In many cases, failed programs offer an opportunity to conduct a post-mortem in attempts to codify lessons learned, identify what successes came out of a program, and what factors led to failure.

In addition to cost, schedule, and performance, researchers have identified other areas that ultimately influence a program’s fate. Some of these factors include the project management team, contracts, planning attributes, the stakeholder environment, risk mitigation, communication, technology readiness level (TRL), and contractor (Clowney, Dever, and Stuban 2016). Our research delves into multiple failed acquisition programs to identify common threads between prior research and case studies to attempt to find viable gamification inputs. To establish some root causes of failure in MDAPs, we examine three well known failures: Future Combat Systems (FCS), Joint Tactical Radio System (JTRS), and Comanche Helicopter. FCS, JTRS, and Comanche helicopter were three failed MDAPs undertaken by the U.S. Army, costing an estimated combined total of \$35.9B before these

programs were ultimately cancelled and deemed failures (Clowney, Dever, and Stuban 2016).

The FCS was the most ambitious program ever undertaken in Army acquisitions, and consisted of 18 systems including manned and unmanned systems, munitions, and sensors all connected via a wireless network (Pernin 2012). The program was planned to cost approximately \$200B and was envisioned to change the way that the Army fights future wars (Pernin 2012). The robust nature of the FCS program and the program's massive budget led to significant congressional oversight throughout the program's life. Numerous Government Accountability Office (GAO) reports examined the program at various stages of its life cycle. In 2008, a GAO report found that requirements definition was still fluid, critical technologies were immature, software development was still in its early stages, and many complementary programs were exhibiting schedule risk (Francis 2008). Cost, schedule, and performance risks were expected issues in failed programs, but the other findings were interesting and worth exploring in other major failed MDAPs. The issues found in the 2008 GAO report ultimately contributed to the program's cancellation in 2009; however, some initiatives continued as follow-on programs (Pernin 2012).

A second major acquisition failure was the Joint Tactical Radio System (JTRS). JTRS was a transformational communications network planned to allow warfighters and support personnel to transmit a wide variety of data across a wireless network (Gansler 2012). The JTRS program was ultimately cancelled in 2011, failing to deliver the required capability to the warfighter. A GAO report from 2003, while the JTRS program was ongoing, identified several major issues and challenges. Radios for air and ground platforms were allowed to proceed into the Systems Development and Demonstration phase without meeting recommended TRLs (GAO 2003). Additionally, other technologies including miniaturized components were found to be immature and likely to push the program off schedule by a year or more (GAO 2003).

A 2003 GAO report noted challenges with the JTRS program and estimated that 250,000 JTRS radios were expected to cost \$14.4B (GAO 2003). As the program continued and problems mounted, the cost of the program continued to balloon. By 2011, it was estimated that 194,000 JTRS radios would cost more than \$23B, which ultimately

contributed to the program's cancellation (Gansler 2012). This program is another example of ill-defined requirements, changing customer needs, and immature technology playing a significant role in the decision to cancel the program without getting the required capability to the warfighter.

Problems were identified and addressed throughout development of the JTRS. The program was a high visibility program that aimed to transform communications. As such, the program received significant management attention (Porter et al. 2009). The JTRS-Ground Mobile Radio (GMR) did not have a MS A review, rather decision makers held the general belief that the technology was ready to advance (Porter et al. 2009). A final factor in the failure of the JTRS program was continued advancement despite concerns with TRLs. JTRS-GMR passed MS B without any of its 20 critical technologies reaching TRL 6 and several below TRL 4 (Porter et al. 2009).

The Army's modernization program to field an advanced helicopter, the Comanche, is another well-known program worth examining. The RAH-66 Comanche Scout/Attack helicopter is an interesting case study because it was terminated by the Army itself instead of Congress or Department of Defense (DOD) oversight (Demotes-Mainard 2012). The Comanche program existed in development for 20 years. The program started as the focus of Army modernization at the end of the Cold War, however over time it transitioned from the number one modernization priority to a termination that occurred without serious opposition (Demotes-Mainard 2012).

The Comanche program consumed \$6.9B over 20 years and included sensor integration, increased agility, and low-observable technology that surpasses anything in the inventory today (Demotes-Mainard 2012). The factors that led to the cancellation of the Comanche program vary greatly from the programs previously discussed. While the previous programs were cancelled by Congress and DOD oversight, this program was terminated from within for a variety of reasons.

The Comanche program was initiated in a time where stealth technology was thought to be of the utmost importance, particularly due to the ongoing Cold War (Demotes-Mainard 2012). The breakup of the Soviet Union in 1991 resulted in a

dissolution of the consensus between the DOD and the Army on the need for such an aircraft (Demotes-Mainard 2012). With the Soviet threat diminished, changes to the concepts of future war, and pressure to rationalize the budget, the program began to lose favor, ultimately resulting in its cancellation because the capability was determined to no longer be needed. This is an example of how major programs that include long lead times can be affected by the constantly evolving threat environment.

Numerous studies have been conducted to identify factors that contributed to a program's failure. These studies have varied in size and scope, with some focusing on MDAPs and others taking broad view of defense acquisitions. Software plays a major role in many modern defense acquisition programs. Software is now an inherent part of most acquisition programs, and software is subsequently partly responsible for driving system cost and schedule overruns (Brownsword et al. 2013).

Brownsword et al. studied several defense acquisition programs that included both hardware and software components and identified seven repeatable patterns of failure. These failed programs repeatedly failed to adequately address the following:

1. Document business goals
2. Resolve conflicts between goals
3. Change to adapting needs
4. Accommodate turbulence in the acquisition environment
5. Give due consideration to software needs
6. Use appropriate acquisition strategies
7. Understand and use software quality attributes to create the architecture.

(Brownsword et al. 2013)

There are many reasons that a program can ultimately fail. Upon review of several major program failures and a review of broader research into MDAP failures, there are several recurring points. First, the scope of the program is important. For broad programs like FCS and JTRS, the structure of the program office is critical. These broad programs attempted to incorporate multiple new technologies and end items while ensuring

interoperability with existing systems and required interoperability. Second, the requirements need to be clearly defined and understood prior to achieving MSs. A third and final recurrent theme throughout the research was programs advancing when they clearly did not meet TRLs (GAO 2003; Pernin 2012). Research into software acquisition challenges reiterates these points. These three factors are possible inputs into the acquisition game that can help identify whether an acquisition will be a success or failure.

2. Characteristics of Completed Acquisitions

Program success is dependent upon the defined need or capability gap being in line with strategic guidance and approved by the Joint Capabilities Integration and Development System (JCIDS), development of an acquisition strategy that aligns all stakeholders toward the overarching goal, and political support that endures throughout the acquisition life cycle. The meaning of “program success” could vary greatly, whether it is to what degree a program met the initial estimates of cost, schedule, and performance, or simply if the program avoided cancelation before achieving the goal of delivering a needed capability to the warfighter. This study’s definition of program success is the latter, delivering a capability to the warfighter. Determining what critical factors are consistent across successful DOD acquisition programs requires looking deeper than the triple headed constraints of cost, schedule, and performance. It requires a more detailed look into programs that led to the successful procurement of the capability the program was built to deliver. GAO reports show cost overruns and schedule slips for every major program and yet, despite these setbacks, many programs continue to reach the success threshold of procurement.

Recent examples of major programs that were/are mired in cost and schedule woes but were still able to successfully navigate the acquisition process to procurement are the F-35 Joint Strike Fighter, the Littoral Combat Ship, and V-22 Osprey (Sullivan 2009). These programs overcame problems and share a common set of critical success factors (GAO 2012, 2016). All successful programs must navigate what the *Defense Acquisition Guidebook* calls “the Big A,” which consist of three separate but interconnected systems. The JCIDS is primarily about requirements development and validation. The Planning,

Programing, Budgeting, and Execution process (PPBE) is the resourcing portion of Big A and heavily tied to the political realm, budgetary cycles, and the National Security Strategy (NSS). Finally, the Defense Acquisition System (Defense Acquisition Guidebook 2004) is all about the acquisition process, where the MS decisions and scheduling occur. The three most salient critical factors shared amongst successful programs are that they all began with an identified and clearly communicated warfighter capability need or gap. This is followed by a thoughtfully designed acquisition strategy that is tailored to the capability being developed. And finally, they maintain the necessary funding from political support throughout the acquisition life cycle.

The identification and communication of a critical capability gap that has the potential to inhibit the Warfighter's ability to accomplish his mission or represents national security implications is a critical factor for program success. The sustainment of Joint Force military advantages is a priority objective written into the National Defense Strategy (NDS) that is nested within the NSS (Department of Defense 2018). Modernization is a key component in both the NDS and NSS; this fact allows for Congress and DOD leadership to be more lenient with cost overruns and schedule slips for programs that are supporting approved JCIDS requirements. The *Defense Acquisition Guidebook* describes the JCIDS process as the systematic method identifying, assessing, validating, and prioritizing Joint military capability requirements (Defense Acquisition Guidebook 2004). An approved JCIDS requirement is a critical factor for program success. The V-22 Osprey is an excellent example of a program plagued with problems, ballooning costs, immature technologies, and multiple delays, but it survived to be a successful program in large part because of the capability it was delivering to the joint force (Co 2009).

Consistency of the requirements is an important factor as well. A program initiated from an "ill-informed requirement virtually mandates changes to contracts as requirements are added or changed" (Fox 2011). There are many variables that can affect requirements especially for the long development processes of major programs. Congressional support, changes in technology, current and future threats all can weigh on a program's requirements (Fox 2011). But even despite changes to requirements, programs that address

vital capability gaps are successful because they are executing within strategic guidance supported by the NSS and NDS.

The *Defense Acquisition Guidebook* states a program's success relies on the Requirements Manager's ability to communicate the capability need and gaps to the Material Developer and partner with them to define what is expected in terms of requirements. This is accomplished through the creation of the acquisition strategy. The Acquisition Strategy is a statutory requirement for MDAPs at MS A and a well thought out, tailored acquisition strategy is a critical factor for a program's success.

The acquisition strategy is a thorough, wide-ranging strategy that characterizes and explains the acquisition approach to manage risks within the program and meet program goals throughout all phases of the acquisition life cycle. It aligns all stakeholders toward a common objective. A program's success hinges on the principal concepts and business practices that are established in this strategy. A survey of literature on acquisition success factors conducted by Kenneth Delano found that the most prevalent factors were "well defined requirements" and "acquisition strategy" (Delano 1999). Delano's study reviewed over 25 sources and he compared his work with a similar study that supported his findings. Within the acquisition strategy is the program's contracting strategy which is a vital tool for setting conditions for success. The contracting strategy describes the plan to effectively manage contract administration to achieve the program's goals. Efficient contract administration provides the leadership of the program the ability to incentivize and monitor the contractor's performance, as all parties work together to provide the capabilities the government needs (Rendon n.d.).

