The Use of System Dynamics to Understand the Consequences of Project Controls with Dynamic Performance Measures in DoD Project Management

by Patrick R. Cantwell

B.S. in Naval Architecture, May 1999, U.S. Naval Academy
M.S. in Engineering Management, August 2008, The George Washington University

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Dissertation directed by

Shahram Sarkani
Professor of Engineering Management and Systems Engineering

Thomas Mazzuchi
Professor of Operations Research and Engineering Management

The School of Engineering and Applied Science of The George Washington University certifies that Patrick Reed Cantwell has passed the Final Examination for the degree of Doctor of Philosophy as of March 5, 2013. This is the final and approved form of the dissertation.

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Dissertation Research Committee:

Shahram Sarkani, Professor of Engineering Management and Systems Engineering, Dissertation Co-Director

Thomas Andrew Mazzuchi, Professor of Operations Research and Engineering Management, Dissertation Co-Director

E. Lile Murphree, Jr., Professor of Engineering Management, Committee Member

James Wasek, Professional Lecturer of Engineering Management and Systems Engineering, Committee Member

Reza Eftekari, Adjunct Professor of Engineering Management and Systems Engineering, Committee Member

Dedication

I dedicate this dissertation to my wife Amy and my daughters Natalie and Chelsea. They have been constant inspirations to me and have endured the time and energy I have had to sacrifice with them to complete this work.

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Many people have contributed to the achievement of this dissertation. I would like to start by thanking my advisors Drs. Sarkani and Mazzuchi who consistently offered profound insight, needed humor, and persuasive motivation when needed. I would also like to thank my dissertation committee who invested their time and energy to making this dissertation the best it could be. Additionally, I would like thank Dr. Charlie Bixler for providing the idea of pursuing a doctorate as well as Dr. Dennis Buede for his wisdom and support. My family has been a tremendous resource and provided so much support and understanding. Finally, I would like to thank God who has provided me the opportunities and gifts to make this dream a reality.

Abstract

The Use of System Dynamics to Understand the Consequences of Project Controls with Dynamic Performance Measures in DoD Project Management

Project management has been a constant challenge for many practitioners, notably the U.S. Department of Defense (DoD) acquisitions community. While most DoD projects are technologically advanced, the tools and methods to manage these projects are the same as for simple, repetitive projects. The current research starts with an assumption that traditional approaches fail because they only evaluate the relationships between two of the three elements of cost, schedule, and performance. Instead, the author has developed a system dynamics model that allows cost, schedule, and performance to interact and influence each other. This model is complementary to other research and intended to be usable by the practicing project manager. The results from model runs provide consequences for three potential control alternatives in DoD project management as well as the impact of additional rework on DoD development program results. This research will advance the understanding of general and DoD project management with contributions of a literature review, a validated system dynamics model, model results and analysis, and recommended future areas of studies.

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List of Acronyms

APM	Association of Project Management
CAS	Complex Adaptive System
CPM	Critical Path Method
DoD	Department of Defense
DSB	Defense Science Board
DSM	Design Structure Matrix
EFV	Expeditionary Fighting Vehicle
EVM	Earned Value Management
FCS	Future Combat System
GAO	Government Accountability Office
IC	Intelligence Community
NASA	National Aeronautics and Space Agency
NPD	New Product Development
NPV	Net Present Value
PERT	Program Evaluation and Review Technique
PM	Project Manager
PMI	Project Management Institute
PMPA	Project Management Performance Assessment
RFI	Request for Information
SAR	Selected Acquisition Report
SRA	Schedule Risk Analysis
TOC	Theory of Constraints
TQM	Total Quality Management

UK	United Kingdom
USMC	United States Marine Corps

Chapter 1 – Introduction

Project management has existed since man began building things. However, many researchers define the beginnings of the formal discipline of project management with the U.S. Polaris missile development and use of critical path methods (CPM) in the 1950s (Lyneis, Cooper, & Els, 2001; Pich, Loch, & Meyer, 2002; Tishler, Dvir, Shenhar, & Lipovetsky, 1996; T. M. Williams, 2005). Tischer, et al. (1996) notes that defense projects are different from commercial projects due to a larger, more interdisciplined design and higher technological risks. Within U.S. DoD project management, the U.S. Congress and many U.S. senior DoD leaders have felt that U.S. DoD project management has needed improvement as early as 1970 and have since changed the guiding acquisition policy guidance nine times (Ferrara, 1996).

Sorenson (2009) provides an in-depth overview of the history of U.S. DoD acquisitions. He notes that "current defense acquisition process is constructed on a foundation of distrust" (Sorenson, 2009). By this he means that the distribution of power as well as the extensive oversight is all in place to ensure that everyone involved in doing the right thing and to avoid the illegal and immoral history of many defense acquisitions events. He notes that there are variations in how projects are executed and decisions that are made on varying projects. Sorenson (2009) further comments that the Secretary of Defense has ended acquisition programs, but Congress never has. He highlights many of the problems with defense acquisitions from poor cost estimates to development delays to changing requirements to excessive oversight (Sorenson, 2009).

Other researchers have found that many DoD projects underestimate costs and

schedules due to the failure of understanding of complexities involved as well as the futile efforts to correct a under-performing project which results in blaming exogenous variables as opposed to endogenous ones (Lyneis & Ford, 2007). They further add that there is a great deal of research noting general theories of the need to reduce elements of project management rework cycles but there is limited domain specific advice or research (Lyneis & Ford, 2007). This is the knowledge gap the authors wish to improve upon. The search for the ideal form of U.S. Department of Defense (DoD) project management has existed since the dawn of DoD projects and is in part driven by a desire to reduce the DoD project failure rate. In fact, many external observers as well as quite a few DoD acquisition professionals would probably say that more DoD projects fail than succeed. Many researchers have explored the reasons for general project failure in great detail. They have developed many theories that withstand academic scrutiny, but the range of even simply understanding the nature of projects varies depending on project characteristics, the project industry, and where the researcher decides to restrict his/her study. Ultimately, there is no one solution to making DoD or any other domain of project management work. It is surprising that the DoD project management industry has not had more research given the large number and size of DoD projects. However, this is a common problem in most project management domains (Love, Edwards, Irani 2008). Certainly DoD could gain more appreciation and insight from an improved understanding of the way it conducts project management which is different from other industries.

1.1 Background

In 2011 the U.S. Government Accountability Office (GAO) declared that half of the major defense acquisition programs are not meeting cost goals and 80% have

increasing unit costs (Office, 2011). GAO further notes that between 2008 and 2010, the 98 major defense acquisition projects have grown in budget by 9% (Office, 2011). In the FY2012 budget request the DoD asked for $85.3 billion of its $553.1 billion budget, or approximately 15.4%, for major defense acquisition projects ((Comptroller), 2011).

Frequently budget pressure, schedule pressure, or changing user demands are cited as the reasons for both commercial and DoD failures (Meier, 2010). However, these challenges have been present for as long as projects have been undertaken, and the trend within DoD is getting worse instead of better (Office, 2011). The fact that many of these projects are developmental and have no or little basis for comparison is a fair excuse for why initial cost, schedule, and performance estimates prove to be incorrect. However, DoD project management needs to develop approaches to overcome the current trends. The first step to improvement is a solid understanding of how most DoD project management works. It is the goal of the authors' research to ultimately provide insight into the practical application of alternative decisions within DoD project management from the perspective of the government project manager.

1.2 Significance of Research

Regardless of the basis for project management decisions, one common area of agreement is that most traditional project management tools are not of great utility. Rodrigues and Bowers state that traditional project management techniques attempt to leverage similar characteristics of previous projects into detailed estimates using linear analysis and are highly dependent on assumptions (Rodrigues & Bowers, 1996a). Williams notes that the three critical assumptions to traditional project management are that "project management is rational", that anyone can gather the actual state at any time,

and that all project work can be decomposed (T. M. Williams, 2005). He then extends these assumptions to highlight the three traditional project management "emphases" of the value of detailed planning, the value of conventional control, and the value of ignoring the environmental impacts (T. M. Williams, 2005). Other researchers agree that traditional project management tools are commonly used because they are simple but are inappropriate for complex projects because they fail to resolve the interdependencies of project elements (Lyneis et al., 2001; Rodrigues & Bowers, 1996a, 1996b; Rozenes, Vitner, & Spraggett, 2006; Shenhar & Dvir, 1996) . Another group of research has declared that these tools are "too narrow in scope" and do not allow for the change of elements and their interdependencies over time (Collyer & Warren, 2009; Lyneis et al., 2001; Rodrigues & Bowers, 1996a). Moreover, other researchers have attributed this to a failure of the traditional tools to resolve external influences, human interactions, as well as "strategic" decisions (Davidson & Huot, 1991; Rodrigues & Bowers, 1996a, 1996b). Despite the short-comings in traditional project management tools, it is important to note that they do help provide a framework for estimation and can expose "mental models" regarding projects (Rodrigues & Bowers, 1996a).

While many agree that traditional tools are not the best solution, there is no agreement on what is. Rodrigues and Bowers note that some project managers attempt to control projects by reducing change through "environmental manipulation" or through the use of customized solutions instead of standardized approaches (Collyer & Warren, 2009). Another solution is to manage the concept of errors or rework which traditional management tools fail to address (K. G. Cooper & Mullen, 1993). Significant numbers of researchers promote the use of a system methodology such as system dynamics as a

solution to improve project management decision-making (Chapman, 1998; K. G. Cooper & Mullen, 1993; Ford & Sterman, 1998; Lamb & Rhodes, 2008; Love, Holt, Shen, Li, & Irani, 2002; Lyneis et al., 2001; Pundir, Ganapathy, & Sambandam, 2007; Rodrigues & Bowers, 1996a; T. M. Williams, 2005) . It is within this framework that the authors look to extend the existing base of knowledge.

1.3 Justification of Research

The current research is needed to potentially advance the understanding of DoD acquisitions and fill a knowledge gap. It further is applying the principles of systems engineering into an applied complex and dynamic problem with the hopes of best understanding and correcting that problem.

1.4 Relevance and Importance

This research is relevant for multiple reasons. First, the DoD acquisitions domain has a significant amount of resources invested in money, experience, and both national as well as individual warfighter interests. It is imperative to the taxpayers of the nation as well as to the warfighter lives that DoD systems are the best possible. Second, the DoD acquisition system has not produced even moderate results, and the trend is still one where more projects seem to fail than succeed. Third, this research further validates the importance and need for systems thinking, system dynamics, and systems engineering which contain the potential to improve the complex and dynamic world we live in today.

1.5 Purpose of Study

The purpose of this study is to advance the knowledge base of DoD program management and to validate a new approach to DoD project management with the use of

a system dynamics model that allows cost, schedule, and performance to dynamically influence each other.

1.6 Overview of Dissertation

This dissertation is divided into five chapters. The first chapter provides the introduction. The second chapter provides the literature review. The third chapter has the contributions to research while the fourth chapter reviews the research methodology, method, and case studies utilized. The fifth chapter provides the results and analysis. The final chapter provides the conclusions and discusses future research.

Chapter 2 – Literature Review

Previous research from the domains of complex systems, project management, and system dynamics has provided a foundation for the current study. Much of the previous research has been of an empirical nature designed to capture and explain the operating environments, interactions involved in each domain, and results of varying environments or interactions. Each of these three domains is less than 65 years old as a professional area of expertise where true academic and critical research has been applied to understanding and improving the knowledge and understanding of their elements and their consequences. The following literature review will highlight previous research that supports and guides the current study.

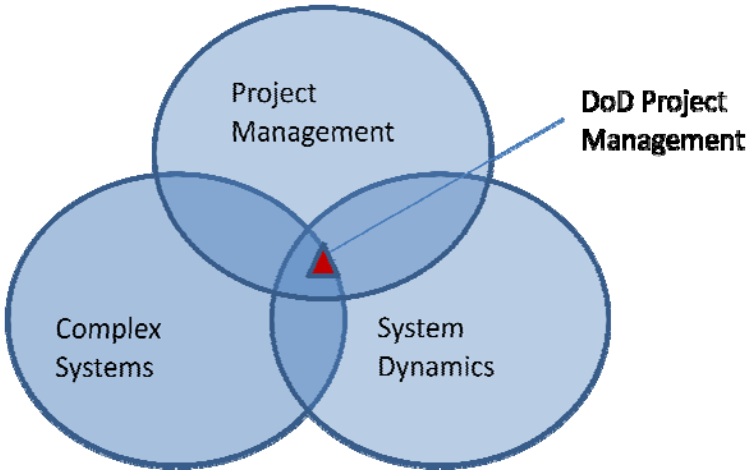

Figure 2-1: Relationship of Current to Previous Research

2.1 Project Management

The domain of project management has a growing wealth of knowledge. Within the context of project management related to the current effort, the previous research has been broken down into five main areas. The first area involves general project management research and provides a foundation for overall project management. The

second area reviews project management performance in an attempt to best understand how to make a project better. The third area involves research related to project management control theory and mechanisms. The fourth area highlights specific project management research that utilizes system dynamics. Finally the fifth area discusses specific research into project management and DoD acquisitions.

2.1.1 General Project Management

While not completely about project management, Oichi's 1980 research on organizations provides an interesting insight on project management. The author notes that bureaucracies exist to provide efficiency in certain situations. However, when work is "highly unique, completely integrated, or ambiguous for other reasons" then bureaucracies fail (Ouchi, 1980). This is appropriate as project management organizations, especially within the DoD, are bureaucracies and their work meets the special circumstances when bureaucracies fail. Therefore, it is not a surprise that many of the DoD projects have the results they do. However, in the current study it will be assumed that these organizational forces are not a significant driver of project performance at the individual project level.

In 1986 Cooper and Kleinschmidt studied 252 new product development projects at 123 Canadian firms to find the best practices. They begin by stating that product development has large risks and that it almost universally is not executed as research prescribes. Of 13 commonly defined new product activities, the authors find that only 1.9% of the projects studied utilized all 13 activities (R. G. Cooper & Kleinschmidt, 1986). In fact, the find that 54.8% of successful projects utilized nine or more activities while 38.2% of failed projects utilized nine or less (R. G. Cooper & Kleinschmidt, 1986).

The authors equate this to a strong recommendation to adhere to the full range of activities whenever possible and to apply as many resources as possible to the early activities (R. G. Cooper & Kleinschmidt, 1986). This research discusses more of the how to execute project management than the strategic focus of the current effort. However, it also provides support to the fact that theoretical project management studies are not supported by empirical work.

In 1988 Jessen took an early assessment of whether project dynamics could even be modeled. His premise is that "traditional 'rules' for 'correct' project execution and monitoring should be questioned" and that a systems approach is preferred (Jessen, 1988). He notes that all projects are unique but that modeling in combination with experience can help identify and determine best courses of action. He further highlights that a project model must be simple, correct, and realistic to be useful (Jessen, 1988). The author further mentions that any realistic project model must have the time, cost, and quality elements that change over the course of the project. Jessen then classifies projects into three classes (construction, research and development (R&D), and decision-support) that have similar time, cost, and quality behaviors. He further adds that rework was a major element of project models and that every project should determine what kind of "overrun" is the most preferable. The author concludes with a causal loop diagram that he believes will build the foundation for future project models (Jessen, 1988). These results greatly support the nature of the model in this research as well as qualitatively support the results.

Davidson and Huot (1991) evaluate the impacts of cost overruns from large projects. The authors begin by stating that indirect costs associated with delays and disruptions are

three to eight times larger than that of direct costs. They continue a frequent note that most project tools are based on linear theory and ignore social elements. The authors also highlight another trend that public projects are almost always underestimated to appear attractive and uses a U.S. nuclear submarine as an example that was underestimated by 1.5 million man-hours of work and delivered two years behind schedule. The authors recommend a new open and dynamic approach as opposed to the traditional approaches that are closed and static (Davidson & Huot, 1991). This research supports the current effort and continues many of the deficiencies in traditional project management techniques.

Crawford (1992) reviews accelerated development and discusses the hidden costs inherent in that strategy. He notes that accelerated development drives innovation to be small and simple rather than large and breakthrough. He also finds that many details are ignored that could be critical in product success. Additionally, he notes that gaining development speed will often cause a poor design or a need to constantly improve the initial design. Crawford concludes the article by providing several recommendations to avoid these problems (Crawford, 1992). While not directly applicable to the current effort, this research does provide better insight in project management and elements to avoid when attempting to improve the current system.

Laufer, Denker, and Shenhar (1996) reviewed successful projects managers for common trends in style. They begin by noting the evolution of project management as starting in the 1960s with a focus on control changing to the 1970s and a focus on integration changing to the 1980s and a focus on flexibility changing to the 1990s with a focus on dynamism (Laufer, Denker, & Shenhar, 1996). The authors provide detailed

guides for project management action based on their style results and recommend project managers be able to balance multiple competing demands largely through improved communication and teamwork (Laufer et al., 1996). This research provides insight into the nature of project management and emphasizes the importance of the social element of project management that is often ignored. The current research provides a framework to further extend the nature of the sociological dynamics of project management in future research.

Shenhar and Dvir (1996) provide an updated classification of project managements. They begin by noting "… project management is quite new and probably not well-understood" due to limited accepted theoretical support and a "lack of concepts", especially in regards to contingencies (Shenhar & Dvir, 1996). They add that many project management references treat all projects as the same. The authors do note that innovation does not suffer from these weaknesses and that innovation is typically classified as incremental or radical. They recommend a similar taxonomy for project management but propose a two-dimensional one. Their x-axis ranges from low to super high technological uncertainty while the y-axis ranges from system scope of an assembly to an array (Shenhar & Dvir, 1996). The authors then describe elements of each major category and conduct ANOVA statistical analysis on two databases of projects to verify their elements. The majority of the elements were correlated, and the authors advocate the further use of this taxonomy as well as the recommendation that projects be treated more specifically or at least by more detailed project types (Shenhar & Dvir, 1996). While this study is not directly applicable to the current effort, it does provide context and supports the fact that DoD acquisitions are likely a unique form of project

management that would require a unique model to provide insight.

In 1998 several authors update Wright's Law on the learning curve with respect to development projects. The authors start by stating that Wright's Law was designed in the 1930s to assess the learning that occurs during manufacturing that has no changes once begun. The authors review many of the simplifying assumptions that support the use of Wright's Law and recommend limited use of the learning curve. They also advise that system dynamics models are better and can provide a more accurate estimate (Eden, Williams, & Ackermann, 1998). This article further supports the use of the system dynamics model.

Another 1998 study reviewed 38 successful companies that have reduced project development cycle time. The authors begin by stating that American managers view on-time schedule delivery a low priority while German managers view it as the number one priority. They also note the presence of extensive interaction with stakeholders, effective teams, quality design practices, and beneficial learning in successful companies. The authors conclude that short cycle times are effective as a competitive advantage (Gupta & Souder, 1998).

Other research has reviewed lessons learned in project management. The author notes three categories of the lessons learned as team architecture, managing rework, and managing plans. He describes individual lessons learned within each category that have been addressed in other research described in this effort. The author concludes that the lessons learned are proven, but they are not applicable in every situation (Graham, 2000).

In 2001 Professor Shenhar utilizes 26 Israeli case studies to provide a framework for project contingencies. He begins by noting that projects are a popular organizational

structure used in a variety of applications but is not well understood. He adds that most research is "… anecdotal or based on single case studies" (Shenhar, 2001a). The author's framework consists of four levels of uncertainty (low, medium, high, and super high) with three levels of complexity (assembly, system, array) and then evaluated 26 Israeli commercial and defense projects using qualitative and quantitative methods (Shenhar, 2001a). The major results highlight many similarities within the author's divisions and also between size and project scope as well as between cost and schedule and scope. This research provides insight into project management and supports the unique approach to a smaller set of project management applications.

Professor Shenhar (2001) extended his research to classify 127 Israeli projects in rejection of the tenet that "one size fits all" with respect to projects. He again starts by stating that project management is poorly understood and not well researched (Shenhar, 2001b). The author presents his framework as noted in the previous study and achieves similar results that the classification system. Shenhar concludes by noting that project managers should utilize organizations, approaches, and practices tailored to their project as well as basing project communication on the degree of technological uncertainty (Shenhar, 2001b). The results of this research support the current research with many of the characteristics of the high technology, system category meeting the projects utilized in this case study. It also supports that common findings can be made with the system reviewed since they are within this same category.

One previous study statistically compared actual versus projected costs within global transportation infrastructure projects which are public projects similar to those in DoD. The authors discuss a concept of "salami tactics" that introduces small changes in a

project over time to "… make costs appear low as long as possible" (Flyvbjerg, Holm, & Buhl, 2002). Within the projects reviewed, the authors determined that 90% of projects have underestimated costs while most actual costs are 28% higher than projected (Flyvbjerg et al., 2002). They further state that this underestimation has not improved over time due to a learning curve effect and postulate that this underestimation is caused by technical misunderstandings, a desire to appear economical, an overly optimistic outlook of the project, and a desire to ensure that projects are started and not canceled (Flyvbjerg et al., 2002). These results are likely to also be found in the DoD domain.

Koskela and Howell (2002) offer insight into the state of project management as a theory. The authors begin by stating that a professional has mastered the theory and application of his field. They review several related theories but note the lack of any one commonly accepted one. The authors also continually refer to the PMBOK's treatment of these issues. As an example, the authors state that the two methods of PMBOK project control are performance reporting and change control (Koskela & Howell, 2002). They conclude that a more developed perspective with a common theory and developed tools is needed that better incorporates "transformation, flow, and value concepts" (Koskela & Howell, 2002). This research supports the current effort and the approach that is taken.

In 2002 Cooper, Lyneis, and Bryant research why project management does not learn and then applies a model to a product development case study. The authors discount that every project is completely different and note that there are commonalities between varying projects. They also note that it is difficult to assess the true cause(s) of project management behaviors, that projects are not enduring, and that project managers only work on average of three or four projects in their lifetime. The authors advocate the use

of simulation models to help with this and highlight the three critical parts to a project management model as a rework cycle, feedback of productivity and work quality, and knock-on effects. Of these the authors mention that rework is the biggest element that is not measured or even well understood in traditional approaches. The authors then highlight an overview of their model and the results of a successful development project. The authors then describe how the model can be used to help educate new project managers through simulation (J. M. Coyle, Exelby, & Holt, 1999). The current research model includes all three of the recommended elements from this study and can achieve the learning tool that the authors recommend for future DoD project managers.

Cooper, Edgett, and Kleinschmidt review best practices of new product development companies. They note the need to provide earlier evaluation of a wide range of options as well as a better understanding of the needs, wants, and goals of a user and the desired system. The authors note that even private industry is stopping internal research efforts outside of short-term focused areas. The authors recommend the use of a gate review process to standardize and ensure key questions are solved before projects are officially executed (Crawford, 1992). This supports the view that management can be short-sighted and that an improved tool for evaluation of varying projects is needed during solution evaluation. The current research can provide that tool within DoD acquisitions.

Cooper and Edgett (2003) apply a portfolio management system to new product development efforts in an attempt to better utilize resource employment. They begin by stating that 75% of new product development projects fail and attribute a large part of this to resource shortages (Singh & Singh, 2002). They add that these resource shortages are caused by a short-term cost focus, too many projects, and too much pressure to

deliver a product as quickly as possible. The authors recommend an improved awareness of resource needs and utilization as well as a better selection of projects. They even advocate cutting as much as half of most project portfolios (Singh & Singh, 2002). While this is insightful research, it is not applicable to the large DoD acquisition projects that are the focus of the current effort as each project has a dedicated program management staff which should alleviate some of problems noted in this study.

Cooper, Edgett, and Kleinschmidt (2004) provide an enlightening three articles on analysis of the successful and failing elements of 105 U.S. companies' new product development (NPD) activities. Their first article focuses on the people aspect of NPD and notes that in the commercial industry only one in ten product concepts succeeds and only one in four development projects succeeds (R. G. Cooper, Edgett, & Kleinschmidt, 2004c). The authors provide extensive analysis and ultimately conclude that organizational and culture aspects do impact NPD (R. G. Cooper et al., 2004c). The authors' second article focuses on strategic management and resource allocation. They find that most companies do not have a NPD strategy and have significant resource shortages (R. G. Cooper, Edgett, & Kleinschmidt, 2004b). In the third article the authors look at the tactics of NPD and conclude that most companies need to improve their NPD process and need to measure and evaluate their performance to ensure they are being effective (R. G. Cooper, Edgett, & Kleinschmidt, 2004a). These articles help provide more context and possible areas of focus for the current research.

Fleming and Koppelman (2003) note that most corporate executives evaluate a project's cost using only estimated and actual costs. Instead, they recommend using EVM as the DoD has been doing successfully since 1977. They mention that EVM

requires a lot of work, but they believe it is worth the resources required (Fleming & Koppelman, 2003).

Dvir and Lechler (2004) review 448 German projects to analyze several factors on planning and execution variables. The authors begin by stating that they do not view good planning as the only key to success because plans will have be adjusted due to uncertainty. They also note that project success has many perspectives based on the different stakeholders who drive project managers to use simple means of determining cost, schedule, and performance estimates. The authors highlight that compromises between cost, schedule, and performance are frequently made without the impacts understood. The authors find that goal changes during the project reduce the chance of project success and the fewer design changes during a project will lead to a greater chance of project success (Dvir & Lechler, 2004). The model in the current effort can be utilized to achieve the recommendations of this article.