The PPBE process is the most political of the three "Big A" systems. The output of the PPBE is the DOD funding proposal for inclusion in the President's Budget for submission to Congress (Defense Acquisition Guidebook 2004). All funds for defense programs are authorized and appropriated by Congress. While the various funding types are approved for different lengths of time, the appropriations that occur in Congress mean that political support is vital to the success of a major program (Fox 2011). Political, budgetary, and operational (both adversarial and friendly) factors contribute to instability for a program. The Joint Strike Fighter and other successful programs garnered political

support by dispersing the production and manufacturing across many congressional districts and even extended the supply chain into partnered nations (Co 2009). In fact, Lockheed Martin's website boasts of the F-35's economic impact in 48 states. The prevailing wisdom here is that congressional members are more likely to support funding defense programs that bring jobs to their districts. For this reason, political support is a critical success factor. Political support for programs and specifically congressional leniency with cost and schedule overruns can also be attributed to the need for a healthy defense industrial base. This is a critical element of U.S power and is explicitly stated in the NSS (White House 2017).

Successful programs are able to effectively synchronize the program's performance requirements, budgetary constraints and execution of the plans and objectives contained in the acquisition strategy (Defense Acquisition Guidebook 2004). Cost, schedule and even performance issues can be overcome by programs that 1) possess a defined need or capability gap being in line with strategic guidance and approved by JCIDS, 2) an acquisition strategy that aligns all stakeholder toward the overarching goal, and 3) political support that endures throughout the acquisition life cycle.

C. MEASUREMENTS

1. The Importance of Metrics

Decision-making is inherent in project management and the defense acquisition environment, whether in analyzing alternatives or managing risk. Measurements aid these decisions by providing information to decision-makers. Hubbard (2011) defines a measurement as a "quantitatively expressed reduction of uncertainty based on one or more observations" and argues that anything that can be observed can also be measured. Metrics are direct numerical measures that represent a piece of data in the relationship of one or more dimensions. Metrics are observable and recordable in ordinal and nominal data tables, ranges/sets of value, simulation, statistics, calibration estimates and confidence limits, decision models, sampling techniques, and decomposition techniques (Kerzner 2017). The DOD's *Risk Management Guide for DOD Acquisition* promotes metrics as a useful risk

management tool (Simpleman et al.1998). Hubbard lists three reasons for why we care about measurements:

1. Measurements inform key decisions.
2. Measurements may have a market value and could be sold for profit (e.g., results of customer surveys).
3. Measurements may entertain or satisfy a curiosity.

Hubbard's work on measurements is often compared to "decision analysis," which he embraces. He argues:

1. Decision-makers usually have imperfect information (i.e., uncertainty) about the best choice for a decision.
2. These decisions should be modeled quantitatively because quantitative models have a favorable track record compared to unaided expert judgment.
3. Measurements inform uncertain decisions.
4. For any decision or set of decisions, there is a large combination of things to measure and ways to measure them—but perfect certainty is rarely a realistic option.

Although anything can be measured, measurements and their analysis come with an associated cost. This makes determining the "what, how, and whether" to measure something an economic decision. We must focus on measuring what matters to make better decisions (Hubbard 2011).

2. Program Management Metrics

Pisano, Rad, and Ginger (2006) studied program management measurements and their importance in the overall success of a program. Using technical performance measurements (TPM), earned value, and risk management techniques, probabilities of success can be calculated and identified early on in acquisitions. Figure 3 represents the TPM Methodology created during retrospective research on several federal procurements.

In using the TPM method in conjunction with risk analysis and probability, the likelihood of collecting relevant and useable data increases which can lead to cost avoidance (Pisano 2002).

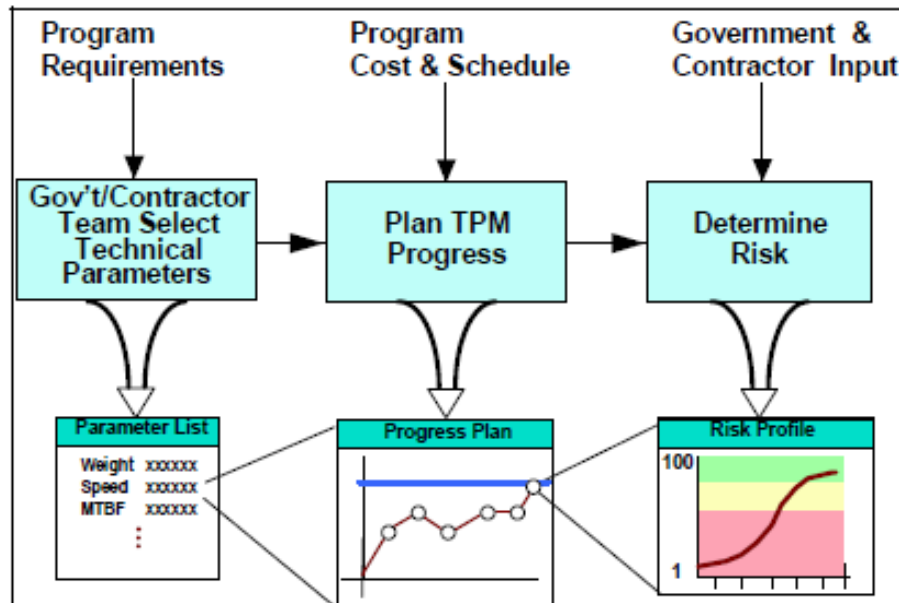


Figure 3. TPM Methodology Overview. Source: Pisano (2002).

There are multiple benefits when it comes to the analysis of program management metrics. A significant benefit of a structured and controlled metrics identification and collection program is that it should reduce biases while providing a transparent view of the performance of the program (Rad and Ginger 2006).

Engineers from MITRE supported the analysis and collection of leading indicators within systems engineering activities for a DOD customer. While not all inclusive, the metrics identified within Table 1 represent significant areas which impact overall success of acquisitions (MITRE 2014). While many of the detailed metrics may appear to be similar, they will be assessed differently within their indicator areas.

Table 1. Leading Indicators. Source: MITRE (2014).

Leading Indicator Area	Detailed Metrics	Measurement Comments
Program Resources	Required Staffing Applied Appropriate Skills Applied Churn Rate Training Available	Staffed to at least 80% according to plan Ideally churn is less than 5% per quarter
Requirements	Volatility/Impact	Low volatility (< 5%) can still be a problem if the changing requirements have a large impact to the cost and schedule
Risk Handling	Trend Appropriate Priority Applied	Are the risks coming to closure without significant impact? Alternatively, are there more risks being created over time? Are resources being applied to the risk? Is there appropriate engineering and PM oversight?
Interoperability	Community of Interest Established and Active Data Sharing Addressed Network Accessibility	Ideally, a data sharing plan exists for members of the COI and addresses the data formats, visibility / discovery (to include metadata), and plan for exposure.
Software Development	Sizing Quality Productivity Defects	(These are fairly standard metrics—for more information on software metrics, see NIST Special Publication 500-234.)
Technology Readiness	Technology Readiness	TRL of at least 6
Risk Exposure	Cost Exposure Schedule Exposure	15% deviation indicates high risk.
Verification & Validation	Complete Requirements Documentation Requirements Test Verification Matrix (RTVM) Verification and Validation (V&V) Plan	The degree of completeness and volatility of these items is the measurement.

Leading Indicator Area	Detailed Metrics	Measurement Comments
Watchlist Items (Risks)	Severity Closure Rate	As opposed to the risk handling metric above, this one looks at the severity of the risks—which ones are likely to occur with a med-high impact to the program.

Our review of gamification, acquisition characteristics, and measurements prepared the team for creation of the methodology and identification of relevant variables used within our project. Through a better understanding of gamification and its uses, our team was able to categorize useful metrics to assist with ERDCs game development. In addition, a thorough understanding of characteristics within both terminated and completed acquisition programs helped identify critical factors and allowed further exploration of them.

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III. CAPSTONE METHODOLOGY

A. PROJECT OBJECTIVES

The purpose of this research project was to investigate the influence of PPC on historical MA initiatives. The team conducted research on historical MAs, conducted an analysis of factors concerning PPC, developed a definition for a successful acquisition program, developed useful measures of effectiveness tied to our definition of success, conducted quantitative analysis of context variables, and provided ERDC with a framework for developing a predictive model for a success measure in follow-on iterations of their gamification effort. Five objectives were accomplished to meet the purpose of this research project:

1. Define program success and develop measures of effectiveness for our definition.
2. Identify common PPC factors impacting MA.
3. Conduct a quantitative analysis of the data elicited from historical MA
4. Identify the factors that contribute to successful or unsuccessful MA
5. Construct a predictive model for incorporation in ERDC's game.

B. MEASURES OF EFFECTIVENESS METHODOLOGY

Prior to beginning quantitative analysis, preparatory work was conducted to set appropriate conditions. This preparatory work included building a definition of success, identifying common PPC factors that may influence the success of MA, collecting data, formatting data, and developing potentially useful measures of effectiveness (MOEs).

1. Definition of Successful Acquisition

To achieve our research objectives, we first defined a successful MA in terms of cost, schedule, and performance. The definition of success driving for the purposes of this study was that a program received MS C approval. This definition coincides with ERDC's understanding of a successful acquisition. The ERDC's game concludes when a system is

deployed, meaning that the capability has received MS C approval and will begin production. This definition is concise and is directly relevant to the goal of an acquisition initiative, delivering capability to warfighters.

2. Identify Common PPC Factors Impacting MA

The next step in the team's approach to meet our project objectives was identifying common PPC factors that could potentially impact MA initiatives. Information from an in-depth literature review of historical acquisition initiatives along with the team's experience in program offices facilitated development of a list of potentially significant PPC factors. Our initial analysis resulted in a wide variety of context variables that included factors in the categories of cost, schedule, and performance, as well as other factors such as urgency of need, TRLs, and level of support. Our next step was to collect data and verify which of these factors had data available for quantitative analysis.

3. Collect Data

With an understanding of the PPC variables we believed would impact a MA in terms of our definition of success, the team began conducting data collection. Data collection was conducted by utilizing the DAVE and DAMIR databases for the majority of schedule, performance, and program administrative data. Simultaneously, the team collected cost data on Acquisition Category (ACAT) I programs from CADE. These three websites extract data from annual, Selected Acquisition Reports (SAR) and compile them into repositories for analysis.

The team only collected data that met the scope of the study, which focused on new acquisition initiatives for technology systems. Programs that were system upgrades, sustainment efforts, or strictly research and development (R&D) efforts were eliminated. These steps resulted in a total of 79 programs remaining for analysis. This helped to ensure that results from this effort and consequent recommendations were appropriate for ERDC's intended use in the acquisition game.

4. Quality Control and Data Format

Results of the data queries were combined into a common data set in Microsoft Excel. Referencing historical information regarding MA initiatives, the team examined the available data and eliminated variables that could not reasonably be assumed to have a relationship with program success. This initial screening resulted in 20 variables in the categories of cost, schedule, performance, and administrative program data (Table 2).

Table 2. Cost, Schedule, Performance, and Administrative Factors

Cost	Schedule	Performance	Program Administrative Data
Average Procurement Unit Cost (Baseline)	Number of Years with a Breach	# of KPPs	Joint (Y/N)
Total Quantity Required (Baseline)	Total Number of Scheduled Years	# KPPs that met Threshold	Lead Service
Cost Breach (Y/N)	Schedule Breach %	# KPPs that met Objective	Reached MS C
Total Program Cost (Baseline)	Schedule Breach (Y/N)	Ratio of KPPs that met Threshold	Terminated (Y/N)
R&D \$ (Baseline)		Ratio of KPPs that met Objective	System Type
R&D % of Program Cost (Baseline)			

The cost category included six variables. These were cost per unit at initial program baseline, the total quantity required, whether the program experienced a cost breach, the baseline total program cost, the baseline R&D budget, and the R&D percentage of baseline program cost. Schedule variables included the number of years with a schedule breach, the total number of scheduled years reported by SARs, the percentage of years with a schedule breach as determined by years with a breach divided by total number of program years, and whether there was a schedule breach. The performance category consisted of data for the total number of KPPs, the number of KPPs that met threshold values, the number of KPPs that met objective values, the ratio of KPPs that met the threshold, and the ratio of KPPs that met the objective. The program administrative data included whether a program

was joint, whether the program reached MS C, whether the program was terminated, the lead military service, and the system type being acquired.

The team recognized that several variables in the data set were categorical in nature. To develop a predictive model, which would likely be a regression model, the team identified a reference value for each categorical factor. Inducting dummy variables for the remaining values for the factor enabled the development of a linear regression model. For the categorical variable “lead service,” as an example, the reference variable would be Army and would not be explicitly identified as a variable, while the other military services would be identified with dummy variables. (Pardoe, 2012).

5. Develop Potentially Useful Measures of Effectiveness

The team determined next if any of the variables could be used directly as a MOE for success. There were three potentially useful MOEs: R&D funds percentage of baseline program cost, schedule breach percentage, and the ratio of KPPs that met threshold. These MOEs would be used as the dependent variables in the analysis in Chapter IV.

C. STATISTICAL ANALYSIS AND PREDICTIVE MODEL DEVELOPMENT

The team took a seven-step approach to our statistical analysis and development of the predictive model.

1. Hypothesis Testing

The team first applied hypothesis testing to screen out MOEs that were not indicators of a successful program. The set of programs were divided into two groups: successful (received approval at MS C) and unsuccessful (did not receive approval at MS C). The team tested if the average MOE for each group was significantly different. If the average MOE was significantly different between the two groups, then the MOE was kept for continued analysis. Otherwise, the MOE was discarded.

2. Visual Analysis

The team then used visualization techniques to identify any possible linear relationship between the MOEs and the variables in the data set. Visualization provides initial insights for developing a mathematical expression for strong relationships. Individual analysis could also further screen out factors that do not indicate any relationship to the MOE.

3. Single Factor ANOVA

Next, the team conducted single factor ANOVAs to understand which factors were statistically significant in terms of their impact on each MOE. The ANOVA offers statistical evidence that changes in the values of the factor influenced the value of the MOE.

4. Initial Main Effects Regression Model

The team constructed a predictive model using only main effects. Regression analyses provided an understanding of which main effects should remain in the model. The initial model development incorporated seventeen (17) factors. The results would show the amount of variance of the MOE that the model could explain. Analysis would direct the development of a more parsimonious model that would explain more of the MOE variability, while increasing the tractability of the model, for instance to reasonably explain how the changes in the main factors would change the MOE.

5. Explore Interactions Terms via Two-Factor ANOVA

The initial predictive model consisted only of main factors. It is reasonable to believe that some of the factors were correlated, therefore requiring interaction terms be part of the model. To examine this possibility, the team employed two-factor ANOVA to identify any significant two-way interactions for inclusion in the final model. Similar to single factor ANOVA, two-factor ANOVA provides statistical evidence that simultaneous changes in factor values influence changes in the MOE.

6. Model Development and Cross-Validation

The final step in the process was to conduct cross-validation on the model. This was accomplished by randomly selecting 20% of our programs and removing them from the database. The remaining 80% of acquisition programs were then used to build the predictive model. This model was then used to predict the outcome of the 20% of programs removed from the dataset to analyze the validity of our model.

7. Residual Analysis

Residual analysis was conducted to assess the appropriateness of the linear regression model. The residual analysis was conducted visually and statistically to ensure that the residuals exhibited the assumptions for developing a regression model.

IV. ANALYSIS AND FINDINGS

A. ACQUISITION PROGRAM DATA

Data collection consisted of examining past and ongoing acquisition programs from a variety of sources. DAVE included many spreadsheets compiled from SARs submitted between 1998–2020. These SARs and subsequent spreadsheets provided the most detailed information available on a wide breadth of acquisition initiatives for study. After initial data collection, the team had information from 211 historical U.S. ACAT I programs. The next step was to format the data and organize the spreadsheet for quantitative analysis. The information extracted from DAVE and DAMIR was compared against the information from CADE. Any programs that did not have data in both spreadsheets were deleted to ensure completeness of cost, schedule, performance, and administrative program data. This resulted in a data set of 79 programs for analysis. The resulting Excel spreadsheet was used to conduct analysis. See Appendix A.

B. T-TEST HYPOTHESIS TESTING TO IDENTIFY USEFUL MEASURES

The means of a useful MOE should be statistically different between successful and unsuccessful programs. We separated programs in the data set into successful programs and unsuccessful programs. We conducted a simple analysis of the averages for programs pooled as successful and those pooled as unsuccessful to identify a statistical difference. The general formulation of the hypothesis test follows.

$$H_0: \mu_A = \mu_B$$

$$H_{alt}: \mu_A \neq \mu_B$$

We ran each MOE through a t-test to determine whether there was a difference in means between successful and unsuccessful programs using the following null and alternative hypotheses:

$$H_0: \mu_{\text{successful programs}} = \mu_{\text{unsuccessful programs}}$$

$$H_{alt}: \mu_{\text{successful programs}} \neq \mu_{\text{unsuccessful programs}}$$

T-tests were run in Excel using $\alpha=0.01$ and we compared the test statistic against the t-critical value which allowed us to determine if there was a statistically significant difference in means. Results with a test statistic greater than the t-critical value indicate a difference in means and leads us to reject the null hypothesis as there is enough evidence to support the alternative hypothesis. Results with a test statistic less than the t-critical value indicates no difference in means and leads us to fail to reject the null hypothesis as there is not enough evidence to support the alternative hypothesis. The results of the t-tests of each MOE are shown in Table 3. A statistically significant difference in means was found in the MOEs “ratio of KPPs that met threshold” and “schedule breach ratio,” indicating that these two MOEs were useful for further analysis and possible development of a predictive model.

Table 3. T-test Hypothesis Testing Results

MOE	T Stat		T Critical
Ratio of KPPs that met threshold	4.066	>	1.894
Schedule Breach Ratio	2.613	>	1.859
Cost Ratio	1.393	<	1.894

Based on our acquisition experience, we believed that these were useful measures of effectiveness with one measure each representing cost, schedule, and performance. These MOEs exhibit characteristics of good measures because they are measurable by the compiled data set, reliable as they are sourced from congressionally mandated annual reports and are operationally practical as they represent a programs performance and schedule.

C. VISUAL ANALYSIS

We visually analyzed scatter plots between MOEs versus the individual factors. Figure 4 is one example. The display shows the ratio of KPPs that met threshold along the

Y-axis versus the ratio of R&D money to the total program baseline cost along the X-axis. This example demonstrates a visual comparison resulting in no definitive relationship between MOE and factor. We continued this process with other factors with similar results.

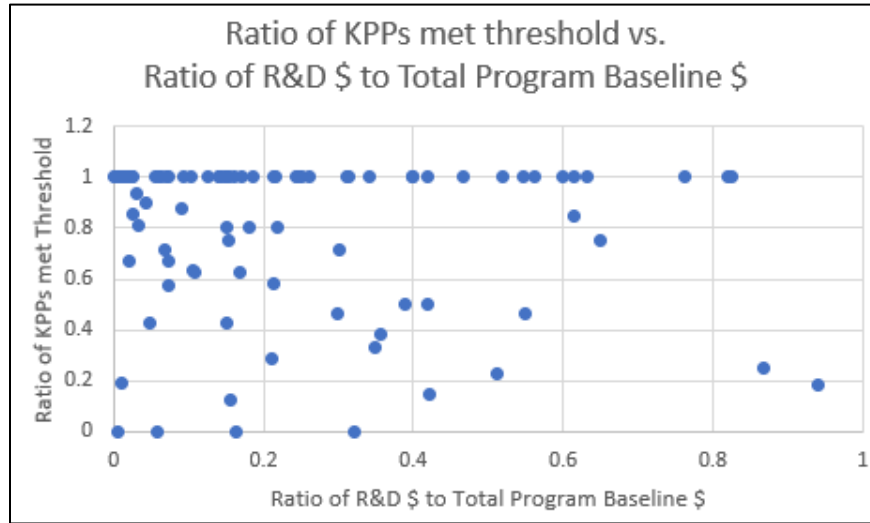


Figure 4. Ratio of KPPs that Meet Threshold vs. Percentage of Baseline Program Cost on R&D

D. SINGLE FACTOR ANOVA

Visual analysis did not show linear relationships between factors and MOEs. However, single factor ANOVA provided another approach to determine if a factor was related to any of the MOEs. Programs were separated by whether they were joint or led by a single military service, for example. Once separated, a single factor ANOVA was conducted to provide the F-statistic and F-critical value for the ANOVA. If the F-statistic is larger than the F-critical value, then the analyzed factor is useful for explaining variability within the MOE. This means that as the factor value increases or decreases, the MOE value will also change. We found that a program's jointness was significant for explaining variability in the ratio of KPPs that met threshold MOE. See Table 4. We see that the F-statistic from the data exceeded the F-critical value, thereby rejecting the null hypothesis that a change in factor values do not affect the MOE.