In 2004 Söderlund provides an overview of research within project management that many argue is not rigorous or "well developed". He does note that "projects are seen as tools and project management is seen as a set of models and techniques for the planning and control of complex undertakings" (Söderlund, 2004). He states that the two major foundations for intellectual project management are engineering science and social science as well as the fact that all projects share the characteristics of being unique, being complex, and having limited time. With that said, he also mentions that given the unique nature of projects it is not appropriate to develop one "universal theory". Söderlund reviews the research surrounding several strategic project management questions and mentions that despite the presence of project management research it does not "explain or

increase our understanding about the behavior of project organizations" (Söderlund, 2004). He concludes by recommending more research into his key questions as well as looking for a balance of empirical with theoretical applications (Söderlund, 2004). The current research is attempting to help explain and increase the understanding of DoD project management in support of an empirical insight into one of the critical questions of why projects behave as they do.

Professor Shenhar (2004) provides an overview of an approach to strategic project management. He begins by noting that traditional project management has been focused on meeting cost, schedule, and performance goals while today's projects require more. The author mentions that some project managers focus on customer needs while others focus on the traditional cost, schedule, and performance measures and recommends the former approach. He describes his strategic project leadership© (SPL) framework as working through strategy to spirit to organization to processes to tools (Shenhar, 2004). He further adds that the last two are the traditional process and while still important need to be integrated into the larger framework. Shenhar then reviews the components of each area as well as seven principles for success in implementing this approach. He concludes with several case studies of the use or failure to use this approach with one DoD acquisition effort cited as the SR-71 aircraft being a success story (Shenhar, 2004). This research supports a flexible tool that can be integrated into the larger strategic project picture which the current model will allow.

Eden, Williams, and Ackermann conduct another study to compare two different methods of cost estimation in projects. The authors begin by stating that a major challenge with understanding delay and disruption is the knowledge of what would have

happened had they not happened. The authors then discuss the measured mile approach and the system dynamics approach. They highlight that the measured mile approach has limited utility because it requires an undisrupted beginning, perfect knowledge of all events that will cause a change, and linear relationships between all elements whereas the system dynamics method has none of these shortcomings (Eden, Williams, & Ackermann, 2005). This further supports the use of system dynamics in this current effort.

Atkinson, Crawford, and Ward (2006) emphasize the importance of managing uncertainty in project management. They note that there is a valid argument that traditional project management focuses too much on operational planning and ignores many of the "softer" elements of project management such as organizational culture and team-building. The authors believe these softer elements would be better in the management of uncertainty. They also highlight that most of the time different people have different opinions and perspectives on risk and how to manage it. They advocate a perspective that project management be focused on removing uncertainty with the use of traditional project management tools in addition to strategic and uncertainty management tools. Ultimately, the authors also recommend a larger focus on the soft elements, especially trust, as a means to better adjust to uncertainty (Atkinson, Crawford, & Ward, 2006). This article supports the current methodology as well as a need for the strategic tools that the current model attempts to provide.

Cicmil, et al (2006) review current project management research and advocate more application studies. They begin by stating that project management is a social activity where "…history, context, individual values and wider structural frameworks" are factors

affecting the outcome (Cicmil, Williams, Thomas, & Hodgson, 2006). They further note that the problem with traditional project management approaches is the view that "… project failure is indicative of inadequate attention to the proper project management procedures" (Cicmil et al., 2006). The authors continue a common trend by nothing that the three elements that cause project problems are structural complexity, uncertainty, and strict timelines. They conclude by recommending more practical approaches in conjunction with theoretical research to better explain what is actually happening in projects (Cicmil et al., 2006). This further supports exactly what the current research is attempting to do.

Another study has applied a system modeling approach to resource allocation in order to reduce project total schedules. The authors highlight the negative influence of iteration and decision delays on resource allocation. They also note that managers are inaccurate at estimating resource needs to achieve effective allocation. The authors' system dynamics model has the two sectors of workflow and resource allocation with a four stock workflow. Their results find that delays often help improve resource allocation and may improve schedule performance (Lee, Ford, & Joglekar, 2007).

Edkins, et al (2007) review multiple methodologies applied to project management and applied them to 11 British construction projects. The authors start by stating that success must be measured with cost, schedule, and performance metrics as well as with user desires. They also note that a challenge in projects with multiple organizations is that there are different objectives and definitions of success as well as different means of viewing and handling information (Edkins, Kurul, Maytorena-Sanchez, & Rintala, 2007). These views support the approach of the current research and concur with the assumption

that a project management approach from the government is different than one from a commercial vendor within DoD acquisitions.

Another study reviewed the required knowledge for modern advanced project management. The authors begin by stating that there is no evidence that certified project managers are any better than uncertified ones because both allow poor estimates and execute substandard control mechanisms. The authors add that the chief problem is the influence of complexity while one of the principal project management references, the PMI Program Management Book of Knowledge (PMBOK) Guide, only covers linear, rational, and analytic approaches. The authors further advocate the need to treat the current certification as a basic level and expand the knowledge of complexity and uncertainty in an advanced project management course or certification (Vanhoucke & Vandevoorde, 2006). The current research supports this recommendation and could be used to help provide a simulation to illustrate the impacts of complexity and uncertainty in a DoD acquisition project.

A 2009 article advances the nature of projects in light of dynamic environments. The authors define "dynamic" to mean "constant change" and note that all projects have some degree of this. They mention that a large amount of the project methods and goals will be changed by this dynamic environment. Additionally, they highlight that unknowns will increase significantly in this dynamic environment. The authors recommend new customized approaches to project planning and control and note that too many details in a project plan might cause managers to avoid changes. They further recommend a highly decentralized staff that can adapt without direction to meet the desired end state (Collyer & Warren, 2009). The current effort also provides a structured tool to accomplish the

recommendations of this research.

Kwak and Anbari (2009) provide a research overview and analysis of 18 premier management and business journal publications to categorize and best determine trends in project management research. They comment that project management has its foundations in engineering and specifically the construction, defense, and information technology industries (Kwak & Anbari, 2009). The authors note that there is no clear acceptance of project management being a "practice or an academic discipline" (Kwak & Anbari, 2009). They also highlight the limited but growing nature of formal academic research into project management. They further note that this expanding research includes both theoretical as well as practical research areas (Kwak & Anbari, 2009). Finally, the authors conclude that given the applied focus as well as the interdisciplinary nature of project management it does not lend itself to being a distinct academic discipline (Kwak & Anbari, 2009).

2.1.2 Project Management Performance

One of the earliest articles on project management failure was in 1965. Stewart notes that commercial project management is a balance between true project management and functional alignment. He further adds that the key to successful project management is the understanding of when to use it and when not to. The author proposes that when a problem is unique, complex, and involves high risk then project management is the preferred approach. He further highlights that the three main problems with project management are "… organizational uncertainty, unusual decision pressures, and vulnerability to top-management mistakes" (Stewart, 1965). Stewart recommends the three steps of defining the project goal, establishing a project organization, and

developing project controls (Stewart, 1965). Of interest, he only recommends budget, schedule, and quality control elements but this is appropriate for the state of project management knowledge at that time.

Another early study was conducted in 1969. In this article the author states that the number of project management failures far exceeds the number of successes (Avots, 1969). He further mentions that traditional methods of management (e.g., functional alignment/organizations) are not appropriate for project management (Avots, 1969). Avots then highlights and discusses his personal experiences on the reasons that projects fail. These include that the initial project baseline is flawed, that the project manager fails, that higher management fails to support the project, the tasks are not sufficiently decomposed, management methods fail, or a project termination is not planned (Avots, 1969). The author further mentions that "cost control always works against schedules and technical performance" and that all three of these aspects must be balanced to be successful (Avots, 1969).

In 1987, Pugh claimed that aircraft development schedule delays and cost overruns are correlated due to "under-estimation of the scope of the development task and changes in specification" (Pugh, 1987). He further adds that these delays cause systems to be fielded later than anticipated which will likely further create greater needs and system improvements. The author analyzes that improved early planning and more iterations of design are directly correlated with lower system unit costs (Pugh, 1987). Pugh concludes by noting that on average utilizing past timelines as an estimate of future projects is largely supported by evidence, but the use of accelerated timelines for future projects is not largely supported by evidence (Pugh, 1987). These aspects serve as motivations for

providing an improved approach to DoD project management.

de Wit tackles the nature of project success in his 1988 research. He begins by stating that there is a difference in the cost, schedule, and performance metrics and project success. He also recommends that project objectives are the best measures of project success and that they are likely to change as the project enters different phases of its lifecycle. The author further highlights U.S. research on 650 completed projects that found no correlation of cost and schedule performance to project success (de Wit, 1988). As he states, "A project can be a success despite poor project management performance and vice versa." (de Wit, 1988) The author extends the understanding of project success by noting that stakeholder perspectives as well as time frame can all impact whether a project is viewed as a success. Furthermore, de Wit highlights a most project managers consider cost and schedule the only objective metrics and that in Government applications performance metrics are as important as cost and schedule combined (de Wit, 1988). This research provides further insights into the nature of project management and conditions the current outcome to focus on cost, schedule, and performance improvements and not general project success.

The research on project failures is robust and may provide some insights into the current effort. Pinto and Mantel (1990) reviewed 97 "failed" projects and extracted common characteristics. As with many elements of project management, there is no definition on when a project fails (Pinto & Mantel, 1990). Pinto and Mantel further note that most project failure research is grounded in anecdotes, project types, and the stage of lifecycle of the project. This leads practitioners to criticize results as not applying to other projects or generalized projects (Pinto & Mantel, 1990). The authors found three

performance metrics that can be used to determine success or failure of a project but are subject to bias (Pinto & Mantel, 1990). The first is the implementation process. The second is the perceived value of the project. The third is the customer satisfaction with the project. They conclude that the combination of these metrics and not any single one help determine whether a project is a success or a failure, and that these may change in weighting over project lifecycle (Pinto & Mantel, 1990).

Another article offers his lessons learned as a project sponsor to better improve project management. Wright (1997) begins by stating the projects are almost always completed with regards to performance but almost never on time or within cost. He adds that multiple goals often compete for resources within project management. The author advocates high levels of communication and motivation as well as a decision by the project sponsor on the prioritization of schedule versus cost when problems arise if not at the beginning of the project (Wright, 1997). This article provides valuable insight and is a good approach for use in DoD acquisitions. Moreover, the current effort's model can be adjusted to easily accommodate a decision on relative priority of cost or schedule.

In 1999 Atkinson provided research in the need for new success criteria. The author begins with the traditional cost, schedule, and performance measures and discusses that while these are a method they ignore a great deal of issues at play within projects. In other words, he proposes that projects are failures because the measurement is too simple and ignores other dynamics. Atkinson then reviews varying other criteria that could be used as measures of success at varying points within a project lifecycle (Atkinson, 1999). While this research is not directly applicable to the current effort, it does provide insight into project dynamics and the possibility that cost, schedule, and performance may not be

the only critical measures of project success. Furthermore, should additional factors be developed, they could be easily added to the current model.

Reichelt and Lyneis continue the research into project performance. The authors again state that projects are complex dynamic systems and find fault with traditional project management tools due to their static perspective, narrow view, and view of every project as unique. Often sample projects these authors study, the average cost overrun is 86% and the average schedule overrun is 55% (Reichelt & Lyneis, 1999). They highlight that three components of a structure are rework, feedback, and knock-on effects. They further hypothesize that rework causes budget and schedule overruns. From the projects studied the authors find that design projects can have between 30-65% of the time spent on rework while build projects average can have between 13-40% (Reichelt & Lyneis, 1999). They also note that most projects are only budgeted to accomplish the original work so that any rework will become a cost overrun.

Gardiner and Stewart (2000) discuss the challenge in using cost, schedule, and performance as a measure of project success. They note that project monitoring and project control are very different activities with control being the more important and more difficult one (Gardiner & Stewart, 2000). The authors further state that most project managers know that a project is in trouble, but they do not know the best method to resolve the trouble. Moreover, 90% believe they are achieving project success with independent perspectives on what "acceptable" cost, schedule, and performance variations are (Gardiner & Stewart, 2000). Advocating continuous net present value (NPV) along with quality assessments as better metrics of project success, the authors provide simple cash flows that support the use of NPV and demonstrate the utility of this

approach which incorporates all costs into one present value (Gardiner & Stewart, 2000).

Eden, Williams, Ackermann, and Howick (2000) provide an overview of delays and disruptions as they impact projects and have the potential to involve legal actions of over $70-100 million dollars (Eden, Williams, Ackermann, & Howick, 2000). The authors define disruptions as impacts on the ability to do work and delays as a schedule overrun. They further note that most people assume they can be computed in a simple manner ignoring the "knock-on effects" and dynamic interactions between the two elements (Eden et al., 2000). The authors mention that even small disruptions can have tremendous consequences and some that are not intuitive. They review some common categories, such as excessive client interest in details, changing legal requirements, poor communication, and changing customer requirements. The authors add that the problem with these impacts is that the schedule and cost of the rework associated with the changes is hard to predict due to the interdependencies of the tasks, impacts on previously completed work that will need to be redone, and impacts on other systems or sub-systems that the current product interoperates with (Eden et al., 2000). The authors offer that the critical path method (CPM) is often utilized to assess the impacts on delay, but that this method cannot effectively assess the total costs, that it does not assess soft factors, and that it ignores actions taken to attempt to mitigate the impacts. They present a dynamic hypothesis (i.e., influence diagram) that supports the claim that disruption and delays are hard to appreciate or effectively estimate and that they will cause the firefighting response as mentioned in other research (Eden et al., 2000).

Cooke-Davies (2001) reviewed 70 multi-national organizations to determine a set of factors that are important to project success. He begins by noting that the first project

management body of knowledge was begun in 1993 and that there is a difference between project success (i.e., measured against the project goals) and project management success (i.e., measured against budget, schedule, and performance). He finds that there was a strong correlation between cost and schedule overruns but notes that schedule delay had a small impact on cost overruns (Cooke-Davies, 2002). His resulting twelve factors are interesting but more appropriate for organizational policies than this effort of improving DoD project management performance.

Research has shown other flaws in traditional methods. Several authors have noted that modern projects can be uncertain in variation, foreseen uncertainty, unforeseen uncertainty, and chaos (De Meyer, Loch, & Pich, 2002). The authors discuss the details of each type of uncertainty and what project management methods are better suited to each. It is the ultimate recommendation of this research that given the potential presence of these elements modern project managers much be prepared to change approaches when needed (De Meyer et al., 2002).

Bryde (2002) provides the results of a survey of project managers regarding project performance measurement. He begins by stating that project performance and project manager performance are very different and that pre-1980 studies only looked at cost, schedule, and performance while the current approach is evaluate multiple views and perspectives. The author finds that customer surveys were not highly effective due to poor perceptions, inaccurate measures, and an inability to demonstrate that customer expectations had been met while the six elements of the project management performance assessment (PMPA) are useful in evaluating the performance of a wide range of projects (Bryde, 2003). This research is supportive of a need for a new project performance

method while attempting to find the one framework to support all projects as opposed to within certain categories.

Love, Holt, Shen, Li, and Irani (2002) utilize a system dynamics model to better understand the drivers of a project performance in a construction case study. These authors note that a project organization often is comprised of people from varying organizations with different viewpoints. They view the project organization as a system with the project management structure as a sub-system. They also note that traditional project management tools (e.g., CPM, PERT, etc) adequate for project details but have limited utility when evaluating strategic issues. They highlight that rework is caused either by changes or errors. Following the discussion of the results of the model, they recommend having a method to identify unplanned issues and quickly adjust to them to develop the best project management performance (Love et al., 2002). It is the intent of the current research to best apply these results, but the nature of the current model is more strategic-focused than tactical-focused where these recommendations would be best applied. The best method of implementing these results is recommended as a future area of research.

In 2003 Williams discusses the weaknesses of the methods available to assess time delays on projects. After describing the effects of delays on a project, the author notes that CPM cannot resolve multiple delays and disruptions at one time, cannot evaluate the "soft" effects of delays, and assumes a management that does nothing to respond to a problem. Instead of the CPM approach, Williams recommends the use of system dynamics to best assess time delays on a project (T. M. Williams, 2003).

In 2005 Williams uses systematic modeling in postmortem analysis to better explain

why failed projects fail. He begins by noting that many projects are unique and have little precedent for comparison. He also observes that project management bodies of knowledge (e.g., PMI and IPMA) assume that project management is rational, that reality of a project can be observed, and that all work can be decomposed which leads them to focus on planning, conventional control, and ignore the environment. He defines complexity as involving structural complexity, uncertainty, and limited time. He adds that conventional methods are able to handle large number of project structures but not highly interdependent projects or those with large amounts of uncertainty. He further notes that when a project's goal is unclear conventional methods do not work. Williams then describes the newer project management styles that focus on project emergence, cooperative control, and acceptance of environmental influences. Finally, he recommends developing metrics for structural complexity, uncertainty, and time constraint; developing new combinations of approaches; and determine which approach fits varying project metrics (T. M. Williams, 2005).

Love, Edwards, and Irani (2008) utilize system dynamics as a forensic project management approach with a commercial construction project to better understand the nature of design errors and rework. They note that projects often seem to be going well and then suddenly have problems due to rework. They also note that rarely does forensic investigation take place on projects unless the failure makes the news. They further propose that most construction organization do not review and apply lessons learned but instead keep working on the next project. The authors support the use of system dynamics with construction projects that they view as "dynamic and complex" with multiple inter-related feedback loops and nonlinear relationships. They conclude from

their quantitative model with several scenarios that construction firms need to apply more resources to early reviews and verifications of designs to best minimize errors (Love, Edwards, & Irani, 2008). These results further support the use of system dynamics for forensic analysis of programs that the current research is attempting to do.

2.1.3 Project Management Control

Wideman (1989) provides basic control concepts to help improve project management. He begins by noting that the degree of successful project management will dominate the impact on project success over any other technical performance area. He adds that the level of effort will vary depending on the project stage in its lifecycle and that clear goals and plan to achieve them is needed for a successful project. He concludes by stating that project management is not hard but doing it effectively to achieve project success is (Wideman, 1989). This research provides more context of the nature of project control and some insights from a practicing project manager.

Pich, Loch, and DeMeyer (2002) provide an overview of project management approaches as they apply to three strategies. The authors begin by noting that traditional project management techniques create conflicting approaches and do not inform a project management which technique to use and why (Pich et al., 2002). They focus their research on evaluating the "adequacy of information" as measure by the lack of ambiguity and complexity. They also add that early network approaches that focused on critical path were replaced by task criticality evaluations, design structure matrices, and risk management techniques which all assume adequate information (Pich et al., 2002). They further add that each of these techniques may be preferred based on the cost of information. The authors propose when there is inadequate information either a learning

strategy where the environment is scanned for clues or a selectionism strategy where multiple strategies are concurrently pursued until a preferred emerges should be chosen (Pich et al., 2002).

Austin, Newton, Steele, and Waskett utilized a graphical model to better understand information flows within construction projects from a client perspective (Austin, Newton, Steele, & Waskett, 2002). The authors note that within construction design the major management activity changes from one of negotiation early in the planning to one of coordination as the design nears completion (Austin et al., 2002). They further highlight that design work is complex, involves a non-linear process, and is iterative which does not support the use of the Critical Path Method (CPM) (Austin et al., 2002). Instead the authors recommend the use of a specialized Analytical Design Planning Technique (ADePT) tool that they help create.

Love and Smith (2003) provide insight into rework in construction industry projects. They note that there is little available data for construction project managers to use as comparisons. They also note that rework causes cost and schedule overruns in construction projects but also add that there is no standard definition of rework or how to measure it (Love & Smith, 2003). The authors discuss that most rework is only measured in specific sub-elements (i.e., defects, changes, errors, or failures) and is not well understood as a complex problem (Love & Smith, 2003). This research supports the importance of rework and the lack of knowledge of rework which makes it an interesting aspect to explore in this effort.

Alessandri, et al (2004) discuss budget issues when evaluating risk and uncertainty in projects. They begin by stating that risk and uncertainty are related with no clear

commonly agreed distinction between the two. They also note that uncertainty is the dominant concern and that as uncertainty increases, research recommends the use of quantitative tools but in reality most managers utilize decisions based on their own intuition or experience. The authors recommend that the use of scenario planning and real options as a means of best integrating quantitative and qualitative approaches (Alessandri, Ford, Lander, Leggio, & Taylor, 2004). This is exactly what the current research is attempting to do by using a system dynamics model to evaluate various scenarios and provide quantitative outcomes for comparison.

Ahuja and Thiruvengadam (2004) review several studies on project control methods within the construction industry. They highlight other research that states that traditional project management tools "… typically do not provide dynamic links between cost estimates and corresponding schedules" and fail to incorporate uncertainties (Ahuja & Thiruvengadam, 2004). They then review studies that have alternate project control approaches as a way to eliminate the problems with traditional project management approaches but note that these are mathematically complex (Ahuja & Thiruvengadam, 2004). While this review is useful, it is solely focused on the construction industry which does vary from the defense industry. However, it does further support the assumption that traditional project management approaches are not effective in the control of complex projects like DoD acquisitions.

Ivory and Alderman (2005) review three case studies to provide insights into new methods of project management. The authors mention that there is a large quantity of research on failure in complex systems which points to extensive linear and non-linear interactions, internal oppositions, and "multiple sites of control and influence" (Ivory &

Alderman, 2005). They note that complex systems do not reach equilibrium and often undergo large changes as a result of small influences. They also add that non-linear interactions are extremely difficult to predict and may go undetected. The authors further highlight that projects are based on technical and social assumptions that do not withstand realities of the world. They declare that the optimization of cost, schedule, and performance goals at the same time is "rarely possible without some compromise" and generally project managers will focus on the short-term challenges instead of the longer-term issues (Ivory & Alderman, 2005). They openly state that they do not agree that strict centralized management is the key to project control. Instead, the authors recommend a lowest level possible response with top level resource reallocation. They reiterate this as stating that traditional project management tools are helpful and should complement activities taken by lower level elements in order to ensure flexibility as the situation changes (Ivory & Alderman, 2005). In order words, Ivory and Alderman view project planning as a step that can effectively utilize traditional project management tools, but that project execution is a very distinct step that requires different and more flexible tools for the best results. This is exactly what the current research is striving to do by providing a flexible model for project managers within DoD to best understand what is happening in execution.

Bourne and Walker (2005) review a case study of common complex organization decision-making in support of ignoring the traditional methods of project control. They begin by noting that project serve to manage change, relationships, and uncertainty. They note that traditional management control works well with known problems and can be used with risk management to successfully handle know unknowns. They also highlight

that the typical response to unknown unknowns is more control mechanisms and/or more frequent reviews. The authors mention that the "paradox of project control" is that the project management must attempt to reduce the impact of change and uncertainty while the same forces are also acting on the management actions and frequently results in instability. The authors analyze an Australian IT case study and recommend that project management accept unpredictability and better utilize being alert to changes, being flexible in responses, and maintaining good communication with all stakeholders for improved performance (Bourne & Walker, 2005).

Rozenes, Vitner, and Spraggett (2006) provide a literature review of project control. The authors note the development of the Association of Project Management (APM) and the Project Management Institute (PMI) that have formed to provide professional associations focusing on project management books of knowledge that the authors make many references to in their review. Of note, the authors highlight that PMI's PMBoK does not have a section dedicated to project control while the APMBoK does. The authors further classify project control systems as being either one-dimensional or multidimensional (Rozenes et al., 2006). They note that a one-dimensional system focuses on one dimension instead of integrating several and provides a limited, but simple view of the project. The authors note that the multidimensional system does integrate several dimensions with EVM being an example. Rozenes, et al., then discuss the extensions of project control by adding quality and statistical control dimensions as well as using total quality management (TQM), theory of constraints (TOC), and risk management into control methods. The authors conclude that cost and schedule are insufficient alone to control a project and that the other methods show promise in

improving project control (Rozenes et al., 2006). This also supports the current effort since the current model integrates cost, schedule, and performance and can easily accommodate additional measures. It is also important to note that while control systems like TQM and TOC are good tools they are hard to implement effectively and require subject matter expertise while the current approach is relatively simple.

Other research has recommended the use of agent-based modeling to assist with new product development. McCarthy, Tsinopoulos, Allen, and Rose-Anderssen (2006) provide a complex adaptive system (CAS) to model NPD processes. The authors note that a CAS approach allows non-linearity, self-organization, and emergence (McCarthy, Tsinopoulos, Allen, & Rose-Anderssen, 2006). The authors provide a literature review, overview of approach, and application to several case studies. They also note that a major weakness in the CAS approach is that it often assumes randomness where there may be a direct relationship (McCarthy et al., 2006). This approach is similar to the current effort but utilizes a different modeling technique. No model was provided but it is likely that the model will be more complex than the one in the current effort which may minimize its utility. It would be valuable future research to compare the results of the two models for possible optimization of both.

Pundir, Ganapathy, and Sambandam (2007) conducted research into the ideal method of managing projects. They discuss that the traditional view of project management is made up of a clearly identified objective, a temporary organization, and cost, schedule, and performance metrics (Pundir et al., 2007). They continue by saying that these elements are not sufficient to manage complex projects and in fact what works in one project management situation may not work in another. These authors further define

project complexity by referencing Baccarini's 1996 research on differentiation and interdependency (cited earlier) as well as Williams' 1999 work on structural complexity (also cited earlier). They then conclude that a complex project is one that is difficult to control and execute and that management must allow a management style to "emerge" instead of strict formal control mechanisms (Pundir et al., 2007).

Professor Anbari (2003) discusses the elements of earned value management in an article. He states that EVM can provide signs that projects need changes by using cost and value as metrics, but he warns that it assumes that past performance will continue as it currently behaves into the future (Anbari, 2003). He further notes that this tool was used as early as the 1800s in industrial applications but was formally introduced by the U.S. government in the 1960s (Anbari, 2003). The author then provides extensive details on how to calculate and utilize the elements of EVM. This article provides good understanding of the nature of EVM and the fact that it is a tool that can help project management in some situations. The current approach will complement and provide an alternate tool that may prove more useful.