Table 4. Single Factor ANOVA for Program Jointness within the KPP Ratio to Meet Threshold MOE

ANOVA						
<i>Source of Variation</i>	<i>SS</i>	<i>df</i>	<i>MS</i>	<i>F</i>	<i>P-value</i>	<i>F crit</i>
Between Groups	0.353	1	0.353	4.022	0.048	2.772
Within Groups	6.765	77	0.088			
Total	7.118	78				

When analyzing system type as a potential contributing factor, analysis revealed that there was significance among some system types in explaining variability, specifically Combat Vehicles and Communications, Command, Control, and Intelligence (C3I). The team reduced the system types into three bins: combat vehicle, C3I, and other systems. Using these three bins, single factor ANOVA showed that system type was a significant factor within the MOE of ratio of KPPs that met threshold. See Table 5. However, system type was not a significant factor for explaining variability in the schedule breach ratio MOE.

Table 5. Single Factor ANOVA for System Type within the KPP Ratio to Meet Threshold MOE

ANOVA						
<i>Source of Variation</i>	<i>SS</i>	<i>df</i>	<i>MS</i>	<i>F</i>	<i>P-value</i>	<i>F crit</i>
Between Groups	1.298	2	0.649	8.477	0.0005	2.374
Within Groups	5.820	76	0.077			
Total	7.118	78				

This process was conducted for each factor that the team believed may have explained variability on the two MOEs. We found that in addition to Jointness and System Type, the factor of Lead Service was also useful in explaining variability within the ratio of KPPs that met threshold MOE. Table 6 shows the results of the single factor ANOVA of Lead Service within the ratio of KPPs that met threshold MOE.

Table 6. Single Factor ANOVA for Lead Service within the KPP Ratio to Meet Threshold MOE

ANOVA						
<i>Source of Variation</i>	<i>SS</i>	<i>df</i>	<i>MS</i>	<i>F</i>	<i>P-value</i>	<i>F crit</i>
Between Groups	0.719	2	0.359	4.269	0.018	2.374
Within Groups	6.399	76	0.084			
Total	7.118	78				

On the other hand, some factors were found to have no significant impact on the MOEs. For example, the team hypothesized that the baseline total program cost for a specific program may have an impact on the selected MOEs. The single factor ANOVA was conducted after separating the programs into cost bin of \$0-\$100M, \$100M-\$1B, and greater than \$1B. Table 7 shows the results of ANOVA of baseline total program cost within the ratio of KPP that met threshold MOE. The F-statistic is less than the F-critical value, indicating that the analyzed factor does not explain variability within the MOE.

Table 7. Single Factor ANOVA for Baseline Total Program Cost within the KPP Ratio to meet Threshold MOE

ANOVA						
<i>Source of Variation</i>	<i>SS</i>	<i>df</i>	<i>MS</i>	<i>F</i>	<i>P-value</i>	<i>F crit</i>
Between Groups	0.007	2	0.004	0.039	0.962	2.374
Within Groups	7.111	76	0.094			
Total	7.118	78				

We continued this process and examined factors using different bin sizes to show potentially hidden interactions. We utilized the same approach for each of the factors and ultimately discovered that only one of the MOEs could be explained by the factors. The variability of the ratio of KPPs that met threshold MOE could be explained by three factors: Jointness, System Type, and Lead Service. No factors were useful for explaining the

variability within the Schedule Breach MOE. Therefore, the team dropped Schedule Breach and focused on KPP% as the MOE upon which to build a predictive model.

E. INITIAL MAIN EFFECTS REGRESSION MODEL

The next step was to construct a predictive model with KPP% as the dependent variable and Jointness, System Type, and Lead Service as the independent variables. This was done using regression.

All explanatory variables were categorical. Therefore, the team used dummy variables to represent the categorical variables. Regression analysis in Excel treats all independent variables in the analysis as numerical. The process of using dummy variables can be explained using Lead Service as an example. For the data, there were three lead service entities: Army, Navy, and Air Force. We established Army as the reference variable, meaning that the value for the dummy variables for Navy and Airforce would each be zero. If the lead service was Navy, Navy would receive a 1 and Air Force would be zero. If Air Force was the lead service, Air Force would receive a value of 1 and Navy would be zero. See Table 8.

Table 8. Dummy Variable Use in Regression Analysis.

Lead Service	Air Force	Navy
Air Force	1	0
Army	0	0
Navy	0	1

The process of incorporating dummy variables continued for each of the other categorical factors. The regression tool was then used to create a simple linear model for each individual factor and KPP%. Each simple model was appropriate for the given data. The team next developed a multilinear regression model (Figure 5).

$\text{Predicted KPP\%} = 0.7578 + -0.0611 * (\text{Joint}) + 0.1029 * (\text{Air Force}) + 0.1379 * (\text{Navy}) + -0.2513 * (\text{C3I}) + -0.0073 * (\text{Combat Vehicle})$
--

Figure 5. Initial Main Effects Predictive Model for KPP Percentage.

Evaluation of this main effects model showed it could explain a much larger percentage of variability in KPP% than a model that used all seventeen possible factors. Residual analysis showed that in general, the assumptions for using regression was met. However, there was an anomaly that the team did not have sufficient time to explore. This anomaly will be further discussed in the development of the full model, which includes interaction terms.

F. EXPLORE INTERACTION TERMS VIA TWO FACTOR ANOVA

The predictive model only accounted for main effects. The next step was to conduct a two-factor ANOVA to understand if any two-way interactions should be included in the model. The team examined three potential two-way interactions: “Joint – System Type,” “Lead Service – System Type,” and “Joint – Lead Service.”

Using the two-factor ANOVA in Excel, we compared the F-statistic and the F-critical values. The results of the two-factor ANOVA are shown in Table 9, which indicates that the coefficients for Joint – System Type and Lead Service – System Type should be included in the model.

Table 9. Two-Factor ANOVA

Two-Way Interaction	F Stat		F Critical
Joint-Lead Service	1.231	<	1.454
Joint-System Type	1.583	>	1.454
Lead Service-System Type	1.949	>	1.454

G. FINAL PREDICTIVE MODEL

Upon completion of two-factor ANOVA, the team moved into building and validating the model. Even though two-factor ANOVA supported that the Lead Service – System Type relationship was significant, further analysis showed that this interaction term was not significant.

$$H_0: \beta_{\text{lead service} - \text{system type}} = 0$$

$$H_{\text{alt}}: \beta_{\text{lead service} - \text{system type}} \neq 0$$

The hypothesis test on the interaction term's coefficient showed that the null hypothesis could not be rejected. Therefore, it should not be a term in the predictive model. At this point, the team rebuilt the model using only a single two-way interaction between joint – system type, along with the main effects terms.

Review of the remaining terms provided an understanding for the tractability of the overall model. For instance, whether a system is joint can have significant effects on the ease or difficulty of procuring the system. A joint system requires more coordination and communication, which can impact the acquisition process. A joint system may have different, competing requirements than for a system that must only meet a specific service's needs. These competing requirements may leave little trade-space and the desired capabilities for different mission sets may be difficult to integrate. This difficulty is represented by the negative coefficient for joint programs. Lead services each have different processes for acquiring new systems. The model showed that the Navy has a higher positive impact than other services. Additionally, system type showed that C3I and combat vehicle were useful in explaining variability. This again made logical sense. C3I systems are often extremely technical, software heavy, require more research, higher interoperability, and are generally more complex. This is accounted for in the large, negative coefficient. Combat vehicles, on the other hand, are not as complex relative to C3I and have a positive coefficient. When these factors were all accounted for, the final predictive model resulted in the formula in Figure 6

$$\text{Predicted KPP\%} = 0.7813 + -0.0769 * (\text{Joint}) + 0.1079 * (\text{Air Force}) + 0.1465 * (\text{Navy}) + -0.3814 * (\text{C3I}) + 0.0309 * (\text{Combat Vehicle}) + 0.2094 * (\text{Joint-C3I}) + -0.2603 * (\text{Joint-Combat Vehicle})$$

Figure 6. Final Predictive Model for KPP%

H. CROSS VALIDATION

The team checked the viability of the model through cross-validation. This was conducted by randomly selecting 20% of the 79 programs in the data set to be test cases. The remaining 63 programs were then used to recreate the final predictive model in Figure 6.

We applied the model to the remaining 20%, or 16 programs that were set aside. Using values from these documented programs, the predictive model computed KPP% for each program. Applying the standard error of the prediction model, we built a 95% prediction interval around the predicted KPP%. A prediction interval is larger than a confidence interval since it must account for the variability of a new observation (Montgomery and Runger 2013). Of the 16 test cases, 15 of the actual KPP% fell within the prediction interval. This result showed that the model was good and appropriate for the data available.

I. RESIDUAL ANALYSIS

The final step was to conduct an analysis of the residuals on the final model using the full data set to assess the appropriateness of the linear regression model. This analysis was conducted by analyzing the residuals in two ways. First, we analyzed the mean. A good model should have a mean that approaches zero. The model's mean residual was statistically zero (1.363E-16).

The second analysis step was visual. We first analyzed the residual scatter plot. Linear regression is appropriate when the plot of residuals in a scatterplot exhibits a random pattern. The residual model is shown in Figure 7.