An alternative to PERT and CPM methods, earned value management (EVM) is often recommended for improved project control. Vanhoucke and Vandevoorde (2007) describe the components of EVM and run three EVM approaches using simulated data to draw conclusions. The authors begin by stating that they assume there are no unforeseen issues or unknown interactions between project activities. They also add that EVM provides an integrated progress of cost, schedule, and performance with the measures designed to flag concerning behavior. The authors highlight a major weakness in EVM in that the results can be biased due to rework. They also find that how the project

network structure is created will greatly influence EVM accuracy especially at project completion. The authors conclude that more work is needed to develop project tools for use in specific circumstances (Vanhoucke & Vandevoorde, 2006). This research demonstrates that EVM at its current state is not a methodology that should be used to help improve project management, especially in the DoD. The conclusion about a project tool for specific contextual needs also supports the approach of the current effort.

Lipke, Zwikael, Henderson, and Anbari (2009) provide additional research into the ability of improving project outcome estimates using EVM. The authors provide an overview of EVM as well as a variation called earned schedule that leads to time-based indicators instead of cost-based indications in standard EVM. They also highlight that other research has found that earned schedule is a better predictor of project duration than EVM methods. The authors believe this method will help project forecasting (Lipke, Zwikael, Henderson, & Anbari, 2009). While the earned schedule method may be improved over other EVM methods, neither method allows dynamic interaction of cost, schedule, and performance. EVM methods only evaluate two of these elements at any time where the current effort allows all three metrics to interact and adjust dynamically as the project progresses.

Other research has discussed the value of EVM in NASA which is another government agency with a complex acquisition system similar to the DoD. Kwak and Anbari (2012) note that cost and schedule control systems were begun by the U.S. DoD in the 1960s and are still in effect due to the public's desire to have governmental performance metrics. The authors do state that EVM is a tool for "… measuring financial and project performance" and note that NASA EVM metrics only involve cost

and schedule limitations (Kwak & Anbari, 2012). While this research supports the use of EVM within NASA, there is other research questioning the value of EVM as well as its checkered history within DoD use.

A recent extension of EVM is that of earned schedule. Lipke (2011) provides a discussion of its use and value using notional data and incorporating stop work and down time. The author notes that the method estimates project duration as well as completion date. In this study, the estimates provide reliable estimates, and the author recommends earned schedule to estimate project duration and completion (Lipke, 2011). While this method may have value, it does not integrate cost, schedule, and performance nor does it mitigate the major assumptions previously noted with EVM.

Khamooshi and Cioffi (2009) explore the use of a contingency budget in project costing. The authors highlight the need for flexibility in the presence of extensive uncertainty and note that often an arbitrary percentage of total cost is determined for contingencies. The authors then take a relatively simple three risk example and using a binomial distribution plot the varying probability distributions with five varying probabilities. From there the authors derived an equation based on number of risks and average risk probability to determine the amount of contingency budget needed. From this, the authors conclude that the use of an arbitrary number is not effective in today's environment to determine the amount of contingency budget needed (Khamooshi & Cioffi, 2009). This recommendation was initially considered as an alternative approach but ignored when the focus was reduced to that of the government project manager. Within the U.S. DoD, the current regulations do not allow for a contingency budget in projects so this technique would not be possible. However, the current model could be

used in varying case studies to provide an empirical estimate of what amount of contingency budget might be needed in DoD acquisitions should leaders wish to explore that option.

Vanhoucke's 2012 research evaluated the impacts of impacts of project control techniques on project schedule only. The author utilized fictitious data as well as 8 real-world Belgian projects to evaluate his approach. He notes that project scheduling originated within operations research and initially utilized CPM and PERT (Program Evaluation and Review Technique) (Vanhoucke, 2012). Despite the advances in more advanced methods, project managers continue to utilize the "basic" methods due to the uncertainty inherent in real-world projects (Vanhoucke, 2012). The author utilizes schedule risk analysis (SRA) and a variation of earned value management (EVM) to generate several conclusions. First, he notes that there is a large degree of variation in results due to the identification of critical and non-critical activities (Vanhoucke, 2012). Second, EVM project control is preferred in a "serial structure" while CPM in conjunction with SRA is preferred with many parallel activities (Vanhoucke, 2012). This research demonstrates the potential for project management research but qualifies it with the idea that it should be simple to be utilized.

Collyer, Warren, Hemsley, and Stevens (2010) conduct grounded theory research on improve project management methods from 37 interviews in 10 industries. These authors also note that traditional project management tools are inadequate in meeting the dynamic nature of current projects. They also highlight that the PMBOK and traditional wisdom prescribes extensive planning and strict control but that these approaches will not allow a project to keep up with today's rate of change. The authors determine that shorter project

deliveries, adaptability, emergent planning, and constant exploration of alternatives are all successful practices in the dynamic environment (Collyer, Warren, Hemsley, & Stevens, 2010). These results are largely based on opinion with little data to support, but they do provide several ideas on ways to improve project management. Any of the recommendations could be utilized with the current effort to improve project management results.

2.1.4 Project Management and System Dynamics

In 1993 Cooper highlights insights the significant shortcomings in traditional complex development project management (K. G. Cooper, 1993). He notes and recommends the use of system dynamics to help improve our understanding of the nature of complex development project management and further highlights its use in evaluating rework with the Litton ship design project as well as over 60 others (K. G. Cooper, 1993).

Rodrigues and Bowers (1996) address traditional project management methods as work breakdown structures, Gantt charts, network techniques (PERT, CPM, PDM, GERT), cost schedules, and earned value. They also note that most project managers are firefighters who avoid strategic decisions. The authors also mention that a good project management system should be able to successfully handle any internal or external influences. They also note that project control relies on perceptions of the project status that is not always accurate. The authors review their dynamic hypothesis that has planning, human resources, implementation, and control elements and provide a very good comparison of elements between traditional methods and system dynamics. Finally, the authors conclude that a combination of both traditional approaches and system dynamics for the best project management (Rodrigues & Bowers, 1996b). This

article supports the use of system dynamics.

Rodrigues and Bowers (1996) also highlight the shortcomings in traditional project management methods and advocate the use of system dynamics. They note that traditional approaches are linear and assume the sum of the parts will provide an estimate of the total project. The authors advocate the use of system dynamics to better view the project as a whole, to improve traditional methods weaknesses, and to incorporate more subjective factors on the project outcome. They review a brief history of the use of system dynamics in project management and state that the first general use was in 1964. The authors mention up until their article the focus of most of the system dynamics in project management is focused on research and development or software development. They conclude by noting that the best project management would include both system dynamics as well as traditional elements (Rodrigues & Bowers, 1996a) .

In Rodrigues and Williams' 1998 research they take an alternate approach by evaluating client behavior within project management. They note that the two main methods of client interaction are through milestones and project reviews. The authors introduce their model and apply it to developing a fire control system for a Korean destroyer. They conclude that system dynamics can provide a valuable tool to project managers (Rodrigues & Williams, 1998).

In Black and Repenning's 2001 research, rework-focused system dynamics models from new product development projects where multiple projects are being conducted simultaneously are used to highlight the need for more resource application to early project functions. The data is taken from the authors' commercial work. They note the consistent project management theme of the criticality of "realistic schedules and

appropriate amounts of resources" (Black & Repenning, 2001). They also note that humans are "not very good at learning in dynamic environments, especially when there is little repetition in events and long delays between cause and effect" (Black & Repenning, 2001). These authors break down phases into early and current with design, test, and revising activities in each phase. Quality is measured as the percentage of correctly designed and launched parts per year. The authors use the model to deliver insight on quality by year of a product through testing and find that less than 40% change or less from the base case allows no "significant degradation of long-term performance" (Black & Repenning, 2001). Also of note, once performance suffers it never regains itself. The authors title the change in allocation from early to current phase as "tilting" (Black & Repenning, 2001). The authors also change the delivery of a prototype and find that this did not prevent titling or create a more "robust" system. They note the three conditions required to performing defect identification well as having appropriate resources to complete early design so that testing is useful, having appropriate testing for launch timing, and having appropriate resources for testing procedures (Black & Repenning, 2001). An option is discussed where managers do not act on improving some identified defects that does increase longer term performance if the proper (unimportant) defects are chosen to be ignored. Another option was discussed with regards to postponing projects that result in an oscillating reduction of performance over time. The best option explored is one where incomplete work is removed from the project scope which results in a single performance degradation followed by a rapid return to initial performance. The authors do caveat that this decision must be well timed at approximately 8-10 months ahead of launch (Black & Repenning, 2001).

Repenning, Goncalves, and Black (2001) continue the study of "firefighting" in projects where large amounts of unplanned resources are applied near the end of product development to resolve unexpected issues. They note that when this firefighter behavior starts occurring in an organization that it continues and becomes the dominant behavior at a tipping point. They add that frequently this occurs in a multi-product development situation where the product closest to completion gets more unplanned resources. The authors highlight that a temporary resource allocation could create permanent performance decline due to the self-reinforcing nature of firefighting where other projects are falling further behind and will require more unexpected resources. They also highlight that the tipping point is determined by the amount of resource utilization where an organization with full resource utilization is very likely to reach its tipping point. The authors further propose that this behavior begins in early development when most experts agree the most resources need to be applied but instead they are applied to other projects closer to completion. Furthermore, the feedback perceived by managers that additional resources are helping more developed projects is more immediate than the feedback of the problems in the newer project. The authors recommend that to avoid firefighting an organization needs to consolidate resource planning and work on fewer projects, to cancel projects earlier, to avoid applying large resources to more developed programs, and to avoid rewarding workers for saving problem projects (Repenning, Goncalves, & Black, 2001). This behavior may be involved to some degree in DoD project management, but it is believed that the larger programs studied have dedicated resources that may prevent this firefighting situation. Nevertheless, the author was aware and looking for the evidence of this behavior when developing and testing the model.

Lyneis, Cooper, and Els also utilize a system dynamics model in support of strategic project management in a DoD application. However, in this case the perspective taken was from the commercial developer and not the government. The authors note that a survey by the organization now known as the Defense Acquisition University found that the average cost overrun was 45% and average schedule overrun was 63% for the development phase of major defense systems (Lyneis et al., 2001). The authors note that PERT and CPM tools were developed in the 1950s and have advanced but are still not effective for mitigating the dynamic complexity of projects by taking too narrow a view or viewing the project in a static nature. Noting that project are complex, dynamic systems, they recommend the use of system dynamics especially in the area of strategic project management which they define as the "decisions taken up front in designing the project, and then the guidance provided to operational decisions that considers the longer-term impact of these decisions on downstream performance of the project" (Lyneis et al., 2001). Lyneis et al. then describe their four stock model that was successfully used by Hughes to deliver the Peace Shield air defense system six months and 13 deals head of schedule, on budget, and to all performance requirements of the U.S. Air Force (Lyneis et al., 2001). The authors recommended continued and expanded use of system dynamics in conjunction with the continuous integration of lessons learned. The current research utilizes much of the components of this research within its framework as well as in its motivation.

Ford, Lyneis, and Taylor (2007) provide preliminary system dynamics model results from three common project management techniques on project performance. They note that system dynamics has a rich history of supporting unintended consequences of

decisions but has not provided as much insight into the specific actions that best support project management (Ford, Lyneis, & Taylor, 2007). They reference Lyneis and Ford's 2007 work that address the four basic drivers of project behavior as a rework cycle, negative feedback loops, ripple-effects, and second (or "knock-on") effects (Ford et al., 2007). As they present their model, the authors have included five stocks that are the initial backlog, a quality assurance backlog for incorrect work, a quality assurance backlog for correct work, a rework backlog, and work released. Using generic inputs, the authors then modeled three management responses of increasing pressure for work intensity, working overtime, and hiring additional staff (Ford et al., 2007). They conclude by noting their use of validation and verification practices as defined by Sterman (2000) and illustrating some sensitivity analysis that they had done with the model.

Dillard and Ford (2009) use two case studies to evaluate the risks of evolutionary acquisition in DoD acquisition. They begin by noting that project risk includes variety and complexity. The authors then discuss many of the risks of evolutionary acquisition especially for long-term development, maintenance-intensive, and binary key requirement projects and recommend an understanding that although evolutionary acquisition helps mitigate risks it creates others that must be managed (Dillard & Ford, 2009).

2.1.5 Project Management and DoD

There have been comparisons of the defense and commercial industries. A notable one reviewed the rework cycles within 21 software development projects in defense and in commercial companies. The authors note that only half of the development project

cost and schedule estimates are met. The authors also propose that rework causes most of the project cost and workload with undiscovered rework as the largest source of cost and schedule overruns. They recommend an approach of managing the rework for best success. The authors then compare several metrics between the defense projects and commercial projects. They highlight that defense projects take approximately three times the planned hours while commercial projects take approximately 1.4 times. The authors attribute much of this to defense midstream requirements changes which do not occur as often in commercial projects. They also highlight that about 34% of the initial defense work required rework while only 68% of the initial commercial work required rework and attribute this to the cost and schedule variations. The authors conclude by recommending that all project managers, and especially defense ones, should focus on initial quality and rework discovery to improve quality, reduce rework, and decrease costs (K. G. Cooper & Mullen, 1993). This proves that there is a great deal of opportunity for improvement of defense projects. However, the defense projects reviewed are from a perspective of actual production or manufacturing as opposed to the pure project management that the government project managers are performing. That research gap is where the current effort is aimed.

A major cornerstone of defense project analysis was conducted by Tishler, et al in 1996 when then analyzed110 Israeli defense projects for common success factors using a multivariate analysis of four factors. Like others, they note the beginnings of the formal approach to project management in the 1950s with the invention of the PERT tool and that there is limited theoretical basis and no common terminology. The authors then note that defense projects differ from other commercial projects because they are “large,

complex, and interdisciplinary" and that they extensively use cutting edge technology (Tishler et al., 1996). They further mention that defense projects are less analyzed and many of the results of defense project analysis are not available for public consumption. The authors also highlight that traditional cost, schedule, and performance metrics with cutting edge technology will often provide poor progress. Within this study, the authors evaluated projects with six groups of variables and four measures of success. Of the factors evaluated, the authors found that the "urgency of need" projects had the greatest possibility of success followed by quality of initial definition team then pre-project preparation and then the quality of the PM and development team (Tishler et al., 1996). It is interesting that the use of systematic cost, schedule, and performance control measures was ranked eighth. The authors conclude by highlighting that this research has a weakness in that all projects vary significantly based on the environment in which it was executed (Tishler et al., 1996).

Ferrara's 1996 article provides an overview of the history of the DoD acquisition process guiding documents. He starts off by first claiming that the DoD acquisition system is "undeniably complex" (Ferrara, 1996). He additionally notes that the DoD has changed its guiding documents nine times since the initial baseline was provided in a May 1970 memorandum by then Deputy Secretary of Defense David Packard that was designed to improve DoD acquisitions management (Ferrara, 1996). Ferrara concludes that consistent themes within all versions of these documents is the need for more change and improvement, "the importance of centralized policy-making and decentralized program execution", the need to conduct extensive test and evaluation before full production, low numbers of management levels, low reporting requirements, and the need

for stable programs (Ferrara, 1996). Furthermore, Ferrara adds that the largest reason for each revision was a change in the presidential administration (Ferrara, 1996).

Some studies have compared the DoD acquisition process to commercial product development. Chew (1997) reviews the Chrysler process against the DoD process. He begins by mentioning that at the time of his article there had been nine revisions to the DoD acquisition policy since its origination in 1971. One of the first differences he notes is that many commercial development timelines last two to three years while DoD timelines last seven to twelve years (Chew, 1997). Chew concludes that there could be more time and funding spent in the formation of DoD programs and that program stability needs to be improved (Chew, 1997). This article supports the need for further refinement of DoD acquisitions, and the current research could help accomplish better early analysis of program details as Chew recommends.

Christensen and Gordon (1998) offer research into the impacts of DoD's rebaselining, especially in regard to costs. The authors note that cost growth is not the same thing as cost overruns because an increase in budget to account for a new requirement will have cost growth but not necessarily cost overrun. They further state that a change in project scope does not guarantee cost overrun and mention that their defense contractor data statistical analysis supports this by finding no correlation between cost overruns and baseline volatility (Christensen & Gordon, 1998). This research provides more context for the current research and supports the exclusion of requirements change as a fundamental element of why DoD acquisition projects fail to meet their cost, schedule, and performance goals.

Other researchers have evaluated whether a different control mechanism would

potentially improve results in defense acquisition. Bhuiyan and Thomson (1999) discuss the extensive resources that are required to meet major milestones, especially time. The authors estimate the total lost time to be approximately 150% of the approval time in these major milestones which can provide significant changes to resource requirements (Bhuiyan & Thomson, 1999). The authors advocate a stable requirement level which they believe is best accomplished through continuous approvals. Using a several Canadian defense case studies and simulation, the authors find that continuous approvals reduce the project time by approximately 30% and if used in conjunction with concurrent activities could realize close to 50% total time reductions (Bhuiyan & Thomson, 1999). These results rely on several assumptions and would require significant culture changes in the defense approval process. However, they do represent one method of improvement to the DoD acquisition system that was considered but ignored given the scope of the current effort on government project manager as opposed to larger defense acquisition system.

In 2008 Dr. Steven Meier who is both a PhD and a practicing government project manager studied several DoD and intelligence community (IC) major acquisition projects through requests for information (RFIs), reports, and interviews to determine the cause of cost and schedule overruns. He begins by noting that large failures have problems at the inception of the projects. The author attributes a great deal of cost and schedule problems in DoD and the IC to "overzealous advocacy" which manifests itself in unrealistic cost, schedule, and performance estimates as well as a lack of immediate reporting of problems. He also notes that short senior project manager terms hinder effective accountability and leads to poor performance. The author notes that this situation also

leads to a situation where many project managers cannot recognize the unrealistic cost, schedule, and performance estimates until too late. Dr. Meier further highlights the fact that most government acquisition projects utilize unproven cutting edge technology citing that studies have found that one GAO study found that only 67% of government acquisition projects used mature technologies at the product decision (Meier, 2008). He adds that the same data shows that once a project gets behind cost, schedule, or performance with regard to technology development it stays behind (Meier, 2008). The author then mentions that requirements growth is another significant influence on cost and schedule overruns as is the reliance on contractor cost estimates in a low bid environment due to the consolidation of many contractors. He does add that a 20-25% management reserve can help mitigate both of these issues, but that many government agencies will not allow that practice (Meier, 2008). Dr. Meier concludes by recommending the changes associated with each of the aforementioned issues as well as improved system engineering practices early in project development and definition (Meier, 2008).

Kwak and Smith (2009) have reviewed DoD acquisitions policies with a focus on risk management. The authors begin by noting that there are very few DoD project management studies. The authors also state that the DoD policies focus on meeting milestones but ignore the role of understanding project cost and performance influences and risks (Kwak & Smith, 2009). They also highlight the lack of DoD project manager evaluation of contractor cost estimation and adding that most managers assume the contractors are submitting accurate estimates (Kwak & Smith, 2009). The authors conclude that the biggest challenges to DoD acquisitions are the inconsistent application

of the policies and the lack of accountability of DoD officials (Kwak & Smith, 2009). The current effort should reinforce this research through the use of empirical results.

Sherman and Rhoades (2010) attempt to apply commercial product development ideas into defense acquisition to reduce cycle time. They start by stating that the defense sector is approximately four percent of the U.S. economy and the largest research and development industry (Sherman & Rhoades, 2010). The authors mention that the defense acquisition differs from commercial product development in that the system developers (requirements managers) are independent from the project management office, the punishment for cost overruns is less in defense, and the defense industry must adhere to the Federal Acquisition Regulations (FAR). Sherman and Rhoades mention that the DoD has been attempting to make its acquisition system more flexible since 2003, especially with the evolutionary development approach (Sherman & Rhoades, 2010). The authors also highlight the four conditions that must exist for a reduction in defense cycle time as higher technology maturity, use of more standard components, large support for the program, and a flexible process (Sherman & Rhoades, 2010). While the recommendations offer some potential for improvement, the assumptions (i.e., "conditions") are extensive and a significant change from the current culture and approach. Many of these conditions are also outside of the control of the project manager which may make them hard to implement unless mandated by the senior leaders.

Continuing his research in 2010, Meier utilized previous defense science board (DSB) findings, personal interviews, and RFIs to defense industries to best determine the causal factors in "large-scale DoD and IC acquisition programs" cost overruns and schedule delays. The author concludes that there are three primary reasons for these

problems. First, the DoD and IC utilize poor human resources approaches by not providing more experienced personnel in critical decision-making positions and requiring frequent rotations (Meier, 2010). Second, Meier notes that there are too many stakeholders involved in the development process which leads to changing requirements and additional program office work that is not originally budgeted (Meier, 2010). Third, the reduction of number of companies in the DoD industry that "…has resulted in aggressive bids by industry to win government contracts", and such actions cause poor estimates of true costs and schedules with limited ability to be refuted by the inexperienced decision-makers (Meier, 2010). The author provides interesting insight without producing any rigorous or statistical analysis and only makes a recommendation that the culture change.

Developing a large model of the entire DoD acquisition system is not completely new. Wirthlin, Houston, and Madachy (2011) have created a discrete event simulation model to best identify leverage points. They note previous DoD simulation studies mostly focusing on software development including one that was a system dynamics model. They also note results from their simulations that indicate approximately 75% of formal projects achieve fielding but that programs starting at the earliest point in the system only have a 60% chance of success as opposed to other entry points that have an 85% chance of success (Wirthlin, Houston, & Madachy, 2011). These insights are informative but are likely explained by the degree of technological maturity of projects entering later in the system. This model is also a large and complex one that is not easily explained or communicated. The current approach improves on this goal by using a simpler, easy to understand, model to achieve potential improvement.

An interesting observation is also noted by Kahneman who states that, “Contractors of kitchen renovations and of weapon systems readily admit (though not to their clients) that they routinely make most of their profits on additions to the original plan.” (Kahneman, 2011). This supports the notion that the current DoD defense acquisition system by its nature has created a ripple effect by encouraging contractors to underestimate initially and expect profit in changes during project execution. While this certainly has an impact on the dynamics in defense acquisitions, it is also outside of the scope of the perspective of the government project manager that the current effort is taking.

The Government Accountability Office (GAO) has conducted multiple research and testimonies on the DoD acquisition system. In fact, they provide a yearly report on major systems and their current status. One GAO testimony found that 47 projects have had 74 Nunn-McCurdy breaches since 1997 (Sullivan, 2011). The testimony describes the Nunn-McCurdy process as a benchmark for Congressional oversight of defense projects where a project breaches when its unit cost is 15% over the current baseline estimate or 30% over the original estimate. The GAO testimony further notes that the design problems, schedule problems, and quantity changes were the primary causes of Nunn-McCurdy breaches (Sullivan, 2011). The testimony concludes by highlighting the DoD culture that supports the undertaking of projects with too many unknowns (Sullivan, 2011). This testimony supports the need for DoD acquisition improvement and the ability to evaluate options to avoid a Nunn-McCurdy breach which the current model can easily accommodate.

2.2 Complex Systems

Project management has been defined as a complex system (Lyneis et al., 2001) as has the DoD acquisition system (Ferrara, 1996). Therefore, it is important to start with an understanding of what a complex system is. Much research has attempted to define and describe what a complex system is, and there are multiple views (Pundir et al., 2007). One of the major divides is over whether uncertainty causes complexity or vice versa (Pundir et al., 2007). Whitty and Maylor have highlighted the diverse definitions of complex within project management domains and conclude that complexity is a variable likely measured in degree but without any standard metric (Whitty & Maylor, 2009). These authors note that uncertainty is an element of all projects, but the key to understanding complexity is the lack of understanding of the state of the system and the inter-relationships of its components (Whitty & Maylor, 2009). Ivory and Alderman support and extend these claims with a broader review of complex system research and note the presence of non-linearity, non-equilibrium, and multiple interdependencies in complex systems (Ivory & Alderman, 2005). They add that projects are planned and executed around assumptions that often are incorrect or change due to "social or technical realities" (Ivory & Alderman, 2005). It is important to highlight here that non-linearity is defined as the sum of components not equaling the total system (Pundir et al., 2007).

Within a system, any component can be optimized given a set of conditions, but the combination of many components that all have a unique set of conditions makes for a very complicated challenge (K. G. Cooper & Mullen, 1993; Rozenes et al., 2006). To further complicate these systems, the results of these interactions may not manifest themselves quickly or as a result of any one change despite our best efforts to attempt to

tie a causal reference to a short-term or single event (John D. Sterman, 2002). This desire for understanding will frequently cause project managers to focus on short-term decisions that may have negative long-term results (Shenhar, 2004). Moreover, these results may be misunderstood or thought to be outside of the control of the project manager (Ivory & Alderman, 2005).

One of the earliest studies of complex systems and elements of systems thinking was conducted by Berndt Brehmer who utilized a computer simulation to evaluate firefighting leaders' reactions to a complex scenario. Brehmer noted that feedback delays are present in these systems and that there was little research on the effects of these delays (Brehmer, 1989). He postulates that efforts to control a complex system given the feedback delay will cause oscillatory effects and that a significant part of the impacts are based on the knowledge of the presence of the delay (Brehmer, 1989). Brehmer further divides delays into either a constant delay that is relatively easy to understand or a slow reporting delay that is more difficult to be aware of or to understand. The results of Brehmer's studies show that people can rapidly adjust to the constant delay but often struggle to deal with delays that they are unaware of (Brehmer, 1989).