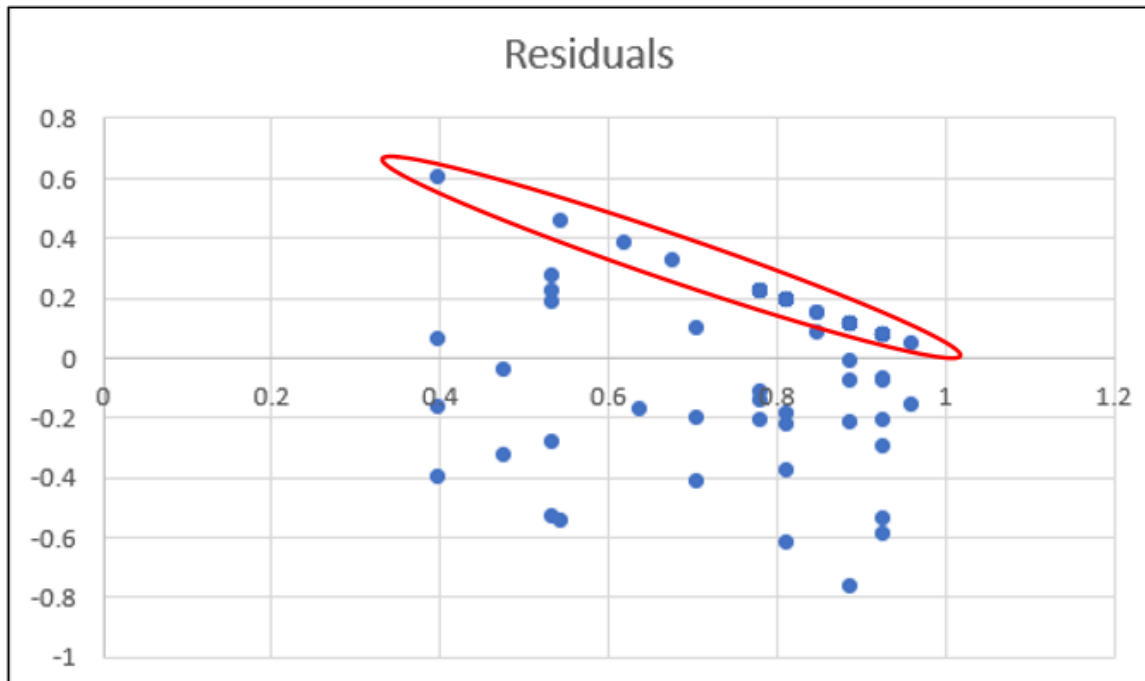


Figure 7. Full Model Residual Plot

The residuals appear random and equally distributed above and below zero. There are no curvatures, fanning, or funneling patterns that would indicate that a regression model is inappropriate for the data. In comparison, charts (b), (c), and (d) in Figure 8 depict problematic patterns for residual plots (Montgomery and Runger 2013).

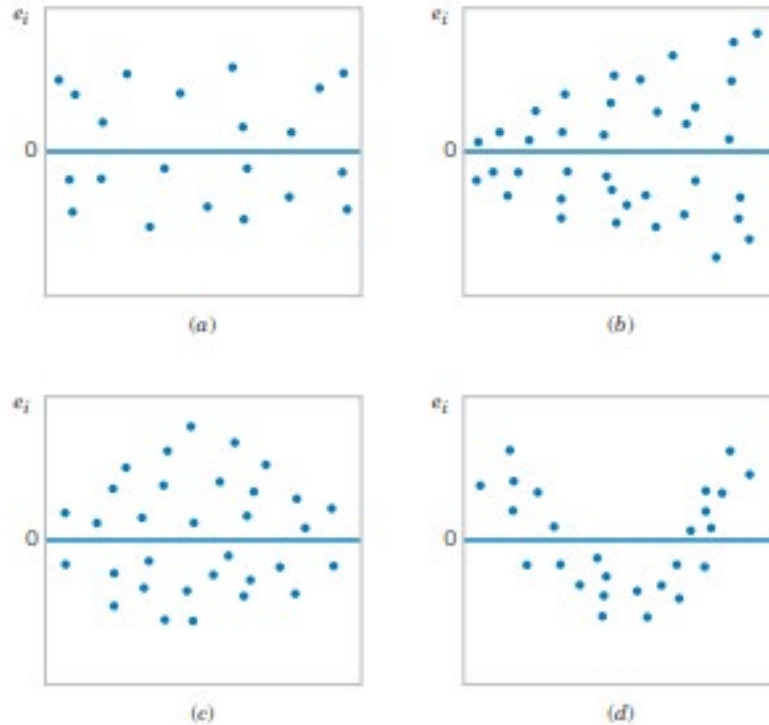


Figure 8. Patterns for Residual Plots. (a) Satisfactory, (b) Funnel, (c) Double Bow, (d) Nonlinear. Source: Montgomery and Runger (2013).

The residual plot in Figure 7 from the final predictive model does not exhibit the issues in Figure 8b, c, or d. In general, Figure 7 most closely matches Figure 8a, a satisfactory residual plot. We acknowledge that at the top part of the plot some of the residuals, circled in red, appear linear. Study of the specific programs associated with those residuals show that three of the four top left points are C3I systems. The remaining points are a mix of joint and not joint, different services, and different system types. The data behind these specific points is in Appendix B. A possible approach for exploration is to transform the C3I or System Type data. However, the team did not have time to explore this anomaly but recognizes that it warrants investigation and will be one of the team's recommendations for future work.

After analyzing the residual scatterplot, the team generated a histogram (Figure 9) of the residuals. A histogram for residuals should exhibit a bell or normal curve. The histogram shows some negative skewness, but still exhibits a somewhat bell shape centered

around zero. It is possible that with additional data, the histogram would follow a normal curve.

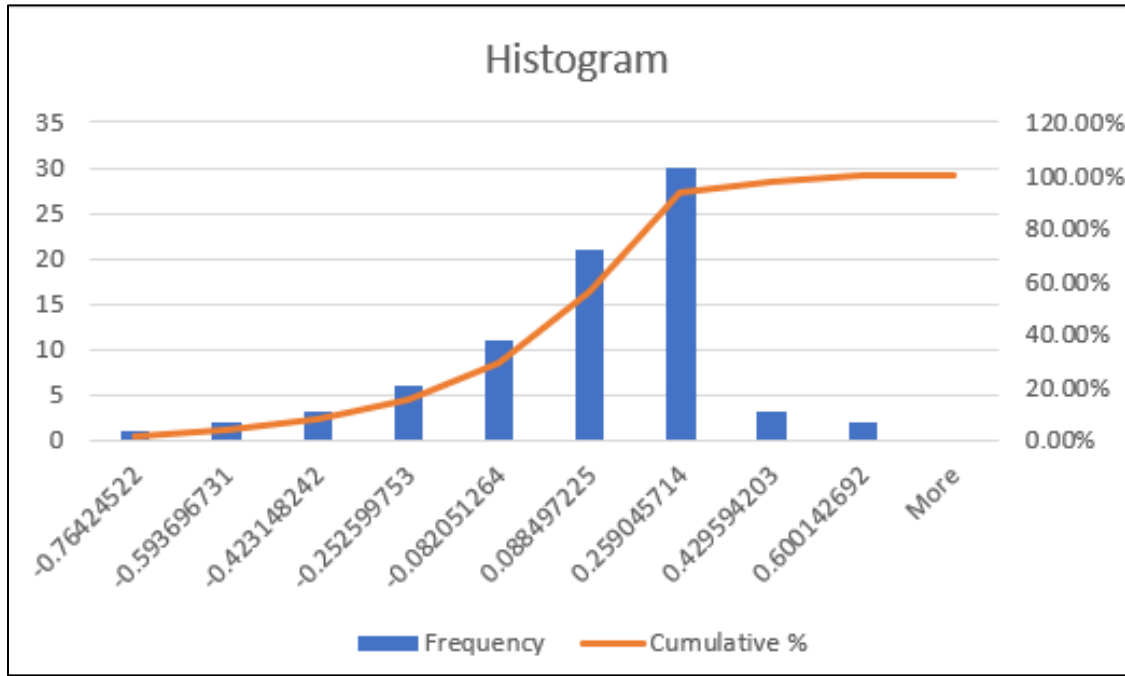


Figure 9. Residual Histogram

The residual analysis allowed us to conclude that the model was appropriate and adequate based on the data that we collected from DAVE, CADE, and DAMIR for ACAT I U.S. acquisition programs. If we included all the possible factors that we started with into the model, the amount of variability of KPP% that the model would explain was less than 9%. The final model we developed now explains over 30% of the variability in the KPP% MOE, a substantial improvement that can indicate success or failure of future acquisition initiatives. Based on our cross validation, the model demonstrates a degree of capability to predict the KPP% for a future MA initiative.

In conclusion, the results of our analysis have led to the development of a stepwise methodology that can be used as a model for future analysis of different context variables as leading indicators of an acquisition program's success. Figure 10 depicts the eight steps of this methodology.

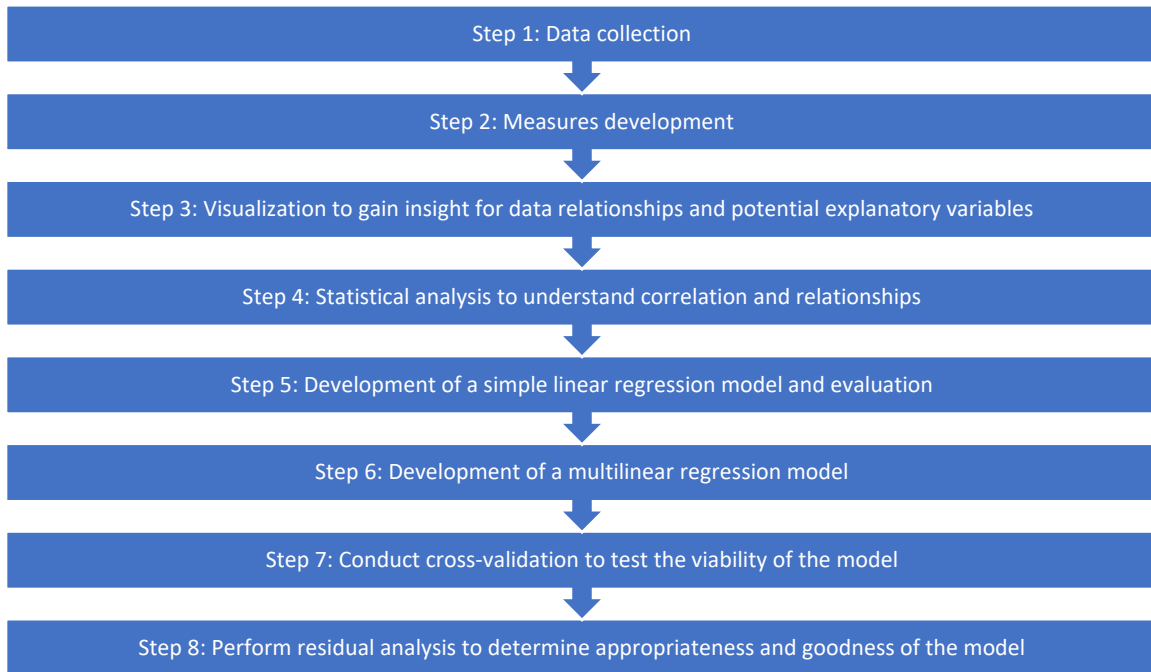


Figure 10. Methodology for Analyzing Context Variables as Leading Indicators of Acquisition Success

Our model is imperfect but is an improvement to no analytical model. As different data sets are explored, there will likely be more useful factors to include in this model. The steps that have been documented in this analysis provided a map for incorporating new factors, new data sets, and new MOEs for success.

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V. CONCLUSION

A. SUMMARY

Our sponsor, ERDC, was seeking to create an acquisition game simulation that could model MAs for not only the United States, but also partnered and adversary nations. Their intent was to better understand how product, process, and context explain why different countries are either more or less successful in their respective acquisition processes. While ERDC had a thorough understanding of gamification and system dynamics, our team contributed to their effort by developing a predictive model and validating a methodology framework for further quantification of context variables.

The ERDC sought to create a game that was not product specific and could be applied to other countries to show how they develop any type of capability. To accomplish this, ERDC looked at a variety of factors when developing their game, such as workforce, military funding, and education. The ERDC defined workforce as “the workforce available for the acquisition process,” while military funding was defined as “relative budget for acquisition.” (Ruvinsky et al. 2021). These factors were largely static and high level for the specific countries studied. Our team instead looked at specific program data for 211 U.S. ACAT I MA initiatives. This approach allowed us to develop potentially useful MOEs, identify factors that explained variability in that MOE, and ultimately impacted the success or failure of specific acquisition initiatives.

The major contribution that our team made to this project was the development of useful MOEs and a predictive model to understand how individual factors explained that variability. While ERDC incorporated context variables in a very broad way, our team was able to use quantifiable data from DAVE and CADE to show how individual factors impact useful MOEs and ultimately impact the success or failure of an acquisition initiative.

Our contribution is not simply understanding how several factors impact the selected MOE, but the analytical framework to continue research into the future. The steps that have been documented in this analysis provided a map for incorporating new factors, new data sets, and new MOEs for success. The methodology used to construct the

predictive model can be used to improve upon the model's usefulness as more data about U.S. MA is compiled, and as well as for different countries if the data becomes available.

Achieving the project objectives provided value to the sponsor. Common PPC factors impacting MA were identified from the available data and quantitatively analyzed. The team initially used logic to identify factors we believed may impact the success or failure of a MA initiative. Once data collection was complete, the team analytically examined factors until they understood the impact that Lead Service, Program Jointness, and System Type had on the ratio of KPPs that met program threshold values. The analytical methodology validated during our analysis will potentially enable ERDC to examine process and product factors in the future.

The team initially had to define what constituted program success. This project defined a successful program as a program that achieves MS C without being terminated or restructured. This mark was chosen because it was available for analysis of the data. It also allowed the separation of programs into successes and failures for further analysis. The team developed measures of effectiveness tied to this definition of success.

The collected data from historical acquisitions was subjected to quantitative analysis that facilitated the examination of a wide breadth of programs. While ERDC examined high level factors that impact the acquisition process at the country level, the team's analysis was focused on historical acquisitions with specific data. This data allowed the development of a predictive model that can be used for predicting the success or failure of future U.S. programs.

B. IMPACT TO SPONSOR

The ERDC acknowledged during the team's final capstone brief that the work the team conducted would be beneficial in follow-on research. Specifically, the MOE "percentage of KPPs that met threshold" aligns well with ERDC's expectation for gameplay. The ERDC examined a country's capability for acquiring a product and understand that a product must meet performance parameters. Their game simulated a prototyping phase and verification/validation phase which determined whether a system

met performance objectives. Our methodology allows ERDC to quantify the performance aspects of an acquisition initiative in the future.

C. RECOMMENDATIONS FOR FUTURE RESEARCH

There are many areas where the methodology of this project can help ERDC expand research into their gamification effort. The team's current analysis was focused on uncontrollable context variables due to the available data. Future research efforts can expand the analytical framework developed by the team and seek additional data to further identify additional factors will allow better prediction of the outcome of specific acquisition initiatives.

One such potential factor to be considered in future research should be the TRL of acquisition initiatives. The team reasoned that the lower level of the TRL (the more immature the technology was) at program initiation, the greater the risk was to program success. The team was unable to collect enough data due to time limitations to analyze this factor. Future research efforts to understand and quantify how TRLs impact success or failure could be done through the study of GAO reports or similar sources to conduct small scale analysis. The team also recommends that acquisition databases like DAVE include TRL information in the future as technology readiness is a likely indicator of program success.

Another area that should be studied in the future is the urgency of the need. In collecting data, the team was unable to find any specific description of the urgency of need. The team reasoned that as the urgency of need increases, the likelihood of program success also increases. This could be due to several factors such as political will, willingness to allocate funds, perceived seriousness of a capability gap; urgency of need appears significant and worthy of additional study as data becomes available.

This study was specifically focused on U.S. ACAT I MAs. In the future, as data allows, further study of individual countries is warranted. The ERDC focused research on Russia and Germany with additional analysis on China. This research was conducted to identify specific acquisition process frameworks for each country but ultimately resulted in a generic acquisition framework. Understanding each country's unique framework and

focusing on those context variables through the lens of this project's predictive modeling methodology would be beneficial in understanding how these principals apply to other countries.

As noted in Chapter IV, visual analysis of the initial scatterplots created with the available data failed to identify correlation between factors. Future research may find additional correlation between factors if they conduct data transformation. This transformation may provide insight into other factors that influence MOEs as well as the potential for additional significant MOEs beyond those included in this research.

Additionally, some potentially unexplained linearity in the residual plot existed, particularly with C3I systems. Future research to attempt to explain this phenomenon appears warranted. Due to the scope and timeline of this project, the team was limited to analyzing the data as collected.

APPENDIX A. CLEAN SPREADSHEET FOR ANALYSIS (79 PROGRAMS)

The spreadsheet shown in Table 10 shows the manageable data set created by the team's data collection and filtering efforts. This spreadsheet served as the clean data set that was used to conduct statistical analysis. Each column represents a different factor that was analyzed. Column M is the Ratio of KPPs that met threshold MOE. Columns B-D are the factors that explain the variance in the MOE.

Table 10. Clean Spreadsheet for Analysis (79 Programs)

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
	Program Name	System Type	Joint ?	Lead Service	cost per unit Baseline	Baseline total quantity required	Baseline total program cost	Baseline R&D \$	Ratio R&D/ Total program cost	Cost Breach	Number of KPPs	Number of KPPs met Threshold	Ratio of KPPs that meet Threshold	# of schedule years with a breaches	# of total schedule years	Schedule Breach/Year
2																
3	ACV FoV	Combat Vehicle	No	Navy	\$ 4,978,000	240	\$ 1,835,700,000	\$ 769,300,000	42%	Yes	10	10	100%	0	5	0%
4	AEHF	Sensor/Radar/Satellite	No	Air Force	\$ 1,328,000,000	2	\$ 2,715,100,000	\$ 59,100,000	2%	No	5	5	100%	9	21	43%
5	AFATDS (ATCCS)	C3I	No	Army	\$ 103,000	5,191	\$ 1,095,900,000	\$ 560,000,000	51%	Yes	13	3	23%	1	2	50%
6	AGM-88E AARGM	Guided Munitions/Missiles	No	Navy	\$ 461,000	1,919	\$ 1,339,800,000	\$ 533,300,000	40%	Yes	3	3	100%	2	17	12%
7	AIM-9X BLOCK I	Guided Munitions/Missiles	Yes	Navy	\$ 193,000	10,000	\$ 2,464,000,000	\$ 531,400,000	22%	Yes	12	12	100%	2	14	14%
8	AMRAAM	Guided Munitions/Missiles	Yes	Air Force	\$ 783,000	15,450	\$ 12,278,200,000	\$ 1,725,700,000	14%	Yes	2	2	100%	6	22	27%
9	AN/TPQ-53	Sensor/Radar/Satellite	No	Army	\$ 17,456,000	189	\$ 3,658,300,000	\$ 340,700,000	9%	No	4	4	100%	0	2	0%
10	ATIRCM/CMWS	Sensor/Radar/Satellite	Yes	Army	\$ 1,310,000	2,002	\$ 2,795,700,000	\$ 593,000,000	21%	No	7	2	29%	9	14	64%
11	B-2 EHF Inc 1	Aircraft/Helicopter	No	Air Force	\$ 7,353,000	17	\$ 659,700,000	\$ 544,900,000	83%	No	2	2	100%	0	10	0%
12	B-2 RMP	Aircraft/Helicopter	No	Air Force	\$ 36,000,000	14	\$ 1,148,400,000	\$ 644,400,000	56%	No	7	7	100%	5	8	63%
13	B61 Mod 12 LEP TKA	Guided Munitions/Missiles	No	Air Force	\$ 386,000	813	\$ 1,321,600,000	\$ 1,007,600,000	76%	No	3	3	100%	0	8	0%
14	BRADLEY UPGRADE	Combat Vehicle	No	Army	\$ 3,778,000	595	\$ 3,724,200,000	\$ 529,600,000	14%	Yes	10	10	100%	1	13	8%
15	C-27J	Aircraft/Helicopter	No	Air Force	\$ 46,605,000	78	\$ 3,449,200,000	\$ 117,100,000	3%	Yes	21	17	81%	1	4	25%
16	C-5 RERP	Aircraft/Helicopter	No	Air Force	\$ 137,225,000	52	\$ 5,415,900,000	\$ 1,691,200,000	31%	No	5	5	100%	3	16	19%