Sterman (1994) proposes that system thinkers see the world as a complex system with all learning based on feedback. He notes that simple feedbacks, such as single loops, do not provide much change in our mental models while double-loop feedbacks help advance the systems thinking goals of a "holistic, broad, long-term, dynamic view" (John D. Sterman, 1994). He further notes that time delays prevent learning and dynamic complexity reduces the amount of learning gained on any feedback loop iteration (John D. Sterman, 1994). Moreover, Sterman adds that complex systems evolve over time and

are inherently unstable, especially with time delays that frequently cause oscillation of system behavior (John D. Sterman, 1994). The author further mentions that our learning is always influenced by "distortions, delays, biases, errors, and other imperfections, some known, others unknown and unknowable" that cause misperceptions (John D. Sterman, 1994). He adds that in complex situations people often ignore the impact of time delays and feedbacks in an attempt to better understand a simple version of what is taking place (John D. Sterman, 1994). This, in turn, leads to degraded performance. Sterman concludes by recommending that the barriers to learning that complex systems present must be overcome with integrated, multi-disciplined approaches and tools. It is exactly these types of tools that this research is attempting to utilize to better understand and learn about the complex system of DoD project management.

Sterman continues his research with Diehl in 1995 with results of experiments on dynamic decisions with complex feedback. They begin by defining a dynamic decision as a decision which changes the system state and future decisions. They also define dynamic complexity as tasks that involve non-linearities, feedback, stocks and flows, and time delays. Diehl and Sterman then note that decision-makers usually ignore feedback, do not recognize or incorporate delays, and cannot understand non-linearities as has been proven in experiments in multiple domains. The authors include a key element of system dynamics in this research by noting that decision makers do not control a stock but rather only the inward or outward flows affecting the stock. Following a discussion of the experiment and its results, the authors note that the subjects' performance was poor and any control method utilized was on average worse than no control methods. They also highlight that subjects focused too much on stocks and ignored the flows as well as time

delays in reports (Diehl & Sterman, 1995). This research supports the approach taken in the current effort with experimentation research on the inability to make effective decisions in a dynamically complex environment. Therefore, the model developed in the current effort could be used to help guide DoD acquisition decision-makers.

Baccarini (1996) provides a literature review on project management project complexity. He states that construction projects have grown increasingly complex since World War II and that "… project-based management is frequently associated with the management of complexity" (Baccarini, 1996). He further mentions that one of the major challenges with complex projects is an unclear understanding of project goals and objectives (Baccarini, 1996). Baccarini further defines project complexity as having interrelated parts that have "differentiation and interdependency", and since it may apply to any aspect of a project, he recommends specifically stating the type of complexity (Baccarini, 1996). Furthermore, he notes that complexity is unique and must not be confused with size or uncertainty (Baccarini, 1996). Baccarini concludes by looking at the two most common project management complexities of organizational complexity and technological complexity and the sub-elements of each.

A similar article that expands on Baccarini's research is Williams' 1999 article on complex projects paradigms. Williams begins by stating that there is no clear definition of a complex project and uses Baccarini's definition. He adds that "first- generation tools (e.g., PERT)" have a weakness in assuming that there is a continuous and constant flow of work during the project (T. M. Williams, 1999). He then combines Baccarini's descriptions with Shenhar's framework of structural uncertainty and uncertainty and extends two elements within each. He notes that structural uncertainty can be assessed

by counting the number of elements and the interdependence of those elements while uncertainty can be measured in uncertainty in goals and uncertainty in methods (T. M. Williams, 1999). The author further states that the uncertainty in goals is very difficult to measure, that complexity can change over a project lifecycle, and that as projects continue to reduce timelines they will become more complex (T. M. Williams, 1999). He concludes by recommending adding stochastic elements to network models, incorporating more soft measures of performance, and the increased use of system dynamics (T. M. Williams, 1999).

Research from organizational science has also touched on complex systems and the theory behind them. Anderson (1999) notes that complexity can be a part of an organization or the environment it operates in. He adds that due to the intricate and nonlinear nature of complex systems many have avoided researching the subject. He notes multiple from complexity research that include the facts that complex systems may never reach equilibrium, may never return to a previous state, may be very sensitive to small changes, may not allow "reductionist analysis" (where one part of the system is studied in isolation), may have simple rules of behavior, and may have rules of behavior that change over time (Anderson, 1999). The author also mentions that system dynamics has been a successful method of addressing complexity and complex systems. This article supports the use of system dynamics in the study of the complex system of DoD project management.

Singh and Singh (2002) provide an overview of how complexity and chaos theory apply to project management. They note that chaos theory is non-linear and runs counter to traditional logic. They also add that dynamic systems become complex when they

change over time with no definitive reason. The authors advocate for an iterative and holistic approach to better mitigate the complexity by looking for non-linear and more subtle influences as opposed to heavy reliance on quantitative analysis and strict controls (Singh & Singh, 2002). This further supports the emergence approach to project management and the one that the current research is taking to develop a better means of project management that deals with the complexity inherent in the system.

Vidal, Marle, and Bocquet (2011) expand on the understanding of complexity in project management. They note that the metrics, resources, and environments of projects are always changing which make them very complex and offer that cost, schedule, and performance are often not appropriate to best measure a project at a given time (Ludovic-Alexandre Vidal, Marle, & Bocquet, 2011). These authors mention that there is not a universally accepted definition of project complexity but recommend measures of complexity along the scales of computational complexity, graph complexity (i.e., "task graph or organization graph"), and information complexity (Ludovic-Alexandre Vidal et al., 2011). However, the authors take care to note the limitations of using each of these measures. Within the scale of computational complexity, the authors note that there is no measure of the complexity of the stand-alone system (Ludovic-Alexandre Vidal et al., 2011). Within the graph complexity scale, the authors mention the lack of reliability due to similar complexity but different requirements for control (Ludovic-Alexandre Vidal et al., 2011). Within the information complexity scale, the authors add that often unskilled users may not be able to accurate assess or analyze these measures (Ludovic-Alexandre Vidal et al., 2011). In this research the authors then utilize the multi-criteria decision-making method of the Analytic Hierarchy Process (AHP) with several project managers

to evaluate the relative complexity of a case study.

Rework has also appeared in complex systems studies. Yu and Efstathiou (2005) review the impact of rework in complex systems. They begin by mentioning that rework involves the two functions of inspection and repair but that a rework task once completed must also be reinspected. They also add that frequently it is more economical to scrap work than to attempt to rework the problem. This leads a reworked item to have multiple options for repair. The authors then qualitatively evaluate methods of rework against level of complexity, cost, and quality and offer some recommendations for several options of rework design. They conclude that complex rework never helps but when it cannot be avoided, there is a trade-off between cost, quality, and further complexity (Yu & Efstathiou, 2005). This research provides a similar study to the current one by reviewing a limited set of options among inter-related measures with results that there is no perfect solution.

In 2006 Nassar and Hegab propose a complexity measure for project schedules. They begin by mentioning that project schedule complexity is unique to the project's total complexity because the project schedule complexity denotes interdependencies. The authors also highlight that traditional project management tracking measures fail to effectively estimate complexity and fail at risk management. Nassar and Hegab then present their complexity measurement methodology and compare it to different methods of measurements. They conclude noting that their method is relatively simple to understand and can be rapidly used by project managers (Nassar & Hegab, 2006). This article further supports the need for new project management methods and tools as well as the need for a simple tool so that it can be usable by project managers.

Another set of authors provided another literature review on complexity in project management. Vidal and Marle (2008) state that project management began in World War II with construction and military projects and argue that every project is unique. They further argue that current project management methods do not work well due to the complexity of projects. The authors describe the two theories of complexity which are that complexity is a component of every system or that complexity is an individual's perception. They further highlight that the larger a project is the more likely it will be complex while smaller projects are usually less complex. They also state that about 70% of complexity is related to organizational functions as opposed to technical function (Ludociv-Alexandre Vidal & Marle, 2008). Vidal and Marle further note that due to the presence of complexity there is always uncertainty present that makes the true project status and impacts of decisions nearly impossible to predict with any accuracy. They also highlight that the "uncertainty propagation" creates even more problems in project estimates. Vidal and Marle then provide a list of requirements for a quality project complexity model. They list the items as important interactions and contexts identified, lack of superfluous details, validity, and understandability (Ludociv-Alexandre Vidal & Marle, 2008). The authors conclude by referencing and recommend a model they are developing called the "attributes, links, objects, and events (ALOE) model which has not been formalized or computed as of the publishing of the article (Ludociv-Alexandre Vidal & Marle, 2008). The project complexity model elements are useful and have been used in the current effort to ensure that its model meets academic rigor.

Whitty and Maylor (2009) provide an overview of the nature of complex project management as well as the standard and implications of one standard of complexity.

They begin by noting that there is no single universal definition of "complex" within project management and little to no tools to assist in project management (Whitty & Maylor, 2009). The authors define a complex system as one where the behavior of the system cannot be determined from the behavior of the system parts and complexity as "a measure of the inherent difficulty to achieve the desired understanding of a complex system" (Whitty & Maylor, 2009). They elaborate on this by adding that complexity is measured on a sliding scale as opposed to being a binary element with few consistent measures (Whitty & Maylor, 2009). Because of this scale, the need to use complex tools in the management of complex systems may not be required in all situations (Whitty & Maylor, 2009). The authors reject the notion that unforeseen events or uncertainty is a definite element of complex systems since uncertainty is present in all projects (Whitty & Maylor, 2009). They further state that complex systems are extremely difficult to predict, especially over a long run, and conclude that more research is needed to identify and validate successful approaches to complex project management (Whitty & Maylor, 2009).

Complex system design efforts also have some bearing on the current research. Deshmukh and Collopy (2010) report on discussions at a National Science Foundation sponsored workshop on complex system design. They note that complex system design challenges have resulted in cost overruns and schedule delays. They further note that the trend of complex project performance is getting worse instead of better within DoD and NASA. They also propose that systems engineering and risk management processes do not work with complex system design and that more work is needed to better understand complex system development as well as successful tools (Deshmukh & Collopy, 2010).

The authors ask a series of critical questions that need to be answered in future research to better understand complex system development. For example, the authors ask how component uncertainties inter-relate and propagate through system aggregation as well as how to measure flexibility in complex systems (Deshmukh & Collopy, 2010)

2.3 System Dynamics

Around the same time that project management began in earnest, system dynamics was also born. Jay Forrester of M.I.T. is frequently credited with creating the field of system dynamics (R. G. Coyle, 1996). Forrester notes that until the last 50-60 years it has not been necessary for people to understand the dynamic and inter-related systems that involve non-linear feedback but now it is critical (Forrester, 1971a). He further advocates that traditional "approaches" may not always work in current and future systems (Forrester, 1971a). A further benefit of system dynamics is being able to better understand the interaction between a system and its environment which is frequently considered external to many models(E. F. Wolstenholme, 2003). System dynamics have been utilized in multiple domains with great success from population dynamics (Forrester, 1971b) to public health and disease dynamics (J. B. Homer & Hirsch, 2006) to terrorism (Burns & Slovic, 2007) to construction industry (Love et al., 2002) to software development (Abdel-Hamid & Madnick, 1991), and in legal claims against the government on the part of industry manufacturers (K. G. Cooper, 1980) among others.

2.3.1 General System Dynamics

The "creator" of system dynamics Jay Forrester has provided extensive research and insight into system dynamics over the years. He began an article introduction in 1971.

Forrester notes that people cannot effectively understand how social systems behave due to the presence of multiple non-linear feedback mechanisms. He further adds that our social systems are often more complex and difficult to comprehend that technological systems. Forrester then discusses that every person uses mental models as decision-making tools and that these models are all "incomplete" to some degree based on the assumptions and relationships used. He also notes that these issues are also inherent in mathematical or computer models for the lack of awareness of the assumptions and relationships used. Forrester believes that we fail to correct social systems because these systems are generally not responsive to the policies most people try to exert, these systems have few "influence points" and most are not where people expect, and these systems have a difference between short and long term impacts where most people focus on the short-term. He advocates the use of "industrial dynamics" as it was called until that time and recommends the use of "system dynamics". The author then highlights results of some of his work on world population dynamics and advocates the further exploration of these system dynamics (Forrester, 1971a).

In 1986 he provided his lessons learned from the previous thirty years. He notes that system dynamics models should give insight into "puzzling or controversial behavior" (Forrester, 1987). He also mentions that complex systems are difficult to appreciate and understand but that system dynamics can better resolve multiple order differential equations that are behind many of these systems. Furthermore, system dynamics models can help evaluate when policies are causing problems or when actions intended to stop problems are making them worse. Forrester adds that these models must change the "way people perceive a situation" (Forrester, 1987). He further mentions that our mental

database has infinitely more information than our written database which has far more information than our numerical database. According to Forrester, a system dynamics model attempt to use data from the mental and written areas, especially to identify nonlinear relationships, while incorporating the numerical data for validation (Forrester, 1987). He states that an effective system dynamics model will be able to identify "surprising behavior" that may be a defect in the model or a new insight and may also provide "general characteristics that are applicable to a broad class of systems, or even to nearly all systems" (Forrester, 1987). It is this goal that the current research is attempting to discover in the area of DoD project management.

Forrester continues his research in an additional article in 1992 on more details regarding system dynamics. He begins by stating that the decision-making element of management is a conversion of information into action and a policy is a guide to daily decisions (Forrester, 1992). He then extends this concept to say that successful management involves selecting the right information and properly converting it into action. Furthermore, he notes that decisions are continuous and often do not have the absolute most current information available for use. Because of the complex interactions of sub-elements of systems, feedback loops cause growth, decline, goal-seeking, and oscillation behaviors according to Forrester (1992). He adds that stocks (or levels) are the "inputs to the flow of decisions" and decisions impact the flows into and out of the stocks (Forrester, 1992). The author breaks down decisions into the three parts of a desired state, an apparent state, and the controlling action to make the apparent state become the desired state. He continues by noting the presence of the level of perspective of a policy, the overcomplicating of a policy, and the lack of consideration for reasons of

a policy confuse many policy modelers (Forrester, 1992). Forrester goes even further to not that nonlinearity happens when the sum of the inputs do not equal the whole and when two or more inputs do not independently cause a response but their interactions do (Forrester, 1992). He also mentions that there are rarely more than ten inputs to any decision and that the presence of noise may be a factor to consider during modeling (Forrester, 1992). These descriptions and recommendations are all useful in the current research and are adhered to.

Forrester continues his insights into system dynamics by expounding on the incorporation of soft operations research in 1994. He provides a step-by-step process for converting a real-world problem into improvements. Forrester notes that system dynamics is about more than simply finding a problem but seeks to "… reveal the way we arrived at the present…" (Forrester, 1994). He further adds that the problems with strict reliance on harder operations research are the use of poor model selection (i.e., reliance on static and linear mathematical models) and too much academic focus rather than practical application. He then translates his insights into system dynamics modeling with one note that he starts with determining the system stocks and then finding what changes these stocks to develop the causal loops. Forrester concludes with the statement that a modeler must first understand why the present conditions exist before moving to solve the problems (Forrester, 1994).

Researchers other than Forrester have provided insight into the application of system dynamics. Professor Morecroft (1983) provides the relationship of system dynamics to decision making research. He highlights the concept of "bounded rationality" where performance is limited by the amount of information that can be absorbed, stored, and

processed effectively and states that this concept is at work in all social systems. He then looks at factored decision making, use of partial information, and standard operating procedures and how they are inherent in many feedback structures (John D.W. Morecroft, 1983). This research was very helpful in approaching the problem and developing the system dynamics model.

A British researcher R.G. Coyle has written two excellent resources. In his 1983 article he notes that system dynamics is essentially "… control engineering applied to non-engineering systems" (R. G. Coyle, 1983). The author then provides a six step process to conducting a system dynamics approach. He states the dynamic hypothesis (or influence diagram as it is sometimes called) is well developed when its results appear "remarkably obvious" (R. G. Coyle, 1983). He further offers questions and guidance for the validation and verification and then classifies system dynamics models and their utility into three areas. Coyle states that the first category of models is "closed models" which do not depend on external time-dependent variables and are used to test behavior mode based on alteration of variables. The second category of models is "driven models- end states significant" which do depend on time-dependent external variables and are used to determine the end state based on possible decisions. Finally, the third category of models is "driven models- robustness significant" which also depend on external variables and are used to make the system less responsive to changes in the variables (R. G. Coyle, 1983). Coyle's research is interesting and helpful to better understanding system dynamics, and his second model category of driven models- end states significant best describes the nature of the system dynamics model created in the current research.

Sharp and Price provide other insights into system dynamics and its usage. The begin

by highlighting that system dynamics is more tied to Forrester (the originator) than other fields of research and that system dynamics models focus on larger topics (Sharp & Price, 1984). The authors continue by noting major assumptions of system dynamics and its use. They emphasize that system dynamics models should replicate the manner in which information is actually used by decision-makers and often use variables with no data that are "aggregate" (Sharp & Price, 1984). They also extend Forrester's belief that the alignment with historical data is not the most important concern of system dynamics models by also adding that the estimate of unknown variables should provide validation and verification support for the model. The authors add that Forrester believes the general system dynamics model results should be "relatively insensitive" to change of variables (Sharp & Price, 1984). They conclude by noting key areas of operations research where system dynamics modeling is ideally suited of which one is that of solve "important" problems (Sharp & Price, 1984). The improvement of DoD project management is indeed an important problem where system dynamics could help.

Morecroft (1988) describes the major developments in system dynamics. He begins by defining the two major theories that system dynamics relies on as information feedback theory and behavioral decision theory. Morecroft adds that behavioral decision theory suggests that decisions are made with very few inputs and often according to simple logic. He further describes a decision's five information filters of cognitive limits, goals and rewards, information systems, structure, and tradition and culture which are commonly the focus areas of information actually used in a decision. The author concludes by providing several areas of future research (John D. W. Morecroft, 1988). All of these recommendations are used and applied in the current research and were

helpful in the research framework.

In 1989 Sterman reported on results of an experiment involving a simulated distribution system with 48 trials and 192 subjects. The author states that feedback involves both results as well as changes in the environment. He further mentions a system dynamics regulation that stocks can be controlled by flows going into and out of it. Sterman's results show that subjects failed to account for the supply line delay as well attribute the influences to external, uncontrollable events. He concludes by postulating that the subjects used an anchoring heuristic as a simple means of controlling a system they could not understand with the results of producing stable behavior at some times and oscillatory behavior at other times (John D. Sterman, 1989). This research is applicable as it likely explains why DoD project managers act as they do.

Lane and Smart (1996) discuss the nature of generic structures within system dynamics. The authors note that system dynamics was always intended to produce comprehensive insights from particular circumstances. They also add that generic structures have evolved with the study of system dynamics and are models that represent "theories of dynamic structure and behaviours" (Lane & Smart, 1996). The authors further highlight that the system dynamics' creator Jay Forrester believed that there were a smaller number of dynamic structures that were behind a large number of "significant dynamic behaviours" (Lane & Smart, 1996). Lane and Smart ultimately classify generic structures into the three uses of dynamic behavior within a specific application, abstract combinations of commonly observed behavior, or "counter-intuitive relationships between policy and behaviour" (Lane & Smart, 1996). The authors further recommend an early understanding of the use of a model will help determine validation and

capabilities and limitations of possible generic structures in system dynamics (Lane & Smart, 1996). This research provides further insight and guidance into the application of successful system dynamics, especially with the use of a generic structure as the baseline of the current model.

Professor Barlas (1996) offers a detailed overview of system dynamics model validation. He begins by noting that there is no standard approach to system dynamics model validation or even an established definition of model validation (Barlas, 1996). He also highlights that a model's validation must be tied to its purpose and that the process of validation cannot be a rigid, formal, and objective process. Barlas notes the difference in "purely correlational (black-box) models" as opposed to "causal-descriptive (white-box) models" (Barlas, 1996). The author notes that the key to black-box model validation is accurate output measured with statistical tests while the key to white-box model validation is internal model structure measured with informal and qualitative means (Barlas, 1996). He further adds that most system dynamics models are of the white-box nature, that statistical tests do not usually apply to them, and that the main system dynamics validation goal is to validate the structure of the model (Barlas, 1996). Barlas expands on the details of the many possible tests of model validation shown in Figure 2-1 as well as notes that there are many options of model validation tests. He concludes by emphasizing that the goal of model validation is to develop a "quality" model for its intended purpose (Barlas, 1996). This article provides the guidance and details for ensuring that the current model is validated effectively.

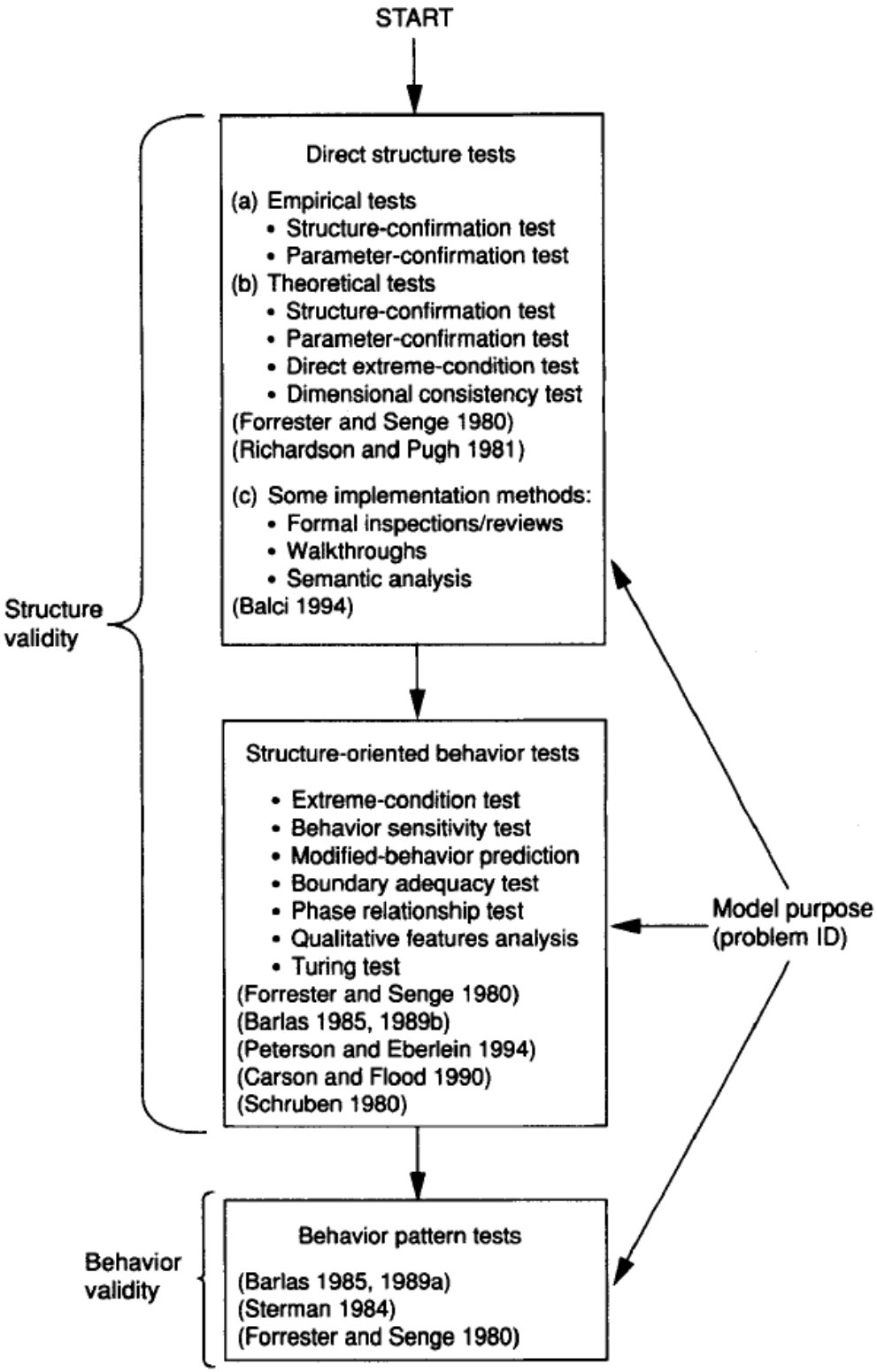

Figure 2-2: System Dynamics Model Validation (Barlas, 1996)

Professor Lane (2000) explores elements of system dynamics. He defines system

dynamics as "… the modeling of social systems using computer simulation, with practitioners working closely with problem owners to structure debate about long-term policy." (Lane, 2000) He defines system dynamics as having the three key elements of information feedback loops, computer simulation that explains dynamic behavior, and the use of mental models while being based on the idea of a dynamic hypothesis. Lane further highlights several arguments against the use of system dynamics that focus on the use of deterministic relationships that may not be reflective of humans or social situations. He attributes many of these conceptual misunderstandings to terminology differences and recommends the use of hard and soft inputs in system dynamics use (Lane, 2000). This article provides additional information on the nature and utility of system dynamics. It also provides several arguments against the use of system dynamics for understanding of the possible limitations of system dynamics research results.

Professor Sterman continues in 2002 with more of his perspective on research as a technical system dynamics expert. Like others before him, he notes that system dynamics relies heavily on control theory and non-linear dynamics. He also adds that most academics focus on complexity and system studies while most managers avoid complicated research, notably calculus and differential equations. Sterman highlights the value of systems thinking as it can be related in management terms without the complication of mathematics. He also mentions the critical system dynamics concept of "policy resistance" where actions taken to solve a problem fail or cause more problems and is caused by a "reductionist worldview" (John D. Sterman, 2002). He further notes that system dynamics can help prevent this limiting mental model with the basic elements of stocks and flows, time delays, nonlinearities, and feedback. The author then highlights

that while accuracy with available data is important it must be balanced with assumptions, appropriate boundaries and feedback structures, as well as the ability of the model to meet its purpose. He advocates using a sensitivity assessment to these issues as well as to the model variables to develop the best model possible. He concludes with a key element of systems thinking that offers the challenge to help others understand that, "All decisions are based on models, and all models are wrong." (John D. Sterman, 1989) This is another of the key motivations of the current research.