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
	Program Name	System Type	Joint ?	Lead Service	cost per unit Baseline	Baseline total quantity required	Baseline total program cost	Baseline R&D \$	Ratio R&D/ Total program cost	Cost Breach	Number of KPPs	Number of KPPs met Threshold	Ratio of KPPs that meet Threshold	# of schedule years with a breaches	# of total schedule years	Schedule Breach/Year
17	CH-47F	Aircraft/Helicopter	No	Army	\$ 22,957,000	525	\$ 10,614,800,000	\$ 179,700,000	2%	Yes	6	6	100%	2	20	10%
18	EFV	Combat Vehicle	No	Navy	\$ 22,240,000	593	\$ 8,493,200,000	\$ 1,532,400,000	18%	Yes	10	8	80%	8	22	36%
19	Excalibur	Guided Munitions/ Missiles	No	Army	\$ 226,000	7,474	\$ 1,654,600,000	\$ 993,400,000	60%	Yes	9	9	100%	1	14	7%
20	F/A-18E/F	Aircraft/Helicopter	No	Navy	\$ 83,815,000	565	\$ 38,884,700,000	\$ 5,889,400,000	15%	Yes	21	21	100%	1	15	7%
21	FCS	Combat Vehicle	Yes	Army	\$ 8,010,027,000	15	\$ 59,100,000,000	\$ 24,988,600,000	42%	Yes	7	1	14%	1	6	17%
22	FMTV	Combat Vehicle	No	Army	\$ 171,000	80,228	\$ 16,697,700,000	\$ 168,800,000	1%	Yes	16	3	19%	2	16	13%
23	G/ATOR	Sensor/Radar/ Satellite	No	Navy	\$ 62,111,000	45	\$ 3,118,800,000	\$ 1,110,900,000	36%	No	13	5	38%	0	9	0%
24	GMLRS/GMLRS AW	Guided Munitions/ Missiles	No	Army	\$ 104,000	79,082	\$ 12,751,400,000	\$ 1,360,000,000	11%	Yes	11	7	64%	4	23	17%
25	GPS III	Sensor/Radar/ Satellite	No	Air Force	\$ 230,167,000	6	\$ 4,142,900,000	\$ 2,623,900,000	63%	No	7	7	100%	4	13	31%
26	HIMARS	Combat Vehicle	No	Army	\$ 3,853,000	888	\$ 3,711,600,000	\$ 206,300,000	6%	No	11	11	100%	0	10	0%
27	HMS	C3I	Yes	Army	\$ 28,000	328,514	\$ 8,242,600,000	\$ 1,254,700,000	15%	No	8	6	75%	13	17	76%
28	IDECM	C3I	No	Navy	\$ 2,764,000	324	\$ 1,305,200,000	\$ 409,700,000	31%	No	2	2	100%	3	13	23%
29	INCREMENT 1 E- IBCT	Combat Vehicle	No	Army	\$ 285,100,000	9	\$ 3,149,500,000	\$ 583,600,000	19%	Yes	3	3	100%	0	2	0%
30	IRST	Sensor/Radar/ Satellite	No	Navy	\$ 7,014,000	170	\$ 1,914,600,000	\$ 764,000,000	40%	Yes	1	1	100%	0	4	0%
31	JAGM	Guided Munitions/ Missiles	Yes	Army	\$ 226,000	26,319	\$ 7,070,400,000	\$ 1,074,900,000	15%	No	10	8	80%	1	6	17%
32	JASSM	Guided Munitions/ Missiles	Yes	Air Force	\$ 1,150,000	2,866	\$ 2,195,000,000	\$ 159,100,000	7%	Yes	3	3	100%	3	23	13%
33	JDAM	Guided Munitions/ Missiles	Yes	Air Force	\$ 17,000	661,305	\$ 2,300,300,000	\$ 490,300,000	21%	No	12	7	58%	4	22	18%
34	JLENS	C3I	Yes	Army	\$ 287,643,000	14	\$ 5,850,000,000	\$ 1,760,000,000	30%	Yes	7	5	71%	4	10	40%
35	JLTV	Combat Vehicle	Yes	Army	\$ 361,000	64,489	\$ 19,699,500,000	\$ 941,400,000	5%	No	7	3	43%	2	8	25%
36	JOINT MRAP	Combat Vehicle	Yes	Navy	\$ 1,504,000	25,474	\$ 22,013,500,000	\$ 227,900,000	1%	Yes	6	6	100%	1	4	25%
37	JPATS	Aircraft/Helicopter	Yes	Air Force	\$ 5,883,000	767	\$ 4,529,000,000	\$ 289,200,000	6%	Yes	14	14	100%	1	16	6%
38	JSIMS	C3I	Yes	Army	\$ 170,800,000	1	\$ 1,281,600,000	\$ 1,110,800,000	87%	No	4	1	25%	2	3	67%
39	JSIPS (CIGS)	C3I	Yes	Air Force	\$ 33,640,000	5	\$ 586,300,000	\$ 322,000,000	55%	No	15	7	47%	0	2	0%
40	JSOW	Guided Munitions/ Missiles	Yes	Navy	\$ 282,000	3,334	\$ 5,544,100,000	\$ 836,800,000	15%	Yes	3	3	100%	7	18	39%
41	JTRS GMR	C3I	Yes	Army	\$ 126,000	108,086	\$ 14,437,200,000	\$ 845,100,000	6%	Yes	10	0	0%	6	11	55%
42	KC-130J	Aircraft/Helicopter	No	Air Force	\$ 88,445,000	104	\$ 9,233,900,000	\$ 35,600,000	0%	No	4	4	100%	0	10	0%
43	KC-46A	Aircraft/Helicopter	No	Air Force	\$ 203,999,000	175	\$ 43,518,200,000	\$ 6,804,200,000	16%	Yes	8	1	13%	3	10	30%
44	LAND WARRIOR	C3I	No	Army	\$ 139,000	58,900	\$ 2,451,500,000	\$ 734,400,000	30%	Yes	13	6	46%	1	5	20%

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
	Program Name	System Type	Joint ?	Lead Service	cost per unit Baseline	Baseline total quantity required	Baseline total program cost	Baseline R&D \$	Ratio R&D/ Total program cost	Cost Breach	Number of KPPs	Number of KPPs met Threshold	Ratio of KPPs that meet Threshold	# of schedule years with a breaches	# of total schedule years	Schedule Breach/Year
45	LCS	Ship	No	Navy	\$ 582,018	53	\$ 32,011,000,000	\$ 3,433,300,000	11%	Yes	8	5	63%	10	17	59%
46	LCS MM	Ship	No	Navy	\$ 69,775,000	59	\$ 6,379,500,000	\$ 2,233,700,000	35%	No	6	2	33%	3	7	43%
47	LHA 6	Ship	No	Navy	\$ 2,677,500,000	1	\$ 2,877,400,000	\$ 199,900,000	7%	Yes	14	10	71%	5	8	63%
48	LHD 1	Ship	No	Navy	\$ 963,967,000	3	\$ 2,931,800,000	\$ 39,900,000	1%	Yes	17	17	100%	0	8	0%
49	Longbow Apache	Aircraft/Helicopter	No	Army	\$ 6,665,000	758	\$ 672,200,000	\$ 412,700,000	61%	Yes	4	4	100%	0	14	0%
50	LPD 17	Ship	No	Navy	\$ 744,950,000	12	\$ 9,018,100,000	\$ 78,700,000	1%	Yes	18	18	100%	8	23	35%
51	M88A2 Hercules	Combat Vehicle	No	Army	\$ 2,464,000	933	\$ 2,354,600,000	\$ 55,900,000	2%	No	8	8	100%	0	4	0%
52	MH-60R	Aircraft/Helicopter	No	Navy	\$ 36,143,000	188	\$ 4,020,500,000	\$ 508,400,000	13%	Yes	3	3	100%	3	20	15%
53	MH-60S	Aircraft/Helicopter	No	Navy	\$ 20,587,000	165	\$ 2,769,000,000	\$ 71,000,000	3%	Yes	21	18	86%	11	17	65%
54	MHC 51	Ship	No	Navy	\$ 135,575,000	12	\$ 1,457,400,000	\$ 17,200,000	1%	Yes	10	10	100%	0	2	0%
55	MIDS	C3I	Yes	Navy	\$ 339,000	630	\$ 924,900,000	\$ 481,100,000	52%	Yes	51	51	100%	8	23	35%
56	MQ-1B UAS Predator	Aircraft/Helicopter	No	Air Force	\$ 11,475,000	248	\$ 3,127,800,000	\$ 282,100,000	9%	No	8	7	88%	0	1	0%
57	MQ-1C Gray Eagle	Aircraft/Helicopter	No	Army	\$ 267,992,000	12	\$ 3,922,300,000	\$ 3,215,900,000	82%	Yes	2	2	100%	1	11	9%
58	MQ-4C Triton	Aircraft/Helicopter	No	Navy	\$ 141,780,000	65	\$ 11,860,500,000	\$ 2,989,300,000	25%	No	6	6	100%	3	11	27%
59	MQ-8 Fire Scout	Aircraft/Helicopter	No	Navy	\$ 30,071,000	168	\$ 2,063,500,000	\$ 541,100,000	26%	Yes	12	12	100%	8	14	57%
60	MQ-9 Reaper	Aircraft/Helicopter	No	Air Force	\$ 25,320,000	388	\$ 10,602,800,000	\$ 778,800,000	7%	No	3	2	67%	3	11	27%
61	MUOS	Sensor/Radar/Satellite	No	Navy	\$ 647,750,000	4	\$ 5,705,000,000	\$ 3,114,000,000	55%	No	7	7	100%	8	14	57%
62	NAS	Sensor/Radar/Satellite	Yes	Air Force	\$ 13,325,000	53	\$ 570,300,000	\$ 96,600,000	17%	Yes	8	5	63%	1	17	6%
63	NSSL	Space	No	Air Force	\$ 391,247,000	181	\$ 13,116,600,000	\$ 1,344,000,000	10%	Yes	10	10	100%	6	23	26%
64	P-8A	Aircraft/Helicopter	No	Navy	\$ 201,018,000	108	\$ 26,376,500,000	\$ 6,429,600,000	24%	No	8	8	100%	0	17	0%
65	PAC-3	Guided Munitions/Missiles	Yes	Army	\$ 4,750,000	54	\$ 4,798,800,000	\$ 2,015,600,000	42%	Yes	2	1	50%	1	14	7%
66	PAC-3 MSE	Guided Munitions/Missiles	No	Army	\$ 4,813,000	1,528	\$ 6,220,900,000	\$ 460,900,000	7%	No	7	4	57%	1	7	14%
67	PIM	Combat Vehicle	No	Army	\$ 10,358,000	580	\$ 6,641,000,000	\$ 1,000,900,000	15%	Yes	7	3	43%	3	9	33%
68	RMS	C3I	No	Navy	\$ 12,115,000	106	\$ 1,304,600,000	\$ 418,000,000	32%	Yes	6	0	0%	5	10	50%
69	SDB I	Guided Munitions/Missiles	No	Air Force	\$ 59,000	24,070	\$ 1,786,300,000	\$ 381,300,000	21%	No	6	6	100%	0	5	0%
70	SINCGARS	C3I	No	Army	\$ 19,000	292,853	\$ 5,611,700,000	\$ 135,400,000	2%	No	18	18	100%	0	12	0%
71	SMART-T	C3I	Yes	Army	\$ 2,203,000	364	\$ 1,027,200,000	\$ 225,400,000	22%	Yes	20	16	80%	1	9	11%
72	Strategic Sealift	Ship	No	Navy	\$ 322,425,000	20	\$ 64,884,000	\$ 39,900,000	61%	Yes	13	11	85%	2	9	22%

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
	Program Name	System Type	Joint ?	Lead Service	cost per unit Baseline	Baseline total quantity required	Baseline total program cost	Baseline R&D \$	Ratio R&D/ Total program cost	Cost Breach	Number of KPPs	Number of KPPs met Threshold	Ratio of KPPs that meet Threshold	# of schedule years with a breaches	# of total schedule years	Schedule Breach/Year
73	STRYKER	Combat Vehicle	No	Army	\$ 2,956,000	2,131	\$ 7,120,200,000	\$ 508,000,000	7%	Yes	15	15	100%	11	13	85%
74	T-45TS	Aircraft/Helicopter	No	Navy	\$ 13,730,000	304	\$ 5,462,000,000	\$ 1,342,900,000	25%	Yes	31	31	100%	0	11	0%
75	T-AKE	Ship	No	Navy	\$ 353,050,000	12	\$ 4,262,600,000	\$ 26,000,000	1%	No	9	9	100%	1	16	6%
76	TWS	Combat Vehicle	No	Army	\$ 12,000	237,788	\$ 2,956,100,000	\$ 72,600,000	2%	No	7	7	100%	0	2	0%
77	UH-60M Black Hawk	Aircraft/Helicopter	No	Army	\$ 11,812,000	1,221	\$ 14,662,000,000	\$ 286,700,000	2%	Yes	18	12	67%	2	19	11%
78	UH-72 LUH	Aircraft/Helicopter	No	Army	\$ 5,838,000	322	\$ 1,883,000,000	\$ 3,100,000	0%	No	5	5	100%	0	2	0%
79	V-22	Aircraft/Helicopter	Yes	Navy	\$ 84,568,000	456	\$ 385,628,000,000	\$ 11,446,500,000	3%	Yes	30	28	93%	8	23	35%
80	WGS	Sensor/Radar/Satellite	No	Air Force	\$ 287,900,000	3	\$ 1,042,500,000	\$ 178,800,000	17%	No	4	4	100%	4	19	21%
81	WIN-T INC 1	C3I	No	Army	\$ 2,299,000	1,677	\$ 3,879,700,000	\$ 23,700,000	1%	Yes	1	0	0%	3	6	50%

APPENDIX B. UNEXPLAINED LINEAR RESIDUAL POINTS

This appendix presents the data for the residual plots that appeared to be linear in Chapter IV. Figure 11 highlights the datapoints in question that we did not have time to investigate, and determine, an explanation for the linear appearance prior to concluding this capstone. Table 11 shows the various system types, joint status, and lead service as well as the corresponding residual values.

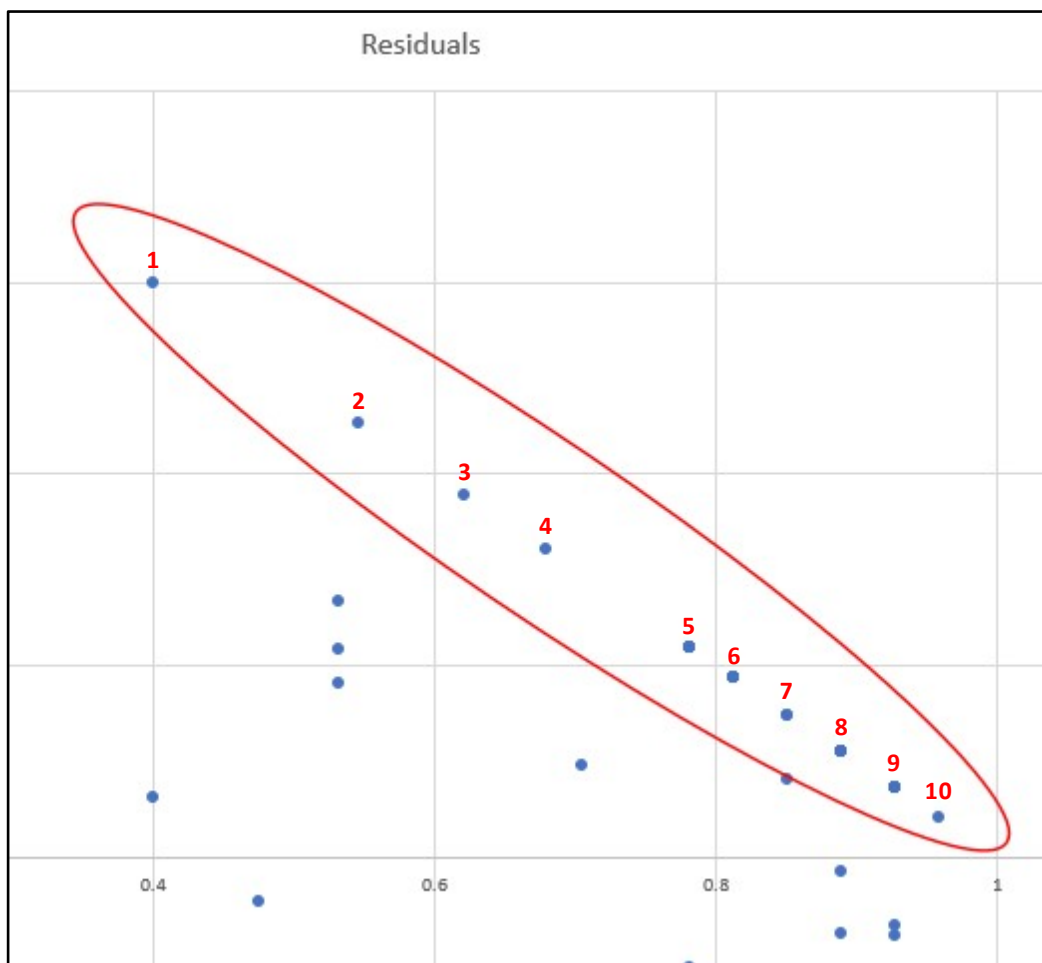


Figure 11. Residual Groupings

Table 11. Residual Plot Dataset

Residual Point #	Joint?	Lead Service	System Type	Joint	Air Force	Navy	C3I	Combat Vehicle	Joint-C3I	Joint-Combat Vehicle	Ratio of KPPs that meet Threshold	Pred KPP %	Residuals
1	No	Army	C3I	0	0	0	1	0	0	0	1	0.39986	0.60014
2	No	Navy	C3I	0	0	1	1	0	0	0	1	0.54644	0.45356
3	Yes	Navy	Combat Vehicle	1	0	1	0	1	0	1	1	0.62153	0.37847
4	Yes	Navy	C3I	1	0	1	1	0	1	0	1	0.67893	0.32107
5	No	Army	Aircraft/ Helicopter	0	0	0	0	0	0	0	1	0.78131	0.21869
	No	Army	Aircraft/ Helicopter	0	0	0	0	0	0	0	1	0.78131	0.21869
	No	Army	Aircraft/ Helicopter	0	0	0	0	0	0	0	1	0.78131	0.21869
	No	Army	Aircraft/ Helicopter	0	0	0	0	0	0	0	1	0.78131	0.21869
	No	Army	Guided Munitions/ Missiles	0	0	0	0	0	0	0	1	0.78131	0.21869
	No	Army	Sensor/ Radar/ Satellite	0	0	0	0	0	0	0	1	0.78131	0.21869
6	No	Army	Combat Vehicle	0	0	0	0	1	0	0	1	0.81229	0.18771
	No	Army	Combat Vehicle	0	0	0	0	1	0	0	1	0.81229	0.18771
	No	Army	Combat Vehicle	0	0	0	0	1	0	0	1	0.81229	0.18771
	No	Army	Combat Vehicle	0	0	0	0	1	0	0	1	0.81229	0.18771
	No	Army	Combat Vehicle	0	0	0	0	1	0	0	1	0.81229	0.18771
7	Yes	Navy	Guided Munitions/ Missiles	1	0	1	0	0	0	0	1	0.85094	0.14906
	Yes	Navy	Guided Munitions/ Missiles	1	0	1	0	0	0	0	1	0.85094	0.14906
8	No	Air Force	Aircraft/ Helicopter	0	1	0	0	0	0	0	1	0.88925	0.11075
	No	Air Force	Aircraft/ Helicopter	0	1	0	0	0	0	0	1	0.88925	0.11075
	No	Air Force	Aircraft/ Helicopter	0	1	0	0	0	0	0	1	0.88925	0.11075
	No	Air Force	Aircraft/ Helicopter	0	1	0	0	0	0	0	1	0.88925	0.11075

Residual Point #	Joint?	Lead Service	System Type	Joint	Air Force	Navy	C3I	Combat Vehicle	Joint-C3I	Joint-Combat Vehicle	Ratio of KPPs that meet Threshold	Pred KPP %	Residuals
	No	Air Force	Guided Munitions/ Missiles	0	1	0	0	0	0	0	1	0.88925	0.11075
	No	Air Force	Sensor/ Radar/ Satellite	0	1	0	0	0	0	0	1	0.88925	0.11075
	No	Air Force	Space	0	1	0	0	0	0	0	1	0.88925	0.11075
	No	Air Force	Guided Munitions/ Missiles	0	1	0	0	0	0	0	1	0.88925	0.11075
	No	Air Force	Sensor/ Radar/ Satellite	0	1	0	0	0	0	0	1	0.88925	0.11075
	No	Air Force	Sensor/ Radar/ Satellite	0	1	0	0	0	0	0	1	0.88925	0.11075
9	No	Navy	Aircraft/ Helicopter	0	0	1	0	0	0	0	1	0.92789	0.07211
	No	Navy	Aircraft/ Helicopter	0	0	1	0	0	0	0	1	0.92789	0.07211
	No	Navy	Aircraft/ Helicopter	0	0	1	0	0	0	0	1	0.92789	0.07211
	No	Navy	Aircraft/ Helicopter	0	0	1	0	0	0	0	1	0.92789	0.07211
	No	Navy	Aircraft/ Helicopter	0	0	1	0	0	0	0	1	0.92789	0.07211
	No	Navy	Guided Munitions/ Missiles	0	0	1	0	0	0	0	1	0.92789	0.07211
	No	Navy	Sensor/ Radar/ Satellite	0	0	1	0	0	0	0	1	0.92789	0.07211
	No	Navy	Ship	0	0	1	0	0	0	0	1	0.92789	0.07211
	No	Navy	Ship	0	0	1	0	0	0	0	1	0.92789	0.07211
	No	Navy	Ship	0	0	1	0	0	0	0	1	0.92789	0.07211
	No	Navy	Ship	0	0	1	0	0	0	0	1	0.92789	0.07211
	No	Navy	Sensor/ Radar/ Satellite	0	0	1	0	0	0	0	1	0.92789	0.07211
10	No	Navy	Combat Vehicle	0	0	1	0	1	0	0	1	0.95887	0.04113

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