Saeed (1992) provides insight into methods of breaking a complex problem into smaller parts. He notes that gaining an appreciation of change and why it occurs is more important than an accurate forecast and that a model must be understandable. Saeed's recommended process is to create a "reference mode" that leads dynamic hypothesis and then a formal model. He then notes that once a formal model is achieved behavior tests are conducted. Saeed adds that models should be balanced between time separation, geographic separation, and simultaneous modes in order to produce the best model possible (Saeed, 1992).

Wolstenholme established an approach to system dynamics model development and analysis that he referred to as "a stepwise approach" (E. F. Wolstenholme, 1992). He notes that the model should be based on the creator's mental models and should have a clearly defined purpose. From there he recommends that one of two approaches (or a combination thereof) be used to create the model. The first approach is termed the "feedback loop approach", and it seeks to highlight and link the "feedback structures (or loops)" that cause common system behavior (E. F. Wolstenholme, 1992). The second approach is the "modular approach", and it seeks to highlight the sub-elements of the

system that cause the common system behavior (E. F. Wolstenholme, 1992). Wolstenholme further advises that the model time and level of fidelity must be considered as appropriate for the model's purpose. He further emphasizes that a key component of system dynamics is the change of state of resources where the states are commonly called "levels or stocks" and the change is commonly called "rate variables" (E. F. Wolstenholme, 1992). A key aspect of system dynamics is that only rate variables can be controlled, and this is major element of using the model to reach the ideal state (E. F. Wolstenholme, 1992). The final steps of the model creation are to incorporate delays and organizational boundaries that impact and cause inefficient systems (E. F. Wolstenholme, 1992).

Professor Wolstenholme continues his research in 1999 by discussing the use of quantitative versus qualitative modeling in system dynamics. He begins by stating that causal loop diagrams can be used independently in problem solving and that qualitative system dynamics is often termed systems thinking (E. F. Wolstenholme, 1999). The author further notes that other studies have found that more managers prefer qualitative analysis and often quantitative models produce results that are not understood or able to be applied to other situations. He advocates the use of both a qualitative and quantitative approach and recommends avoiding overly complicated models. Woltenholme then provides his seven step system dynamics problem solving process which he terms the "intertwined project learning (IPL) process" as well as his organizational implementation process which he terms the "accelerated business learning (ABL) process" (E. F. Wolstenholme, 1999). The current research utilizes these ideas by following the IPL process and attempting to be as simple as possible to help further reflection and change.

Homer and Oliva (2001) discuss the balance of quantitative and qualitative simulation research. The authors note that causal-loop diagrams (i.e., influence diagrams) have an important role within system dynamics as a means of communicating a dynamic hypothesis and a model's feedback. They state that simulation is needed to determine the sufficiency and appropriateness of the dynamic hypothesis from system behavior within the given assumptions and associated limitations. Without simulation, the authors claim that one is merely exploring the system structure and not its behavior and dynamics (J. Homer & Oliva, 2001). This research provides insight into system dynamics and supports the approach utilized in the current effort.

Professor Wolstenholme has also conducted research into generic system dynamics structures or archetypes. He notes that these structures help communicate system insights especially to those not familiar with a systems approach as well as form a proven foundation for specific model development. He describes an archetype as having the five properties of an intended consequences feedback loop, an unintended consequences feedback loop, a delay, an organizational boundary, and a solution archetype for every problem (E. F. Wolstenholme, 2003). The author then defines and describes the four most common two-loop archetypes of underachievement, out of control, relative achievement, and relative control. He further elaborates that the common system behaviors of limits to success, growth and underinvestment, and tragedy of the commons are "special cases of the underachievement archetype"; fixes that fail, shifting the burden, and accidental adversaries archetypes are special cases of the out of control archetype; success to the successful is a special case of the relative achievement archetype; and escalation and drifting goals are special cases of the relative control archetype (E. F.

Wolstenholme, 2003). The author recommends using these to help explore boundaries and improve the results of system dynamics efforts (E. F. Wolstenholme, 2003).

Caulfield and Maj (2002) discuss what system dynamics is, its merits, and results supporting Brooks' Law regarding the futility of adding more software developers to an already late project. They begin by nothing that technical systems are often "best understood from the perspective of human perceptions and also that of a wider socio-economic context"(Caulfield & Maj, 2002). They add that system dynamics allows for the inclusion of "soft" factors such as motivation and perceptions. They further note that building system dynamics models is not easy and requires experience. Caulfield and Maj then discuss their system dynamics model that supports Brooks' Law and conclude that all engineering disciplines should include system dynamics (Caulfield & Maj, 2002).

2.3.2 System Dynamics Applications

An early and successful application of system dynamics involved a lawsuit by Ingalls Shipbuilding against the U.S. Navy for delay and disruption costs. Cooper (1980) initiates the article by stating that the two origins of project overruns are errors in the initial estimate or changes after contracting. He adds that in defense systems there is a pressure to estimate a total project cost that will be accepted by Congress whether it is accurate or not. The author highlights that shipbuilding is also a complex activity where not all of the likely problems and issues will be identified during project planning. He then reviews his system dynamics model that includes the functions of cost and schedule monitoring, business planning, and contract management. The use of the model in a legal case helped Ingalls win a settlement of $447 million (K. G. Cooper, 1980). This research sets the stage by giving system dynamics judicial credibility which typically has

a high degree of scrutiny. It also supports the methodology and approach taken in the current research.

One of the more well-known system dynamics models was designed to assess the software development process. Professor Abdel-Hamid expanded his PhD research into a book and elaborated on his findings of a system dynamics software development project based on three NASA projects in 1990. He begins by noting that in project management experiments are not practical and often it is not known what happened in a project and why. He continues by mentioning that there is a wide variation in software models for cost and schedule relationships. He further adds that underestimating a project's schedule has the same effect as intentionally compressing the schedule. The author concludes by stating that there are a variety of cost-schedule relationships that can be used based on the management approach (Gong, 1997). This research supports the use of system dynamics to evaluate projects. It also provides a reference of comparison for the DoD acquisition model since there are some features that are similar but many unique.

As noted earlier, the more "soft" component of system dynamics is systems thinking. Yeo (1993) provided research into the application of systems thinking on project management. He notes that project management, systems thinking, and systems engineering all started with systems analysis. The author documents a list of project management tools and states that they all consistently provide between 40-500% cost and schedule errors (Yeo, 1993). Yeo attributes many of the project management problems to complexity, uncertainty, and ambiguity. He also recommends that the key to future success is the ability to learn and more deliberately and frequently apply systems thinking as a way of learning (Yeo, 1993). This research supports the use of system dynamics as a

quantitative approach and method to support the qualitative systems thinking that Yeo recommends furthering the knowledge and understanding of project management.

Similar to Cooper's 1980 article, Williams, Eden, Ackermann, and Tait (1995) developed a system dynamics model to explore the reasons for delay and disruption on an engineering project. They focus on three problem areas of design changes, approval delays, and poor comments with the quantitative and qualitative results. They noted that a larger amount of parallel (i.e., concurrent) development led to more challenges in successfully freezing the system design. The authors highlight a major benefit of system dynamics as being its ability to show "patterns of behavior" as well as incorporating the impacts of decisions of the project management. Their model had 29 stocks, 43 flows, and 120 variables and provided results in man-hours of the changes between a low and high amount of each of the problem elements (T. M. Williams, Eden, Ackermann, & Tait, 1995). This study further supports the use of system dynamics and three generic events to determine general system behavior.

Coyle, Exelby, and Holt (1999) provide an overview of several system dynamics models within the defense industry that were useful although they also note that most defense models are not publically available. They begin by noting that "combat is inherently non-linear" which lends itself to a system dynamics approach. They then highlight a command and control model where an influence diagram (i.e., dynamic hypothesis) helped understanding and appreciation of the behaviors experienced as well as a search and rescue model that had the same impact. The authors further state that academic system dynamics efforts may rely on literature or assumptions but consultants must ensure the client(s) are pleased. They recommend a balance of quantitative and

qualitative elements which they believe system dynamics offers as the best approach (J. M. Coyle et al., 1999).

Repenning (1999) uses a system dynamics model to find inefficiencies in a multi-product development environment. He discusses a previous queuing model where resources are static but work is allowed to progress and notes that his system dynamics approach is preferable since both resources and work are dynamic. The author then expounds on his dynamic hypothesis that is based on the notion of "tilting" or "firefighting" where limited resources are applied to a greater degree later in the product development timeline to resolve unexpected problems. He further adds that once organizations adopt this approach they tend to perpetuate or increase its use. Repenning provides an overview of his two product, four stock model and finds that fixing a resource allocation provides better robustness to workload variations as opposed to allowing managers to allocate resources based on perception (Repenning, 1999).

Chapman (1998) developed a system dynamics model involving the construction industry design process. He begins by noting that the design process is largely focused on communication or information exchange. He also highlights problems in current strategies with failing to account for the interactions and non-linear nature of project elements, failing to account for disruptions caused by personnel changes, and failing to effectively conduct risk management (Chapman, 1998). Chapman advances systems thinking and the system dynamics approach as a way to mitigate the current problems. He presents no quantitative data but does make good use of dynamic hypotheses and qualitatively discusses the impacts of personnel changes using his model framework.

Another system dynamics application was performed by Lai, Ip, and Lee (2001).

They utilized their model to analyze the behavior and operation of an engineering service department. Their results provided valuable insights that were able to provide managers with targeted areas of improvement (Lai, Ip, & Lee, 2001).

Ford (2002) utilized a system dynamics model to evaluate contingency management of real estate development project managers. He notes that project managers desire tools that can evaluate cost, schedule, and performance simultaneously and that there are "few formal theories of project budgeting and cost control…" (Ford, 2002). He also adds that most project management tools support planning but do not help decisions in execution (Ford, 2002). This research supports the need for improved project management tools that simultaneously balance cost, schedule, and performance. The current effort will accomplish that need.

In 2011 Howick and Eden present their system dynamics modeling with a UK police force to help create strategic change. The authors note that a critical element to strategic development is the determination of the key influences on organizational performance (Howick & Eden, 2011). They mention that the conversations between stakeholders were often more influential to strategic change than the model itself, that major change was achieved, and that this approach is recommended in similar applications. While this research is not directly related to the present research, it does show that the development of a system dynamics model can have profound and important impacts on strategic decisions.

Ford and Sterman (1998) utilized a system dynamics model to better understand the dynamics of product development. The authors used a semiconductor chip development project to calibrate and validate their model. They begin by noting how managers have

failed to improve the dynamic influences on a project which minimizes their ability to successfully plan and manage a project. They further discredit the use of CPM and PERT tools due to the fact that they generally do not include iterations and provide a single time estimate for each activity (Ford & Sterman, 1998). The authors state that a quality project model must include "the influences of processes, resources, scope and targets on performance" which system dynamics can easily do (Ford & Sterman, 1998). These authors also establish a precedent for assuming all tasks are of the same level of effort and of equal priority. Ford and Sterman conclude that the most sensitive aspect of overall project execution is the completion time for tasks which can change as much as 50% from the baseline (Ford & Sterman, 1998). They further conclude that as internal forces within projects become more complex and dynamic the current tools will become less useful. This research supports the approach taken in the current research.

In 2003 Ford and Sterman used a multiple-phase development system dynamics model to evaluate schedule problems in concurrent development projects. The premise of this research rests in the belief that concurrent development will reduce cycle time and therefore the overall project time. Instead, the authors argue that concurrent development increases complexity among information transfers which are not addressed effectively by management (Ford & Sterman, 2003b). A key aspect of this research is the impact of the "90% syndrome" where a project is estimated to be 90% complete and then seems to slow down and drag out which the authors attribute to unanticipated rework (Ford & Sterman, 2003b). The authors set the precedent for a generic task work package which is how work is modeled in the current effort. Ford and Sterman note that the more the schedule is planned to be concurrent then the larger the disparity between resources

needed and resources available which leads to a reduction in quality assurance and other error detecting activities (Ford & Sterman, 2003b). They also conclude that simulation results do show that concurrence reduces project costs and schedules but also significantly reduces the project quality due to the presence of large amounts of undetected errors (Ford & Sterman, 2003b).

Also in 2003 Ford and Sterman used the previous article's model to evaluate the impacts of concurrent development that lead to a hiding of known rework. The authors begin by noting the disparity between the various types of process complexity and the management mental models that fail to account for them. They also note that it is common for people to conceal known rework either from internal management or from a customer while concurrent development is "designed to promote open and early sharing of problems" (Ford & Sterman, 2003a). The authors mention that concealing known rework appears to be helpful when viewed from a small scale, but in a larger view such actions cause more problems in concurrent execution and in overall project quality (Ford & Sterman, 2003a). Ford and Sterman advocate the use of PERT and design structure matrices to identify interdependencies in conjunction with cultural and behavioral tools that create improved trust and increased flexibility (Ford & Sterman, 2003a).

Another study of project management using system dynamics was undertaken by Taylor and Ford in 2006. The authors developed a four stock model of a single development project to evaluate tipping point dynamics and design robustness. They begin by noting that a clear definition of project failure does not exist and reference a GAO study that reviewed several Department of Energy projects that met performance objectives but still failed (Taylor & Ford, 2006). They also note that traditional project

management models (e.g., critical path, etc) cannot evaluate rework and additional project tasks and assume linearity of the tasks. The authors also discuss the fact that near tipping points, where the dominance of one feedback loop changes to another, a small change in rework or ripple effects can cause a project to begin significant success or major failure. They recommend that project managers monitor control loop dominance through rework fractions and added new tasks difficulty as well in the evaluation of robustness (Taylor & Ford, 2006). These results provide a corollary and extension of the results of the second part of the model results involving rework of this research.

Taylor and Ford's research on tipping points is continued in 2008. In this study the review tipping points based on a nuclear power plant construction case study. They find that projects are most sensitive to rework and the least sensitive to project deadline (Taylor & Ford, 2008). They also note that there are no tools for project managers to measure rework or ripple effects but that the dynamics must be understood with the determination of tipping point structures and elements that can move a project to a tipping point (Taylor & Ford, 2008). This research supports the decision of the current model to focus on rework as a secondary thrust due to its likely role within all project management.

Maruja (2009) uses system dynamics to evaluate rework in overlapped product development schedules. He begins by stating that traditional project management approaches believe that a total project is the sum of the project parts which ignores the interrelationships that are present. He concludes that the results prove that quantitative results can be gained from evaluating rework in a system dynamics model (Marujo, 2009).

Repenning and Sterman (2001) provide an overview of system dynamics models to help improve processes. They note that learning is not the problem with performance improvement but rather successful execution is the challenge (Repenning & Sterman, 2001). They conclude that this problem is caused by the systematic interaction of approaches, methods, and people (Repenning & Sterman, 2001). Using a relatively simple system dynamics model, the authors show the system responses to working harder versus working smarter. They assess that working harder does produce greater short-term results with worse long-term consequences which seems attractive to many managers who are unable to see the longer trends over time (Repenning & Sterman, 2001). They note that this phenomenon creates a culture of "firefighting" to solve last minute problems and likely creating shortcuts to achieve inflated goals while also leading many managers to assume that training and other improvement efforts are a waste of resources and unnecessary (Repenning & Sterman, 2001). The authors conclude by discussing the case studies of DuPont and British Petroleum who were able to overcome these challenges.

Eden, Williams, and Ackermann (2005) have also utilized system dynamics to help resolve why projects have failed. In one study they have compared the system dynamics model with a "measured mile" approach. They note that the "measured mile" approach is a relatively simple one that uses an undisrupted segment of the project to determine productivity and efficiency of the project as a point of comparison for other parts of the project and frequently results in determinations of management over-optimism (Eden et al., 2005). They also note that system dynamics is a method that models disruptions and delays as "categories or clusters" rather than discrete events and aids in improved

understanding of the nature of the project, especially the potential impacts of the removal of the disruptions and delays (Eden et al., 2005). This article supports the current use of system dynamics, especially over the measured mile approach.

Größler (2007) reviews several examples where "successful" system dynamics models fail to achieve an organizational impact. He notes that often system dynamics modelers focus on results rather than implementation of new strategies. In order to be successful, Größler states that change process elements of senior leader buy-in and broad understanding of the value of change are critical to successful implementation (Größler, 2007). Größler then reviews several case studies to illustrate his points. While these insights are profound, the current research effort is driven primarily by academic curiosity and secondarily by a desire to engender true change in DoD acquisitions.

One of the cornerstones of system dynamics and project management was the survey, assessment and recommendations for future research performed by Lyneis and Ford in 2007. The authors note that system dynamics is ideally suited to the study of project management due to the presence of feedback loops, nonlinear relationships, and accumulations of various resources but also add that the level of detail provided varies considerably. The authors further define the four critical model elements of a system dynamics model as actual project features, rework, project control, and ripple and knock-on effects. (Ripple and knock-on effects are defined as the primary and secondary impacts of project control actions respectively (Lyneis & Ford, 2007)). They mention that work must be modeled to "flow through a project" and that resources help adjust the flow of work. They also note that the rework cycle is the most important part of a project model and advocate the use of the four stocks as first mentioned in the Lyneis,

Cooper, and Els 2001 article but add that there are other methods of modeling this cycle. The authors also review other works on project control and ripple and knock-on effects. They also summarize the applications and results of major system dynamics research regarding project management. From this baseline, the authors advocate additional work be focused on the inter-relationships and change over time of ripple and knock-on effects as well as the consequences of changing performance targets (Lyneis & Ford, 2007). The current research is attempting to help fill both data gaps by evaluating the inter-relationships of performance targets as well as the adjustment of performance targets over time. Furthermore, also absent from this survey is any discussion of a system dynamics model from the perspective of the government in DoD project management.

Lyneis, Cooper, and Els also utilize a system dynamics model in support of strategic project management in a DoD application. However, in this case the perspective taken was from the commercial developer and not the government. The authors note that a survey by the organization now known as the Defense Acquisition University found that the average cost overrun was 45% and average schedule overrun was 63% for the development phase of major defense systems (Lyneis et al., 2001). The authors note that PERT and CPM tools were developed in the 1950s and have advanced but are still not effective for mitigating the dynamic complexity of projects by taking too narrow a view or viewing the project in a static nature. Noting that project are complex, dynamic systems, they recommend the use of system dynamics especially in the area of strategic project management which they define as the "decisions taken up front in designing the project, and then the guidance provided to operational decisions that considers the longer-term impact of these decisions on downstream performance of the project" (Lyneis et al.,

2001). Lyneis et al. then describe their four stock model that was successfully used by Hughes to deliver the Peace Shield air defense system six months and 13 deals head of schedule, on budget, and to all performance requirements of the U.S. Air Force (Lyneis et al., 2001). The authors recommended continued and expanded use of system dynamics in conjunction with the continuous integration of lessons learned. The current research utilizes much of the components of this research within its framework as well as in its motivation.

Dillard and Ford (2009) provide case study research between two programs to evaluate the positive and negative elements of evolutionary acquisition. The authors mention that the use of evolutionary acquisition is designed to reduce project scope through the use of more mature technology. They conclude that DoD should not adopt a single approach as evolutionary acquisition is preferred when projects meet certain conditions. However, they also note that when the projects do not meet the conditions the use of a single stage acquisition is preferred (Dillard & Ford, 2009). This research supports much of the project management research that recommends tailored approaches to project management. It also highlights the need for improved understanding of DoD acquisitions and can be incorporated within the current model in future research.

Research by Professor Ford and Dillard (2009) utilized a system dynamics model to evaluate evolutionary acquisition. The authors use the Javelin anti-tank missile development project as the case study and revise the model to evaluate a traditional single step acquisition process versus an evolutionary or spiral process. The find that the spiral process does significantly reduce initial requirements achievement but takes longer to complete, costs more, and requires more complex project management (Ford & Dillard,

2009). While this research used the same Javelin case study as in the current effort, they only evaluated the development costs and time and their model did not have dynamic and interacting cost, schedule, and performance. Their model did rely on a work flow very similar to the current model, and the approach was similar. Finally, this model could be made to work with the current model to further evaluate DoD acquisition approaches.

Chapter 3 – Contribution to Research

If you were to ask many DoD professionals to describe how acquisitions truly work at the strategic level, they would describe a framework similar to that depicted in Figure 3-1. In this figure one strategic activity is all or the vast majority of what influences the next downstream strategic activity. Therefore, a given threat (or change in threat) causes a new delivered requirement that changes a budget estimate which causes the schedule estimate, and the end result is a performance expectation. At the budget event, Congress may intervene and adjust up or down the budget which impacts the downstream activities. Eventually, the expected performance will have an impact on the threat.

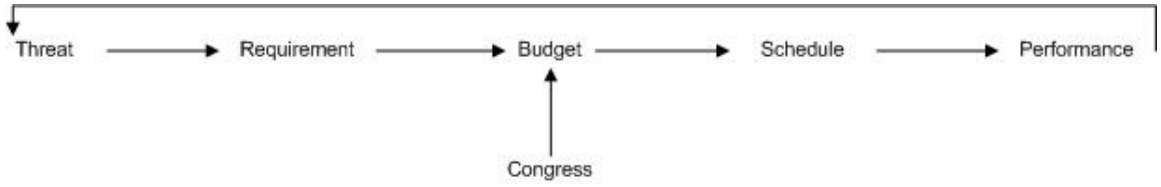

Figure 3-1: Current Mental Model of U.S. DoD Acquisitions

While this mental model is relatively simple to understand, there are multiple problems with it. First, it assumes that many of the drivers of project performance are external (i.e., endogenous) to the system. Second, it ignores that feedback loops created by the changes to cost, schedule, and performance levels. Third, it ignores the speed of change in many of these sub-activities (i.e., budget development every two years while the requirements may change every year or less) as well as other impacts of the sub-activity interaction. This mental model further assumes that a single change can be controlled or managed with "simple processes" such as through the monitoring of a

detailed work breakdown structure or earned value management. As previously discussed, there are significant short-comings in these approaches and they may be part of the reason while DoD sees the results it does.

As an alternative, the author recommends a mental model as shown in Figure 3-2-2. In this figure all of the same activities as Figure 3-1 are present. However, in Figure 3-2 the fact that delays are present and that every activity impacts every other activity are illustrated. This means that an adjustment to the budget will impact schedule and performance over time. That this is a more accurate depiction of the real world is usually not in question, but the major issue is how we deal with this.

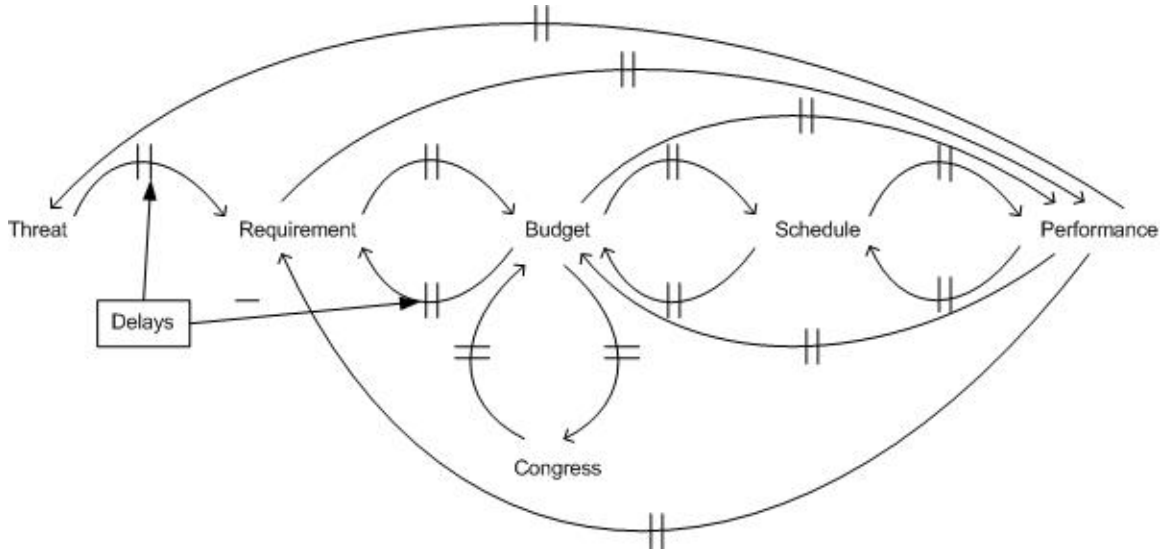

Figure 3-2: Proposed Mental Model of U.S. DoD Acquisitions

As noted in the literature review, there are significant data voids within project management, system dynamics, and DoD acquisitions. The integration of research from the three domains provides a substantial knowledge base, but it lacks true understanding of the dynamics of DoD acquisition project management. In fact, outside of an exploration of DoD evolutionary development and a discrete event simulation model,

there is limited academic research into the dynamics of DoD acquisition. The current research will help fill that knowledge gap by providing a system dynamics model on DoD acquisitions using dynamic cost, schedule, and performance measures. In other words, the model will allow the changes in cost, schedule, and performance to influence each other as current happens.

The current research will provide more understanding and insight into the consequences of using a more dynamic, systems view of DoD project management. It will help explain the behavior of why so many DoD projects experience cost and schedule overruns and help provide potential ramifications of several project manager alternatives with regard to project control. Furthermore, the current research may provide a new tool that can be used to help future project managers learn and explore additional alternatives that may achieve general system improvements or even improvements within a specific project scenario.

Chapter 4 – Research Methodology

This chapter explains the research methodology used in this study. It explains the (1) goals and objectives; (2) scope and limitations; (3) the research method; (4) a model overview; (5) model validation and verification; (6) FCS case study; (7) Javelin case study; and (8) EFV case study.

4.1 Goals and Objectives

The main goal of this research is to help identify the dynamic consequences of cost, schedule, and performance on DoD acquisition from the perspective of the Government project manager. This goal will provide a framework to develop a system dynamics model that can be utilized to test several generic project control alternatives to attempt to evaluate the positive and negative elements of each. A secondary goal evolved during the research to explore the nature of rework in DoD acquisitions since this concept is a major focus of research in other project management domains.

Ultimately, this model or its extension can become a foundation from which programmatic decisions might be discussed and debated with stakeholders as they are developing strategic cost, schedule, and performance objectives. Furthermore, this model can be further developed to incorporate more detailed programmatic decisions to better estimate the impacts of those decisions.

4.2 Scope and Limitations

The main focus of this research involves U.S. DoD project management for developmental ground combat systems. It does not include general service support activities or sustainment and system disposition phases of these project lifecycles. It also

does not include any rapidly fielded systems as acquired through any process outside of the traditional acquisition framework identified in the DoD 5000 series. The author utilized only open-source, publically available reports and website information. Moreover, when a project was rebaselined, the most recent baseline was used as the project estimate. This also led to the removal of any options of performance enhancement through the assumption that the initial requirements (or updated requirements at a rebaselining) accurately described the needs of the system. This meant that performance was restricted to an optimum score of 100% of required capability.

This approach does incur some limitations. Notably, it does not explain the impact of rebaselining a project and focuses on three ground combat systems while aviation and naval projects may exhibit different behaviors. It also does not provide a total lifecycle perspective of the systems which may limit (or underestimate) the value of the current approach. Another significant limitation is the inconsistent reporting time spans and in the fidelity of numbers. For example, some yearly costs were reported in fractions of a billion while others were reported to the closest thousand. This research strove to maintain a consistent degree of accuracy throughout with all numbers reduced to the lowest common accuracy available.

4.3 Research Method

The study utilizes a simulation research method. This method is chosen as a means of providing a quantitative framework to best evaluate whether the dynamic interaction of cost, schedule, and performance does influence DoD acquisition project behavior as well as whether several simple policy alternatives could improve system results.

The author follows a standard system dynamics framework that is mentioned with minor variations in multiple system dynamics references (R.G. Coyle, 1996; Forrester, 1994; John D. Sterman, 2000; E. F. Wolstenholme, 1990). Figure 4-1 illustrates this framework. This framework begins with problem formulation and progresses into a problem exploration and system description which results in an influence diagram and dynamic hypothesis. The framework then moves to simulation modeling, validation, and policy evaluation. Additional steps exist for further policy exploration and optimization, but the goal of this study did not require those steps.

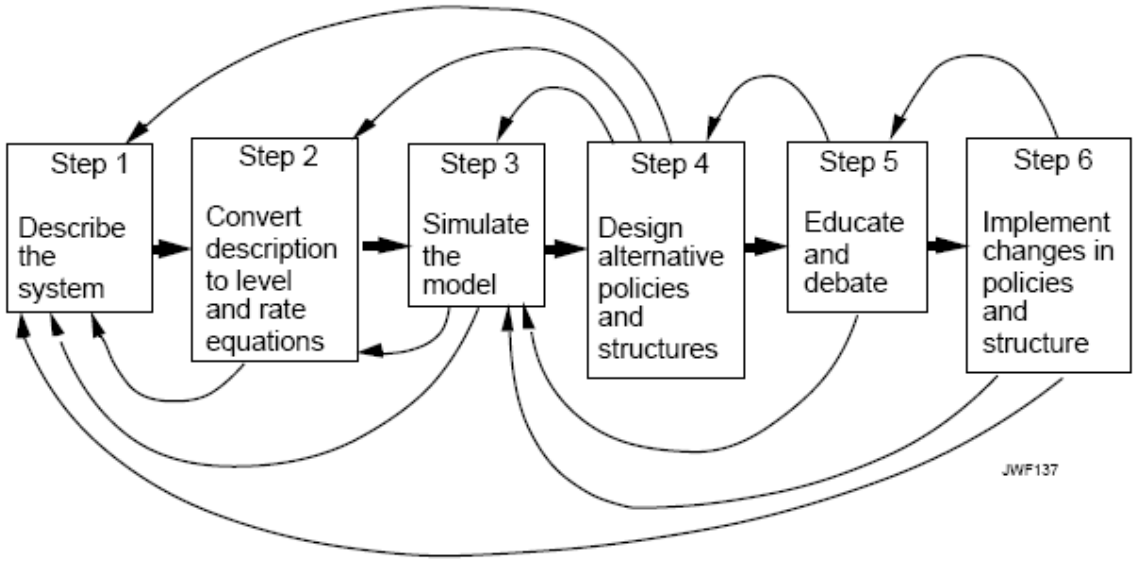

Figure 4-1: The System Dynamics Process (Forrester, 1994)

While the development and validation of a model is useful, this research further exercises its utility by evaluating several project manager alternatives. Given the generalities and assumptions inherent in the overall model, modeling detailed decisions and behaviors did not seem appropriate. Therefore, four general project manager actions have been selected. The first scenario is the normal approach where the project manager alters cost, schedule, and performance (both quantities and qualities) as a result of

comparisons to the estimated values. It is believed that this is generally how most DoD project managers operate today. The second alternative is an approach where the project manager would ignore the schedule comparison and simply use budget and performance comparisons to adjust work flows. The third alternative is an approach where the project manager would ignore the budget comparison. Finally, in the last alternative the project manager would let work progress as intended with no controls. It is assumed that this final approach would be a best case approach and that while these alternatives are not completely realistic they are effective bounds to enable conclusions on improved system behavior.

Furthermore, it was determined that due to the general performance measure as a percentage that there was little utility in evaluating the impact of ignoring performance. It is also believed that project performance measurement is a very subjective issue that is not repeatable. Future research can significantly improve this area and be incorporated into future versions of the model.

4.4 Model Overview

As previously mentioned, this study started with a simple baseline model that is discussed in next. In the following sub-section, an additional model that incorporated rework is discussed.

4.4.1 Baseline Model

The baseline model used in this research is shown in Figure 4-2. In order to be best understood and potentially used in more detailed applications in the future, the model is as simple as it can be. This led the author to take several oversimplifications

that may reduce the predictive capability of the model but that allow future research to better study those elements and provide accurate inputs as opposed to assumptions and conjecture.

The foundation of the model is a work flow process surrounding system design/understanding. The work flow process is very simple and defines system design/understanding project work of any kind as a unit-less dimension that could represent percentage of required work or a number of required work packages to accomplish system development. These work elements exist within the initial simple closed system in one of three states- work to be done, work in progress, and work completed. The completion of all work would equate to a perfect understanding of the system being acquired which should be the goal of all projects. There is also a simplifying assumption that all work is equal in priority and execution which is appropriate as a generalization and until further project specific details can be incorporated. This also supports the model's purpose of determining if a model with dynamic cost, schedule, and performance measures is effective in evaluating decisions and will support future enhancement.

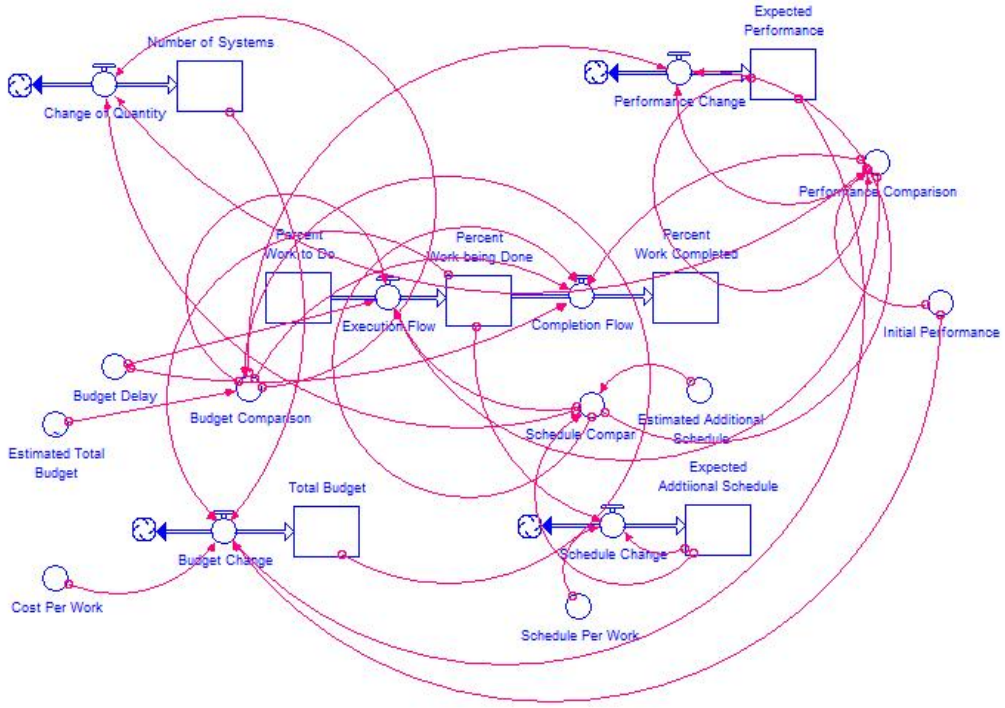

Figure 4-2: Baseline System Dynamics Model

With all other influences and variables removed, the work flow will complete all activities within 12 to15 years, which is appropriate for most DoD projects. A range of execution and completion flow rates was evaluated that ranged from 10 to 38 years. It was determined that these rates are critical variables within the model as they determine how long work is being done. If flow rates are executed too rapidly and not completed proportionately, then the model will increase the budget too quickly. If the flow rates are completed too rapidly, then the model can have no budget as the state of work in progress will not have sufficient (or any) volume to determine a budget in the current model structure. The average execution flow rate/completion flow rate that worked well for this model was 1.3, but it is important to note that all case study models varied in this

variable.

In order to allow for dynamic consequences, control of starting and completing work is done through a comparison of the projected or estimated budget, schedule, or performance to the actual budget, schedule, or performance. In the case of the budget comparison, we have incorporated a 2 year delay due to the DoD budgeting (i.e., PPBE) process where a project budget is submitted and about two years later the actual approved budget is delivered. When the difference between the estimated budget, schedule, or performance and the actual budget, schedule, or performance is positive (i.e., the project is under cost and/or ahead of schedule and/or less capable than initially desired), then work is allowed to start and be completed at an accelerated rate corresponding to an increase in work execution. However, when the difference in the estimated budget, schedule, or performance and the actual budget, schedule, or performance is negative (i.e., the project is over cost and/or behind schedule and/or more capable than initially desired), then the work is slowed to a decelerated rate corresponding to a slowing of work execution or delaying of work. The factor of flow reduction is determined by the difference between the estimated budget, schedule, or performance and the actual budget, schedule, or performance at that time divided by the total current budget. This method derives a percentage which is then multiplied together with the other measure percentages and the execution and completion flow rates to get the total execution and completion flows.

As an example, if the actual budget is 25% over the estimated budget, then the work execution and completion rates are slowed by 12.5% due to the two year delay. In this model, budget and schedule are equally important and contribute the same to the

work rates. Therefore, a situation with a 25% over budget and a 25% over schedule would result in a corresponding 3% reduction to the work rates factor (i.e., 0.25 * 0.125 = 0.03).

Budget and schedule flows are based on the work in progress. The budget flow is the product of work in progress multiplied by a cost per work constant that is multiplied by the ratio of the number of systems to desired number of systems and the ratio of current performance to the desired performance. This assumes there is a cost reduction associated with a fewer quantities of systems and less system performance at a reduction of the current quantity divided by the initial desired quantity (at the time of a rebaseline if one exists). The schedule flow is the product of the work in progress multiplied by a schedule per work constant. Either the budget or schedule flow can move in a positive or negative direction allowing for budget or schedule reductions; but it is important to note that because of the proportion of execution to completion rates used, there is some amount of work in progress at any time so that the budget and schedule flows will never be negative. It is also important to note that budget and schedule do not directly influence each other in this model. This is due to observations that a budget increase does not guarantee a reduction in schedule or a schedule increase guarantee a budget reduction assuming all other factors are the same.

4.4.2 Rework Model

As an exploration and advancement of the baseline model, the model was augmented to become a more realistic, open system as shown in Figure 4-3.

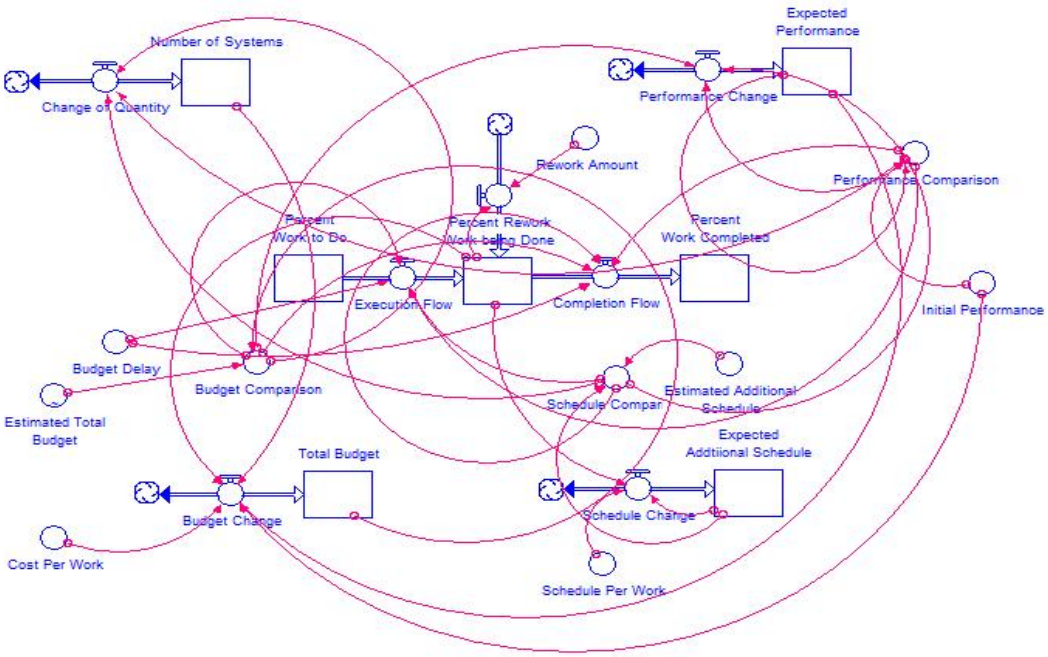

Figure 4-3: Rework System Dynamics Model

The only changes from this model to the baseline model are the inclusion of a rework flow into the work in progress and a rate variable. This enabled the author to vary the rework percentage of the work in progress to evaluate the effects on system behavior. All other relationships and inputs remained the same as in the baseline model.

This treatment of rework differs from the commonly used four state rework structure commonly used by Ford (Ford et al., 2007; Ford & Sterman, 1998). This was done intentionally as the additional stock and flow due to backlog would have been an

assumption without any supporting data. This is an area that future research can conduct to better complete the detail of the model to be an accurate predictor of future behavior.

4.5 Validation and Verification

As noted in Barlas (1996), the first key to effective validation is to define the model's purpose. Since this model was mainly about increasing understanding and verifying the approach, the direct structure tests were of principal value. Table 4-1 shows the tests applied as described by Barlas (1996) and the results.

Table 4-1: System Dynamics Model Validation Test Results

Structural Validity Tests	**Direct Structure Tests**	
	Structure-confirmation test	Mathematical equations in model are appropriate for empirical results.
	Parameter-confirmation test	Conceptual and numerical parameters are appropriate for empirical results.
	Dimensional consistency test	Parameters have real-world meaning and are appropriately used in equations.
	Structure-oriented Behavior Tests	
	Extreme-condition test	Extreme inputs produce expected behaviors in the model.
	Qualitative features test	Major qualitative element changes produce expected behavior.
Behavior Validity Tests	**Behavior Pattern Test**	Use of graphic responses of system behavior produce expected system response.

In early versions of the model, the budget, schedule, and comparisons were manually input in order to ensure that the model behaved properly. As expected, when the budget, schedule, or performance comparisons were positive, the model reduced budget, improved schedule, or maintained performance (due to the assumption that each of these scenarios improved performance).

During this phase or model exploration, it was noted that one change would not

produce completely intuitive behavior. For example, if the cost per work variable was increased, the total budget would increase but so would the total schedule. This feature supports previous research on both the behavior of complex systems and human intuition (Forrester, 1971a; John D. Sterman, 1989). It also led to a complex process in establishing initial factors and variables. The values used in the current models were the optimized solutions based on trial and error.

The author also adjusted the delta time (DT) variable to examine its impact on the model. The initial DT was 0.25 which equates to the model updating results every quarter of a year. In early model runs the DT was decreased to 0.05 and increased to 1.0. This resulted in more frequent results which provided more data, but the final system behavior did not change. The author felt that 0.25 was sufficient to evaluate changes in system behavior but not produce too many or too minute changes.

In the final stage of verification and validation, the model cost, schedule, and performance results were compared to the available system cost, schedule, and performance data. The errors varied between each case study model and are noted in chapter five. In the case of high errors as with two of the case studies, it is believed that the inputs of initial cost and schedule were not accurate. This leads to the question of whether early and inaccurate data should be used or if later and more accurate data should be used. The choice does impact final decision and within the context of this research the available data, which happened to be the only data, led to its use. Future research should investigate the differences in input variance to the differences in output. This is a similar problem noted in previous project management research (Flyvbjerg et al., 2002) and is likely an issue with open source DoD data where many details are

overlooked or ignored for a variety of motivations.

All of these validation and verification efforts support that the model is appropriate for its purpose of evaluating use within DoD project management. If future efforts wish to use this model to develop an optimized project management solution, then additional validation and verification efforts are needed. However, in the current effort the model is appropriate and will be used to evaluate several case studies.

4.6 Case Study 1 – Future Combat System (FCS)

In 1999, the U.S. Army began designing the Future Combat System (FCS) as a means of preparing itself for what it expected to be the future of warfare. The Army expected to have the first unit equipped in 2011 and the entire Army equipped by 2032. FCS involved multiple air and ground systems that interoperated and were networked as shown in Figure 4-4.

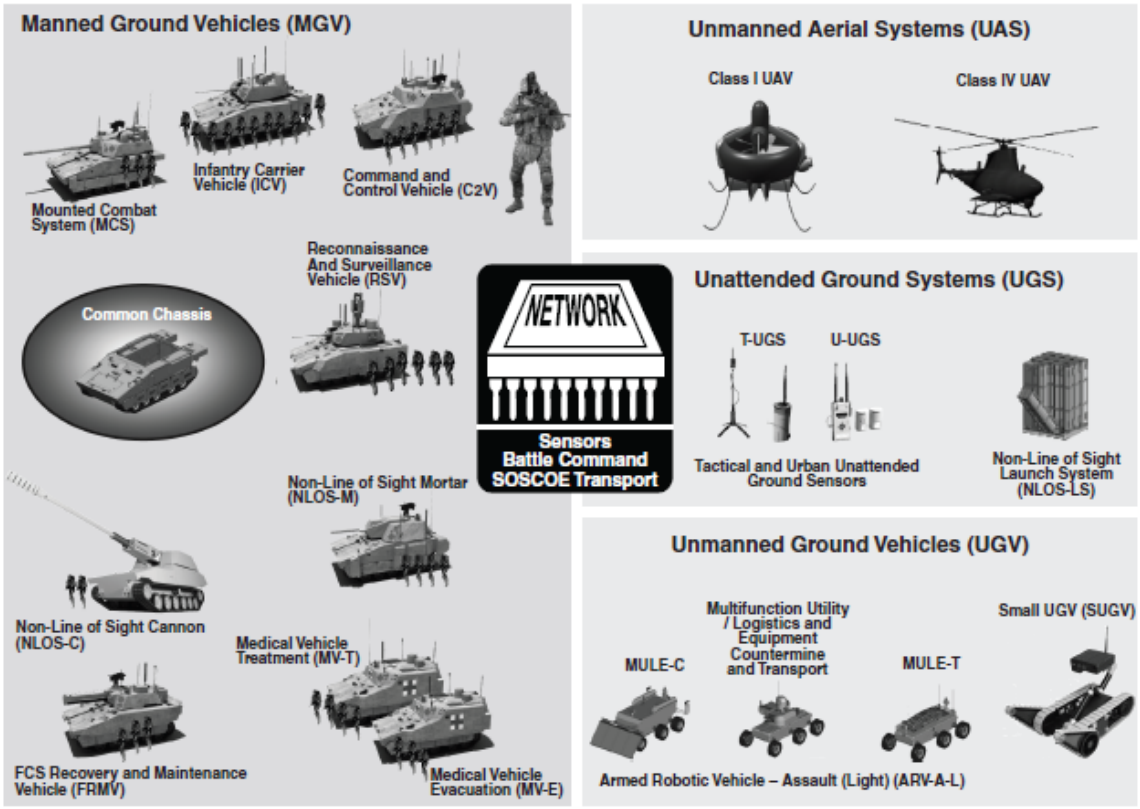

Figure 4-4: Overview of the Future Combat System (Francis, 2008)

One key tenet of the FCS effort was that information could replace mass, and a second tenet was that FCS components could be deployed rapidly. The ultimate combination was a highly technical and revolutionary system-of-systems that sought to push technology and balance many competing priorities (Francis, 2008). FCS was officially terminated as a program in the summer of 2009 before the program could be effectively evaluated but there are several detailed reports that offer useful data.

While there are many unique and interesting dynamics surrounding this program, it is used as a means of verifying and validating our model. In the model, the key inputs are the project cost and schedule estimates. These inputs were taken from the 2006 Congressional Budget Office report on FCS. The model set 2005 as the base year, which was based on availability of fiscal information, and extends until 2025. Through trial

and error, the execution flow is set to a factor of 6.667 while the completion flow is set to a factor of 5.667 while the cost per work is 1.215 and the schedule per work is 0.25. These factors were used to best provide an accurate initial baseline from which to work.

4.7 Case Study 2 – Javelin Missile

The author desired to find a DoD program that achieved full fielding to best attempt to challenge the model's results over time. The rationale was that a program "killed" prior to fielding may support overly pessimistic results, especially if large cost overrun was a reason for the program termination. Therefore, the Javelin anti-tank missile was selected as another case study as shown in Figure 4-5. While this system may not be as complex as the FCS, it does offer a different data point to evaluate the approach and model.

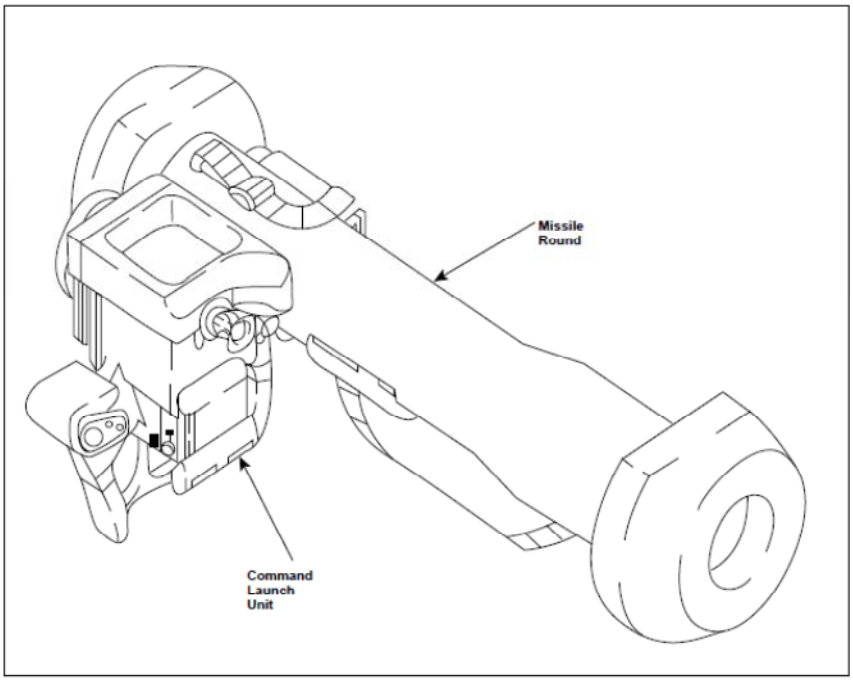

Figure 4-5: The Javelin Missile System (Office, 1996)

The Javelin anti-tank missile system is used by the Army and Marine Corps as a medium range, fire-and-forget, anti-tank missile system used by dismounted infantrymen (Buck, 1995). The program was started in 1986 with a 27-month competitive prototype period between systems built by Ford Aerospace and Communications Corporation, Hughes Aircraft Company, and Texas Instruments, Inc. (Buck, 1995). Ultimately, the Texas Instruments system in conjunction with Martin Marietta was selected; and at its initial programmatic milestone in 1989, the program was expected to take six years, cost a total of $3.389B, and purchase approximately 63,000 missiles and launchers (Buck, 1995). During system development, both the Army and Marine Corps underwent organizational changes that reduced the needed quantities to approximately 34,000, and the project was restructured twice due to multiple reasons (Office, 1996).

The Javelin model used cost and schedule inputs from Buck (1995) and starts in

1993 when the latest restructuring occurred. Through trial and error, the Javelin execution flow is set to a factor of 9 while the completion flow is set to a factor of 6.2 while the cost per work is 0.0427 and the schedule per work is 0.2.

4.8 Case Study 3- Expeditionary Fighting Vehicle (EFV)

In an effort to identify provide more rigor to the approach and model, a third case study was chosen with the U.S. Marine Corps' Expeditionary Fighting Vehicle (EFV) shown in Figure 4-6.

Figure 4-6: Picture of the Expeditionary Fighting Vehicle (Office, 2006)

The EFV is an amphibious assault vehicle for the U. S. Marine Corps (USMC). The historical roots of amphibious assaults go back as far as the historical use of the sea for power projection and the accomplishment of military objectives. Within the USMC, the roots of amphibious assaults are grounded in World War II and the island hopping campaign against Japan where the need for a vehicle to transport Marines from Navy ships to beaches and quickly offload them was readily apparent in experiments, training,

and combat situations. Prior to World War II, shallow draft boats were used for this purpose, but these boats moved slowly, and embarkation and debarkation was difficult and lengthy.

The EFV will replace the AAV and increase amphibious capabilities by enabling over-the-horizon movement from Navy ships to beaches. Originally designated as the Advanced Amphibious Assault Vehicle (AAAV), the program was renamed in 2003 as the Expeditionary Fighting Vehicle (EFV). The EFV is built by General Dynamics Land Systems (GDLS), a subsidiary of General Dynamics Corporation. The EFV vehicle design has only two variants- personnel and command and control. The personnel variant (EFV-P) is operated by a crew of three Marines and can carry 17 combat equipped Marines from 20-25 miles at sea to objectives inland. The EFV-P further has a 30mm cannon and multiple computer systems on board to support operations. The command variant (EFV-C) is operated by three Marines and can embark a staff of 9 with full computer interoperability. Both the EFV-P and the EFV-C use water-jets and a planning hull to accomplish the amphibious "swimming" at approximately 20 knots per hour and linked tracks to move at approximately 60mph while on land. These speeds allow the EFV to keep up with the most advanced of vehicles at sea or on land. Furthermore, both variants utilize extensive computer systems for many of vehicle operations as well as larger unit command and control functions.

Program initiation was in 1988 with an engineering development contract awarded to General Dynamics Land Systems in June 1996. In July 2001 a system development and demonstration (SDD) contract was further awarded to General Dynamics. Ten initial prototypes were hand-built in Woodbridge, Virginia, for initial

SDD testing. Following three rebaselines in November 2002, March 2003, and March 2005, and several less than desirable results during the initial operational test and evaluation (IOT&E) in May-August 2006, the program was thoroughly reviewed and recertified under the Nunn-McCurdy Act. A new contract with General Dynamics was awarded in August 2008 for seven second generation prototypes. These second generation prototypes will be built in Lima, Ohio, at the production facility where all 573 of the vehicles will be manufactured (Feickert, 2010).

The EFV model used cost and schedule inputs from the quarterly U.S. DoD selected acquisition reports (SARs) located online at http://www.acq.osd.mil/ara/am/sar/. Through trial and error, the EFV execution flow is set to a factor of 5.85 while the completion flow is set to a factor of 4.85 while the cost per work is 0.13 and the schedule per work is 0.25.

4.9 Case Study 4- M1 Abrams Main Battle Tank

A final case study was selected as the M1 Abrams Main Battle Tank (MBT) as shown in Figure 4-7. This system was chosen due to the fact that it was fielded over 30

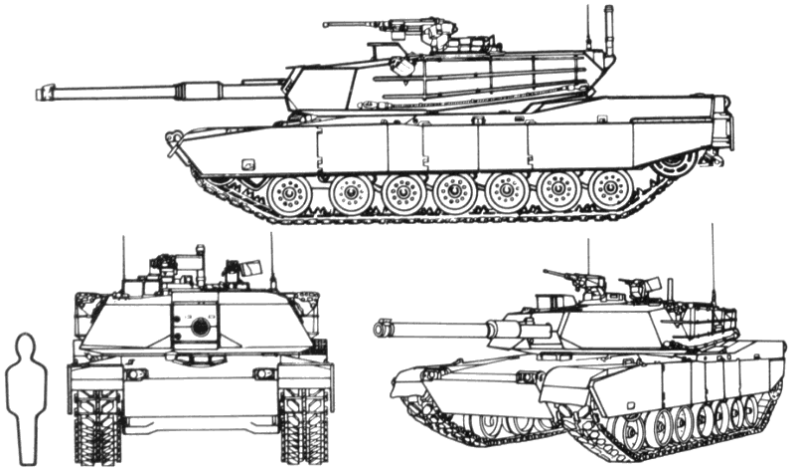

Figure 4-7: M1 Abrams Main Battle Tank (http://www.inetres.com/gp/military/cv/tank/M1.html)

years ago to verify how the approach and model handles older projects.

The M1 Abrams was designed following a cancellation of the joint German-US tank development program titled the MBT-70 that existed in the 1960s to design a tank to replace the Korean War vintage M-60 due to large costs (G. W. Williams, 1974). The M1 program was begun in 1971 with the Chrysler Corporation and the General Motors Corporation both getting competitive prototype contracts (Office, 1980). The Chrysler version was ultimately selected and began entering service in 1980. In 1982 General Dynamics Land Systems Division purchased the Chrysler Defense Division and began producing the M1 and its variants.

As with the EFV model, the M1 cost and schedule inputs were taken from the quarterly U.S. DoD selected acquisition reports (SARs) located online at http://www.acq.osd.mil/ara/am/sar/. Through trial and error, the M1 execution flow is set to a factor of 12 while the completion flow is set to a factor of 9.2 while the cost per work is 0.12 and the schedule per work is 0.25.

Chapter 5 – Results and Analysis

This chapter presents the results of the four case study models as well as an analysis of a) the utility of the model, b) the comparison of the four alternatives evaluated, and c) the impact of rework on DoD acquisitions.

5.1 Case Study 1- Future Combat System Results

The results for the FCS base model runs are summarized in Table 5-1 with all model results in Appendix 2.

Table 5-1: Future Combat System Baseline Model Results

Model Run	Total Budget	Year Complete	Performance %	Number of Systems	Total Work	Maximum Work in One Year
Normal Approach	$156B	2021.75	97%	15	100	15
Ignore Schedule	$156B	2021.75	97%	15	100	15
Ignore Budget	$78B	2014	98%	16	100	15
Ignore Everything	$159B	2022.75	99%	17	100	15

As a point of comparison, the Congressional Budget Office (CBO) estimates of the total system cost in 2025 as $160.6B (Lussier, 2006). The error in the normal baseline results from the best estimate available Lussier's total program measures are a 2.9% budget error, a 0.2% schedule error, and an undetermined performance error as the program was cancelled before the performance could be measured.

The results of the FCS rework model are more complicated, but a summary is provided in Table 4-3. Here each alternative is shown at 0% rework (the baseline case), at a common percentage that every model and alternative can achieve of 7%, and at the

maximum rework achievable before the system cannot complete all the work due to continuous work growth due to the rework.

Table 5-2: Future Combat System Rework Model Results

Model Run	Rework %	Total Budget	Year Complete	Performance %	Number of Systems	Total Work	Maximum Work in Worst Year
Normal Approach	0%	$156B	2021.75	97%	15	100	15
Normal Approach	7%	$306B	2027.75	93%	11	121	27
Normal Approach	10%	$586B	2049.25	78%	0	200	37
Ignore Schedule	0%	$156B	2021.75	97%	15	100	15
Ignore Schedule	7%	$308B	2028	94%	12	122	27
Ignore Schedule	9%	$444B	2035	87%	5	147	33
Ignore Budget	0%	$78B	2014	98%	16	100	15
Ignore Budget	7%	$99B	2014.75	98%	16	106	19
Ignore Budget	25%	$397B	2024.5	90%	8	208	41
Ignore Everything	0%	$159B	2022.75	99%	17	100	15
Ignore Everything	7%	$268B	2025.75	96%	14	117	26
Ignore Everything	12%	$566B	2036.75	87%	5	180	41

5.2 Case Study 2- Javelin Missile System Results

As noted previously, all model results are in Appendix 2 while the Javelin baseline results are summarized in Table 5-3.

Table 5-3: Javelin Missile System Baseline Model Results

Model Run	Total Budget	Year Complete	Performance %	Number of Systems	Total Work	Maximum Work in One Year
Normal Approach	$3.0B	2004.5	100%	34435	100	26

Model Run	Total Budget	Year Complete	Performance %	Number of Systems	Total Work	Maximum Work in One Year
Ignore Schedule	$2.4B	2003.75	100%	34434	100	30
Ignore Budget	$1.9B	2001	100%	34435	100	26
Ignore Everything	$3.6B	2009.25	100%	34434	100	31

At the 1993 Javelin restructuring , the program was estimated to take another 14 years, cost a total of $4,666M, and purchase approximately 33,000 missiles (Buck, 1995). In comparison with these results, the Javelin model has a 35% budget error, a 0.01% schedule error, and an undetermined performance error. As another data point, the model used in Ford and Dillard (2009) estimated the Javelin project to end with a cost of $722M in 2003 and having a 100% requirements achievement. This highlights a major challenge with projects in general, but especially within DoD. The frequent rebaselining and lack of standard measurement procedures makes forensic evaluation very difficult as has been noted before (Christensen & Gordon, 1998).

The results of the Javelin rework model are provided in Table 5-4. As with the FCS rework results, each alternative is shown at 0% rework (the baseline case), at a common percentage that every model and alternative can achieve of 7%, and at the maximum rework achievable before the system cannot complete all the work due to continuous work growth due to the rework.

Table 5-4: Javelin Missile System Rework Model Results

Model Run	Rework %	Total Budget	Year Complete	Performance %	Number of Systems	Total Work	Maximum Work in Worst Year
Normal Approach	0%	$3.0B	2004.5	100%	34435	100	26

Model Run	Rework %	Total Budget	Year Complete	Performance %	Number of Systems	Total Work	Maximum Work in Worst Year
Normal Approach	7%	$6.2B	2010.75	96%	34431	123	36
Normal Approach	10%	$13.8B	2023.75	87%	34422	175	43
Ignore Schedule	0%	$2.4B	2003.75	100%	34434	100	30
Ignore Schedule	7%	$5.9B	2012.25	97%	34432	129	41
Ignore Schedule	9%	$10.4B	2022	90%	34425	167	46
Ignore Budget	0%	$1.98B	2001	100%	34435	100	26
Ignore Budget	7%	$2.5B	2001.75	99%	34434	109	32
Ignore Budget	24%	$14.0B	2015.25	89%	34424	281	53
Ignore Everything	0%	$3.6B	2009.25	100%	34434	100	31
Ignore Everything	7%	$7.14B	2014.75	96%	34431	135	46
Ignore Everything	10%	$15.8B	2027.5	86%	34424	214	55

5.3 Case Study 3- Expeditionary Fighting Vehicle Results

As noted previously, all model results are in Appendix 2 while the EFV baseline results are summarized in Table 5-5.

Table 5-5: Expeditionary Fighting Vehicle Baseline Model Results

Model Run	Total Budget	Year Complete	Performance %	Number of Systems	Total Work	Maximum Work in One Year
Normal Approach	$15.0B	2025.75	92%	565	100	17
Ignore Schedule	$15.0B	2025.75	92%	565	100	17
Ignore Budget	$7.0B	2015.75	99%	572	100	17
Ignore Everything	$14.0B	2025.75	94%	567	100	17

In comparison with 2011 EFV program estimates of a total cost of $11.163B and a full fielding by 2019, the EFV model has a 34% budget error, a 0.003% schedule error, and an undetermined performance error. It is also important to highlight that there is a lack of change between the normal approach and the ignore schedule alternatives.

The results of the EFV rework model are provided in Table 5-6. As with the previous case study rework results, each alternative is shown at 0% rework (the baseline case), at a common percentage that every model and alternative can achieve of 7%, and at the maximum rework achievable before the system cannot complete all the work due to continuous work growth due to the rework. It is important to note that the normal approaches and ignore schedule alternatives do not have a condition larger than 7% as this was the highest rework percentage before sustained growth.

Table 5-6: Expeditionary Fighting Vehicle Rework Model Results

Model Run	Rework %	Total Budget	Year Complete	Performance %	Number of Systems	Total Work	Maximum Work in Worst Year
Normal Approach	0%	$15.0B	2025.75	92%	565	100	17
Normal Approach	7%	$58B	2046.5	75%	548	157	33
Ignore Schedule	0%	$15.0B	2025.75	92%	565	100	17
Ignore Schedule	7%	$60B	2046.75	75%	548	159	34
Ignore Budget	0%	$7.0B	2015.75	99%	572	100	17
Ignore Budget	7%	$10B	2016.5	98%	571	108	23
Ignore Budget	20%	$37B	2026	89%	567	197	43
Ignore Everything	0%	$14.0B	2025.75	94%	567	100	17
Ignore Everything	7%	$30B	2031.25	88%	561	127	32
Ignore Everything	10%	$71B	2046.5	76%	549	199	44

5.4 Case Study 4- M1 Abrams Main Battle Tank Results

As noted previously, all model results are in Appendix 2 while the M1 baseline results are summarized in Table 5-7.

Table 5-7: M1 Abrams Main Battle Tank Baseline Model Results

Model Run	Total Budget	Year Complete	Performance %	Number of Systems	Total Work	Maximum Work in One Year
Normal Approach	$11B	1985	93%	3266	100	15
Ignore Schedule	$11B	1985	93%	3266	100	15
Ignore Budget	$14B	1977.75	95%	3268	100	23
Ignore Everything	$10B	1983	93%	3266	100	23

No quality data could be found to verify the cost, schedule, and performance data on the M1 project. As with the EFV, there is a lack of change between the normal approach and the ignore schedule alternatives. This leads the author to believe that the source data may cause these results.

The results of the M1 rework model are provided in Table 5-8. As with the previous case study rework results, each alternative is shown at 0% rework (the baseline case), at a common percentage that every model and alternative can achieve of 7%, and at the maximum rework achievable before the system cannot complete all the work due to continuous work growth due to the rework.

Table 5-8: M1 Abrams Main Battle Tank Rework Model Results

Model Run	Rework %	Total Budget	Year Complete	Performance %	Number of Systems	Total Work	Maximum Work in Worst Year
Normal Approach	0%	$11B	1985	93%	3266	100	15

Model Run	Rework %	Total Budget	Year Complete	Performance %	Number of Systems	Total Work	Maximum Work in Worst Year
Normal Approach	7%	$18B	1986.75	92%	3265	111	23
Normal Approach	15%	$68B	2000	82%	3255	194	42
Ignore Schedule	0%	$11B	1985	93%	3266	100	15
Ignore Schedule	7%	$18B	1986.75	92%	3265	111	23
Ignore Schedule	15%	$71B	2000.75	81%	3254	200	43
Ignore Budget	0%	$14B	1977.75	95%	3268	100	23
Ignore Budget	7%	$17B	1978	95%	3268	105	26
Ignore Budget	35%	$90B	1988.25	88%	3261	249	49
Ignore Everything	0%	$10B	1983	93%	3266	100	23
Ignore Everything	7%	$14B	1984.25	92%	3265	113	31
Ignore Everything	17%	$48B	1995.5	84%	3257	212	49

5.5 Comparison of Alternatives Evaluated

The model results from the baseline runs have been used to evaluate the four alternatives previously discussed. Table 5-9 shows the percent changes of each of the baseline models with the ignoring schedule alternative. In this section, a positive percentage equates to a reduction in value while a negative percentage equates to an increase in value.

Table 5-9: Ignore Schedule Results Comparison

System	Budget Change (%)	Schedule Change (%)	Performance Change (%)	Quantity Change (%)	Maximum Work in One Year
FCS	0	0.00	0	0	15
Javelin	-20	-0.04	0	0	30
EFV	0	0.00	0	0	17

System	Budget Change (%)	Schedule Change (%)	Performance Change (%)	Quantity Change (%)	Maximum Work in One Year
M1	0	0.00	0	0	15
Average	5	0	0	0	19.25

While this may seem strange, there are two hypotheses on the results observed. First, the schedule comparisons were performed using a year estimate (i.e., 1999) which allows a fairly wide range of error potential. Second, the schedule estimates were accurate reflections of the actual project schedule and therefore the comparison had little impact on the overall system performance. These results lead to a recommendation of further testing of the model with initial and refined estimates.

When evaluating the approach of ignoring the budget, the results are more interesting and shown in table 5-10.

Table 5-10: Ignore Budget Results Comparison

System	Budget Change (%)	Schedule Change (%)	Performance Change (%)	Quantity Change (%)	Maximum Work in One Year
FCS	-50	-0.38	1	7	15
Javelin	-36	-0.18	0	0	26
EFV	-53	-0.49	8	1	17
M1	27	-0.37	2	0.1	23
Average	-28	-0.36	2.75	2.025	20.25

There are two significant findings in these results. The first is the large variation in budget change while the second is the unequal performance quality versus quantity reductions.

In regards to the budget changes, it is believed that these are the results of inaccurate flow rates within the model. The execution and completion flows were the product of trial and error and have little to no empirical basis. Therefore, they likely cause work flows that are not realistic, and these work flows impact the work in progress

which is the basis for the yearly budget. Further evidence of this are the maximum work elements in one year results which has been provided in each of the result comparison tables. This is a known weakness of the model, but one that is easily corrected with accurate empirical estimates or data and would be valid future research.

In regards to the variation in performance levels, it is believed that these are the results of mathematical percentage calculations. For example, the FCS quantities were small with 17 versus Javelin with an extremely large number of systems of 34,344. However, detailed investigation finds that the performance changes are proportionally equal which can be adjusted to provide more accurate results.

When evaluating the approach of ignoring everything, the results are shown in table 5-11.

Table 5-11: Ignore Everything Results Comparison

System	Budget Change (%)	Schedule Change (%)	Performance Change (%)	Quantity Change (%)	Maximum Work in One Year
FCS	2	0.05	2	13	15
Javelin	19	0.24	0	0	31
EFV	-7	-0.00	2	0.4	17
M1	-9	-0.10	0	0	23
Average	-1.75	0.0475	1	3.375	21.5

It is believed that these variations are the result of the work flow rates which do vary between models. Given the dynamic interactions between the multiple variables, there are many ways of achieving the same end system behavior. This supports the fact that projects have unique contexts and influences that make one standard approach virtually impossible, even within a smaller domain such as DoD acquisitions.

The overall comparison of each of these alternatives within the context of the

given projects means that there is no clear single best approach. Each project must be evaluated with respect to its goals, objectives, and stakeholder opinions. Therefore, even two similar projects may have different project management approaches that may not work for the other. This finding is also supported in previously discussed research and encourages the use of a method and mechanism to enable DoD project managers to evaluate options with their stakeholders.

5.7 Impact of Rework on DoD Acqusitions

As a final note, the results of this study show that rework can have a significant impact on DoD acquisitions. That rework is difficult to assess and not measured or monitored has been proven in previous research. However, the consequences are evidenced with the four case studies for the normal approach as shown in Figures 5-1 through 5-3 and Table 5-12.

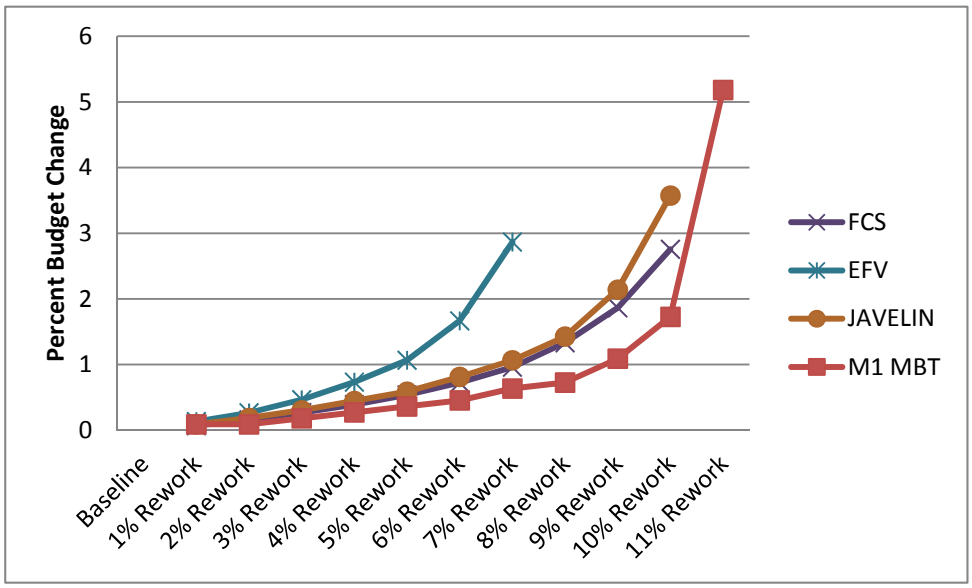

Figure 5-1: Rework Impacts on Budget

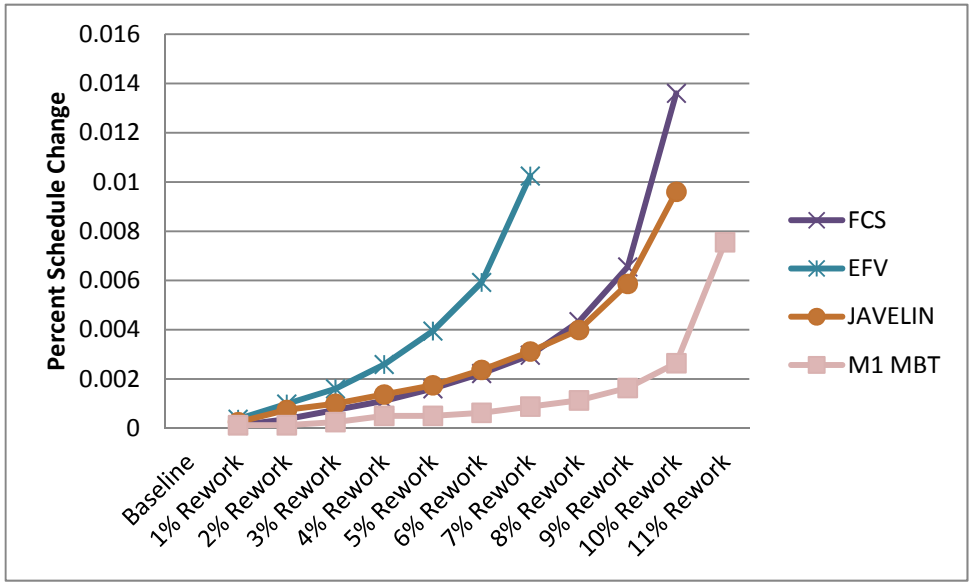

Figure 5-2: Rework Impacts on Schedule

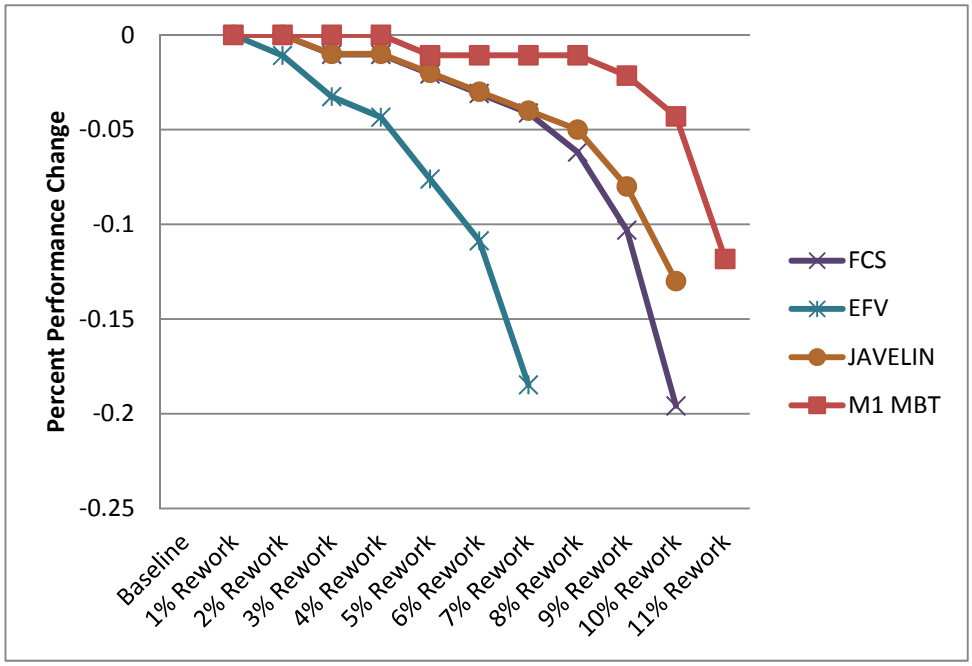

Figure 5-3: Rework Impacts on Performance

Table 5-12: Maximum Rework Before Sustained Growth Comparison

System	Normal Approach	Ignore Schedule	Ignore Budget	Ignore Everything
FCS	10%	9%	25%	12%
Javelin	10%	9%	24%	10%
EFV	7%	7%	20%	10%
M1	15%	15%	35%	17%

These figures and table highlight that rework must be monitored and controlled to prevent disastrous consequences. This, in fact, may be one of the causes of DoD acquisition projects' problems but more research is needed to determine the exact quantity of rework. Additionally, it is important to note that at a certain point rework causes sustained cost, schedule, and performance growth such that a project can never achieve completion. In the normal approach to FCS, this occurs when the rework is at a constant rate of 11% which could be a small margin of error. In all the models and scenarios run, the lowest rework percentage above inherent undocumented system rework that sustained growth was 8% which does not leave much margin for error. Finally, while the Ignore Budget approach appears to provide more resilience (i.e., higher quantity of rework), the total budget was approximately 30% higher when the other approaches entered sustained growth.

5.6 Utility of Model

The model developed in this research meets many of the qualities of previous research. It is relatively simple and while the results are not always intuitive the manner

in which it achieves those results is easy to understand. There are currently several weak elements in the model that require significant further study to optimal model results or provide sufficient confidence in its use for accurate estimation and forecasting. However, the model can provide an effective means of evaluating the simple approaches used or more detailed ones where priorities are adjusted based on contextual demands or stakeholder desires. The author then concludes that this model is useful as a communication tool especially in early system and project definition.

Chapter 6 – Conclusions

6.1 Conclusions

Projects fail, and DoD projects are not an exception to that rule. This research set out to attempt to better understand why that happens and potentially develop a tool to improve the results. Following a literature review on the topics of project management, complex systems, and system dynamics, the author found several themes. First, project management is a complex system characterized by non-linearity and interdependency. Second, humans are not able to intuitively understand or predict the behavior of complex systems. Third, project managers are generalists who attempt to utilize simple models and tools regardless of project characteristics. Fourth, the true performance measures of a project are best determined by the goals of the project as perceived by the project stakeholders.

Using this knowledge base, the author developed a new tool to potentially recreate the dynamics in project management. Using data from DoD acquisition system developments, which are also complex system, the author then was able to test several approaches to project management control with and without rework considered. The author believes the approach was validated and turns to the subject of quantifiable results.

The model results were useful and produced the general system behaviors that are the focus of system dynamics models. The results demonstrate that all projects are different and respond differently based on many factors that dynamically respond. Even with the relatively limited number of five variables used in this model, the manipulation of one variable did not produce expected results and multiple variable manipulations led to unpredictable results. Ultimately, the author believes that the best means of project

management success, in DoD or otherwise, is the honest and open communication of alternatives and impacts of decisions. A tool such as the system dynamics model created in this research can serve as an effective means of beginning discussions on outcomes of varying scenarios and alternative project management approaches and decisions. However, there are several challenges with the model and its results that are worth noting.

6.2 Research Challenges

The largest challenge came from the required model inputs. In an effort to be as efficient as possible, the model requires estimated cumulative costs by year, an expected time to complete, and a predicted level of performance. The author had significant problems in locating data that utilized consistent assumptions and limitations. Specifically, the quality and availability of DoD project cost data is frightening. While there is a website of public reports on the yearly budget submissions and major project activity, there is cause for concern that the data may have additional cost elements included or ignored without appropriate justification. Moreover, the system reports as provided by the GAO aggregate their data in a manner that only allows a single point estimation or inaccurate graphic. This prevented any verification of the inputs and often conflicted with data from other sources.

Another significant challenge arose in the treatment of project manager decisions. The author firmly believes that different project managers employ different techniques and approaches that vary in time as well as detail. Furthermore, the type and frequency with which project managers monitor metrics and take action to correct the trends likely varies. This reduces the value of the generic approach to project management and is no

different within DoD.

The final significant challenge has already been mentioned with the lack of knowledge and understanding of rework in general and within DoD acquisitions. Given the fact that these results are quite sensitive to relatively small rework changes, the author believes that further research should be conducted into the causes, manifestations, and impacts of rework within project management and especially DoD acquisitions.

6.3 Recommendations for Future Research

In answer to the previously discussed challenges and to improve upon this research, there are several recommendations for future research. First, detailed investigation into the nature of how work is accomplished within DoD projects should be conducted. This is somewhat unique because of the fact that DoD project offices do not accomplish work but rather monitor contractor work execution. Therefore, the true decision points, delays, and data used in actual DoD projects should be researched and documented to better represent the work flow. The resulting work flow can be updated in this model for more accurate predictions of future project behavior.

Second, more research should be conducted into the nature of rework in projects and within DoD. As a starting point, it would be extremely valuable to qualify and quantify the amount of rework within DoD projects as well as to develop a metric to monitor the rework level. The author believes there is significant rework within DoD acquisitions and one 20 year old study (K. G. Cooper & Mullen, 1993) confirms this within software. It would be very informative to evaluate this in other program types. As an extension of this, the nature of quality control backlog as used in Ford's work flow elements would help advance the state of a DoD project model closer to where

construction models are presently.

Third, this research can be advanced by taking Ford and Dillard's evolutionary acquisition model (Ford & Dillard, 2009) and integrating it into this model. The inputs and assumptions would need to be clarified as currently there are some differences in scope that could easily be resolved. The integrated model could then be used to quantify the value of single-stage acquisitions versus evolutionary acquisitions using dynamically interacting measures. Furthermore, the previously discussed rework research would help better develop a robust solution.

Fourth, comparative research should be done on this approach and other project management approaches. Specifically, multiple tools and approaches of project management should utilize equivalent inputs to best determine which is preferred in given conditions. Given the highly contextual nature of project management, it is likely that this research would take a long time and need many data points to draw conclusions. It would also be informative to compare similar commercial and DoD approaches to determine the specific differences as well as capabilities and limitations of each.

Finally, future research should investigate the recommendation of Kwak and Smith (2009) to institute more accountability within DoD projects. This motivation would likely advance the desire to understanding and improve DoD project management. This would help evaluate varying approaches and tools and possibly provide a culture that demands that the trends of the past fifty years be changed.

References

(Comptroller), Under Secretary of Defense. (2011). *Overview- FY2012 Defense Budget*. Washington, DC: Retrieved from http://comptroller.defense.gov/budget.html.

Abdel-Hamid, Tarek, & Madnick, Stuart E. (1991). *Software project dynamics an integrated approach*. Upper Saddle River, NJ: Prentice Hall.

Ahuja, V., & Thiruvengadam, V. (2004). Project scheduling and monitoring: current research status. *Construction Innovation (Sage Publications, Ltd.), 4*(1), 19-31. doi: 10.1191/1471417504ci064oa

Alessandri, T.M., Ford, D.N., Lander, D.M., Leggio, K.B., & Taylor, M. (2004). Managing risk and uncertainty in complex capital projects. *The Quarterly Review of Economics and Finance, 44*(5), 751-767.

Anbari, Frank T. (2003). Earned value project management method and extensions. *Project management journal, 34*(4), 12-23.

Anderson, Philip. (1999). Complexity Theory and Organization Science. *Organization Science, 10*(3), 216-232.

Atkinson, Roger. (1999). Project management: cost, time and quality, two best guesses and a phenomenon, its time to accept other success criteria. *International Journal of Project Management, 17*(6), 337-342.

Atkinson, Roger, Crawford, Lynn, & Ward, Stephen. (2006). Fundamental uncertainties in projects and the scope of project management. *International Journal of Project Management, 24*(8), 687-698.

Austin, Simon, Newton, Andrew, Steele, John, & Waskett, Paul. (2002). Modelling and managing project complexity. *International Journal of Project Management,*

20(3), 191-198.

Avots, I. (1969). Why does project management fail?(Project management systems failure analysis, discussing cost, products quality and project objectives). *California Management Review, 12*, 77-82.

Baccarini, David. (1996). The concept of project complexity—a review. *International Journal of Project Management, 14*(4), 201-204.

Barlas, Yaman (1996). Formal aspects of model validity and validation in system dynamics. *System Dynamics Review, 12*(3), 183-210. doi: 10.1002/(sici)1099-1727(199623)12:3<183::aid-sdr103>3.0.co;2-4

Bhuiyan, Nadia, & Thomson, Vince. (1999). The use of continuous approval methods in defence acquisition projects. *International Journal of Project Management, 17*(2), 121-130.

Black, Laura J., & Repenning, Nelson P. (2001). Why firefighting is never enough: preserving high-quality product development. *System Dynamics Review, 17*(1), 33-62. doi: 10.1002/sdr.205

Bourne, Lynda, & Walker, Derek .H. T. (2005). The paradox of project control. *Team Performance Management, 11*(5/6), 157-178.

Brehmer, B. (1989). Feedback delays and control in complex dynamic systems. *Computer Based Management of Complex Systems. Berlin: Springer Verlag*, 189-196.

Bryde, David James (2003). Modelling project management performance. *International Journal of Quality & Reliability Management, 20*(2), 229-254.

Buck, Christopher S. (1995). A Case Analysis of the Dual Sourcing Strategy as Used in

the Acquisition of the Army's Javelin Medium Anti-Armor Weapons Program: DTIC Document.

Burns, William J., & Slovic, Paul. (2007). The diffusion of fear: modeling community response to a terrorist strike. *The Journal of Defense Modeling and Simulation: Applications, Methodology, Technology, 4*(4), 298-317. doi: 10.1177/154851290700400402

Caulfield, C.W., & Maj, S.P. (2002). A case for System Dynamics. *Global Journal of Engineering Education, 6*(1).

Chapman, Robert J. . (1998). The role of system dynamics in understanding the impact of changes to key project personnel on design production within construction projects. *International Journal of Project Management, 16*(4), 235-247.

Chew, James S. (1997). Commercial best practices and the DoD acquisition process. from http://handle.dtic.mil/100.2/ADA487531

Christensen, David S., & Gordon, James A. (1998). Does a Rubber Baseline Guarantee Cost Overruns on Defense Acquisition Contracts? *Project Management Journal, 29*, 43-51.

Cicmil, Svetlana, Williams, Terry M., Thomas, Janice, & Hodgson, Damian. (2006). Rethinking project management: researching the actuality of projects. *International Journal of Project Management, 24*(8), 675-686. doi: 10.1016/j.ijproman.2006.08.006

Collyer, Simon, Warren, Clive, Hemsley, Bronwyn, & Stevens, Chris. (2010). Aim, fire, aim—Project planning styles in dynamic environments. *Project Management Journal, 41*(4), 108-121. doi: 10.1002/pmj.20199

Collyer, Simon, & Warren, Clive M. J. (2009). Project management approaches for dynamic environments. *International Journal of Project Management, 27*(4), 355-364.

Cooke-Davies, Terry. (2002). The “real” success factors on projects. *International Journal of Project Management, 20*(3), 185-190.

Cooper, Kenneth G. (1980). Naval ship production: a claim settled and a framework built. *Interfaces, 10*(6), 20-36.

Cooper, Kenneth G. (1993). The rework cycle: why projects are mismanaged. *PM Network. 7. 2., 5*, 7.

Cooper, Kenneth G., & Mullen, Thomas W. (1993). Swords and plowshares: the rework cycles of defense and commercial software development projects. *American Programmer*(May 1993).

Cooper, Robert G., Edgett, Scott J., & Kleinschmidt, Elko J. (2004a). BENCH MARKING BEST NPD PRACTICES--III. *Research Technology Management, 47*(6), 43-55.

Cooper, Robert G., Edgett, Scott J., & Kleinschmidt, Elko J. (2004b). BENCHMARKING BEST NPD PRACTICES--II. *Research Technology Management, 47*(3), 50-59.

Cooper, Robert G., Edgett, Scott J., & Kleinschmidt, Elko J. (2004c). BENCHMARKING BEST NPD PRACTICES-I. *Research Technology Management, 47*(1), 31-43.

Cooper, Robert G., & Kleinschmidt, Elko J. (1986). An Investigation into the New Product Process: Steps, Deficiencies, and Impact. *Journal of Product Innovation*

Management, 3(2), 71-85.

Coyle, J. M., Exelby, D., & Holt, J. (1999). System dynamics in defence analysis: some case studies. *Journal of the Operational Research Society*, 372-382.

Coyle, R. G. (1983). The technical elements of the system dynamics approach. *European Journal of Operational Research, 14*(4), 359-370.

Coyle, R. G. (1996). *System dynamics modelling: a pracitcal approach*. London: Chapman & Hall.

Coyle, R.G. (1996). *System dynamics modelling: A practical approach* (Vol. 1): Chapman & Hall/CRC.

Crawford, C. Merle. (1992). The hidden costs of accelerated product development. *Journal of Product Innovation Management, 9*(3), 188-199.

Creswell, J. W. (2009). *Research design*: *Qualitative, quantitative, and mixed methods*. Thousand Oaks, CA: Sage Publications.

Davidson, Frank P. , & Huot, Jean-Claude. (1991). Large-scale projects: management trends for major projects. *Cost Engineering, 33*(2), 15-23.

De Meyer, A., Loch, C.H., & Pich, M.T. (2002). Managing project uncertainty: from variation to chaos. *Engineering Management Review, IEEE, 30*(3), 91-91.

de Wit, Anton. (1988). Measurement of project success. *International Journal of Project Management, 6*(3), 164-170.

Deshmukh, A., & Collopy, P. (2010). *Fundamental Research into the Design of Large-Scale Complex Systems.* Paper presented at the 13th AIAA/ISSMO Multidisciplinary Analysis and Optimization Conference, Fort Worth, TX, AIAA, AIAA-2010-9320.

Diehl, Ernst, & Sterman, John D. (1995). Effects of Feedback Complexity on Dynamic Decision Making. *Organizational Behavior and Human Decision Processes, 62*(2), 198-215.

Dillard, John T., & Ford, David N. (2009). From amorphous to defined: balancing risks in evolutionary acquisition. *Defense Acquisition Review Journal 16*(3), 236-253.

Dvir, Dov, & Lechler, Thomas. (2004). Plans are nothing, changing plans is everything: the impact of changes on project success. *Research Policy, 33*(1), 1-15.

Eden, Colin, Williams, Terry M., Ackermann, F., & Howick, S. (2000). The role of feedback dynamics in disruption and delay on the nature of disruption and delay (D&D) in major projects. *Journal of the Operational Research Society, 51*(3), 291-300.

Eden, Colin, Williams, Terry M., & Ackermann, Fran. (1998). Dismantling the learning curve: the role of disruptions on the planning of development projects. *International Journal of Project Management, 16*(3), 131-138.

Eden, Colin, Williams, Terry M., & Ackermann, Fran. (2005). Analysing project cost overruns: comparing the “measured mile” analysis and system dynamics modelling. *International Journal of Project Management, 23*(2), 135-139.

Edkins, A.J., Kurul, E., Maytorena-Sanchez, E., & Rintala, K. (2007). The application of cognitive mapping methodologies in project management research. *International Journal of Project Management, 25*(8), 762-772.

Feickert, Andrew. (2010). The Marines' Expeditionary Fighting Vehicle (EFV): Background and Issues for Congress. Washington, D.C.: U.S. Congressional Research Service.

Ferrara, Joe. (1996). DoD's 5000 documents: evolution and change in defense acquisition policy. *Journal of the Defense Acquisition University, 3*(2).

Fleming, Q.W., & Koppelman, J.M. (2003). What's Your Project's Real Price Tag? *harvard business review, 81*(9), 20-22.

Flyvbjerg, Bent, Holm, Mette Skamris, & Buhl, Soren. (2002). Underestimating Costs in Public Works Projects: Error or Lie? *Journal of the American Planning Association, 68*(3), 279.

Ford, David N. (2002). Achieving multiple project objectives through contingency management. *Journal of construction engineering and management, 128*(1), 30-39.

Ford, David N., & Dillard, John T. (2009). Modeling the performance and risks of evolutionary acquisition. *Defense Acquisition Review Journal, 16*(2), 143-158.

Ford, David N., Lyneis, J.M., & Taylor, T. (2007). *Project controls to minimize cost and schedule overruns: a model, research agenda, and initial results.* Paper presented at the 2007 International System Dynamics Conference.

Ford, David N., & Sterman, John D. (1998). Dynamic modeling of product development processes. *System Dynamics Review, 14*(1), 31-68. doi: 10.1002/(sici)1099-1727(199821)14:1<31::aid-sdr141>3.0.co;2-5

Ford, David N., & Sterman, John D. (2003a). The Liar's Club: concealing rework in concurrent development. *Concurrent Engineering, 11*(3), 211-219.

Ford, David N., & Sterman, John D. (2003b). Overcoming the 90% syndrome: Iteration management in concurrent development projects. *Concurrent Engineering, 11*(3), 177-186.

Forrester, Jay W. (1971a). Counterintuitive behavior of social systems. *Theory and Decision, 2*(2), 109-140. doi: 10.1007/bf00148991

Forrester, Jay W. (1971b). *World dynamics*. Cambridge, Mass.: Wright-Allen Press.

Forrester, Jay W. (1987). Lessons from system dynamics modeling. *System Dynamics Review, 3*(2), 136-149. doi: 10.1002/sdr.4260030205

Forrester, Jay W. (1992). Policies, decisions and information sources for modeling. *European Journal of Operational Research, 59*(1), 42-63.

Forrester, Jay W. (1994). System dynamics, systems thinking, and soft OR. *System Dynamics Review, 10*(2-3), 245-256.

Francis, Paul L. (2006). Defense acquisitions: Improved business case key for future combat system's success (GAO-06-564T). Washington, DC: U.S. Government Accountability Office.

Francis, Paul L. (2008). Defense Acquisitions: 2009 Review of Future Combat System Is Critical to Program's Direction (GAO-08-408). Washington, D.C. : U.S. Government Accountability Office.

Gardiner, P.D., & Stewart, K. (2000). Revisiting the golden triangle of cost, time and quality: the role of NPV in project control, success and failure. *International Journal of Project Management, 18*(4), 251-256.

Gong, D. (1997). Optimization of float use in risk analysis-based network scheduling. *International Journal of Project Management, 15*(3), 187-192.

Graham, Allan K. (2000). Beyond PM 101: Lessons for Managing Large Development Programs. *Project Management Journal, 31*(4), 7.

Größler, A. (2007). System dynamics projects that failed to make an impact. *System*

Dynamics Review, 23(4), 437-452.

Gupta, Ashok K., & Souder, William E. (1998). Key drivers of reduced cycle time. *Research Technology Management, 41*(4), 38.

Homer, Jack B., & Hirsch, Gary B. (2006). System Dynamics Modeling for Public Health: Background and Opportunities. *American Journal of Public Health, 96*(3), 452-458. doi: 10.2105/ajph.2005.062059

Homer, Jack, & Oliva, Rogelio. (2001). Maps and models in system dynamics: a response to Coyle. *System Dynamics Review, 17*(4), 347-355.

Howick, S., & Eden, Colin. (2011). Supporting strategic conversations: the significance of a quantitative model building process. *Journal of Operational Research Society, 62*(5), 868-878.

Ivory, Chris, & Alderman, Neil. (2005). Can project management learn anything from studies of failure in complex systems? *Project Management Journal, 36*(3), 5-16.

Jessen, S.A. (1988). *Can project dynamics be modeled?* Paper presented at the 1988 International Conference of System Dynamic Society Proceedings.

Kahneman, Daniel. (2011). *Thinking, fast and slow*: Farrar, Straus and Giroux.

Khamooshi, H., & Cioffi, D. F. (2009). Program Risk Contingency Budget Planning. *Engineering Management, IEEE Transactions on, 56*(1), 171-179. doi: 10.1109/tem.2008.927818

Koskela, Lauri, & Howell, Gregory. (2002). *The underlying theory of project management is obsolete.* Paper presented at the Proceedings of the PMI Research Conference.

Kwak, Young H., & Anbari, Frank T. (2009). Analyzing project management research:

Perspectives from top management journals. *International Journal of Project Management, 27*(5), 435-446. doi: http://dx.doi.org/10.1016/j.ijproman.2008.08.004

Kwak, Young H., & Anbari, Frank T. (2012). History, practices, and future of earned value management in government: Perspectives from NASA. *Project Management Journal*.

Kwak, Young H., & Smith, Brian M. (2009). Managing risks in mega defense acquisition projects: Performance, policy, and opportunities. *International Journal of Project Management, 27*(8), 812-820. doi: 10.1016/j.ijproman.2009.02.002

Lai, CL, Ip, WH, & Lee, WB. (2001). The system dynamics model for engineering services. *Managing Service Quality, 11*(3), 191-199.

Lamb, C. T., & Rhodes, D. H. (2008, 7-10 April 2008). *Systems thinking as an emergent team property: ongoing research into the enablers and barriers to team-level systems thinking.* Paper presented at the Systems Conference, 2008 2nd Annual IEEE.

Lane, David C. (2000). Should system dynamics be described as a‘hard’ or‘deterministic’ systems approach? *Systems Research and Behavioral Science, 17*(1), 3-22.

Lane, David C., & Smart, Chris. (1996). Reinterpreting ‘generic structure’: evolution, application and limitations of a concept. *System Dynamics Review, 12*(2), 87-120.

Laufer, A., Denker, G.R., & Shenhar, A.J. (1996). Simultaneous management: the key to excellence in capital projects. *International Journal of Project Management, 14*(4), 189-199.

Lee, Z.W., Ford, D.N., & Joglekar, N. (2007). Effects of resource allocation policies for

reducing project durations: a systems modelling approach. *Systems Research and Behavioral Science, 24*(6), 551-566.

Lipke, Walt. (2011). Earned Schedule Application to Small Projects. *PM World Today, 13*.

Lipke, Walt, Zwikael, Ofer, Henderson, Kym, & Anbari, Frank T. (2009). Prediction of project outcome: The application of statistical methods to earned value management and earned schedule performance indexes. *International journal of project management, 27*(4), 400-407.

Love, Peter E. D., Edwards, David J., & Irani, Zahir. (2008). Forensic project management: an exploratory examination of the causal behavior of design-induced rework. *IEEE Transactions on Engineering Management, 55*(2), 234-247.

Love, Peter E. D., Holt, G. D., Shen, L. Y., Li, H., & Irani, Zahir. (2002). Using systems dynamics to better understand change and rework in construction project management systems. *International Journal of Project Management, 20*(6), 425-436.

Love, Peter E. D., & Smith, Jim. (2003). Benchmarking, Benchaction, and Benchlearning: Rework Mitigation in Projects. *Journal of Management in Engineering, 19*(4), 147-159. doi: 10.1061/(asce)0742-597x(2003)19:4(147)

Lussier, Frances M. (2006). *The Army's future combat systems program and alternatives*: Government Printing Office.

Lyneis, James M., Cooper, Kenneth G., & Els, Sharon A. (2001). Strategic management of complex projects: a case study using system dynamics. *System Dynamics*

Review, 17(3), 237-260. doi: 10.1002/sdr.213

Lyneis, James M., & Ford, David N. (2007). System dynamics applied to project management: a survey, assessment, and directions for future research. *System Dynamics Review, 23*(2-3), 157-189. doi: 10.1002/sdr.377

Marujo, L.G. (2009). Rework Impacts Evaluation through System Dynamics Approach in Overlapped Product Development Schedule. *Journal of technology management & innovation, 4*(2), 90-101.

McCarthy, Ian P., Tsinopoulos, Christos, Allen, Peter, & Rose-Anderssen, Christen. (2006). New Product Development as a Complex Adaptive System of Decisions. *Journal of Product Innovation Management, 23*(5), 437-456. doi: 10.1111/j.1540-5885.2006.00215.x

Meier, Steven R. (2008). Best project management and systems engineering practices in the preacquisition phase for Federal intelligence and defense agencies. *Project Management Journal, 39*(1), 59-71. doi: 10.1002/pmj.20035

Meier, Steven R. (2010). Causal inferences on the cost overruns and schedule delays of large-scale U.S. federal defense and intelligence acquisition programs. *Project Management Journal, 41*(1), 28-39. doi: 10.1002/pmj.20142

Morecroft, John D. W. (1988). System dynamics and microworlds for policymakers. *European Journal of Operational Research, 35*(3), 301-320.

Morecroft, John D.W. . (1983). System dynamics: Portraying bounded rationality. *Omega, 11*(2), 131-142.

Nassar, Khaled M., & Hegab, Mohamed Y. (2006). Developing a Complexity Measure for Project Schedules. *Journal of Construction Engineering & Management,*

132(6), 554-561. doi: 10.1061/(asce)0733-9364(2006)132:6(554)

Office, U. S. General Accounting. (1980). *XM1 tank's reliability is still uncertain: report to the Congress*: General Accounting Office.

Office, U. S. General Accounting. (1996). *Army Acquisition: Javelin is Not Ready for Multiyear Procurement: Report to Congressional Committees (GAO/NSIAD-96-199)*. Washington, D.C.: U.S. General Accounting Office.

Office, U.S. Government Accountability. (2006). Defense Acquisitions: The Expeditionary Fighting Vehicle Encountered Difficulties in Design Demonstration and Faces Future Risks. Washington, D.C.: U.S. Government Accountability Office.

Office, U.S. Government Accountability. (2011). Defense acquisitions: assessment of selected weapon programs, Report GAO-11-233SP.

Ouchi, William G. (1980). Markets, Bureaucracies, and Clans. *Administrative Science Quarterly, 25*(1), 129-141.

Pich, Michael T., Loch, Christoph H., & Meyer, Arnoud de. (2002). On uncertainty, ambiguity, and complexity in project management. *Management Science, 48*(8), 1008-1023.

Pinto, J. K., & Mantel, S. J., Jr. (1990). The causes of project failure. *Engineering Management, IEEE Transactions on, 37*(4), 269-276.

Pugh, P. G. . (1987). *Where does the time go.* Paper presented at the A review of development time-scales for aircraft and guided weapons. Royal Aeronautical Soc. Conf.'Development Time Scales: Their Estimation and Control', London.

Pundir, Ashok K. , Ganapathy, L., & Sambandam, Narayanasamy. (2007). Towards a

complexity framework for managing projects. *Emergence: Complexity & Organization, 9*(4), 17-25.

Reichelt, K., & Lyneis, J. (1999). The dynamics of project performance: benchmarking the drivers of cost and schedule overrun. *European Management Journal, 17*(2), 135-150.

Repenning, Nelson P. (1999). *Resource dependence in product development improvement efforts.* Paper presented at the 16th International Conference of the System Dynamics Society Quebec.

Repenning, Nelson P., Goncalves, Paulo, & Black, Laura J. (2001). Past the tipping point: The persistence of firefighting in product development. *California Management Review, 43*(4), 44-44-63.

Repenning, Nelson P., & Sterman, John D. (2001). Nobody ever gets the credit for fixing problems that never happened: Creating and sustaining process improvement. *California Management Review, 43*(4), 64-64-88.

Rodrigues, Alexandre, & Bowers, John. (1996a). The role of system dynamics in project management. *International Journal of Project Management, 14*(4), 213-220.

Rodrigues, Alexandre, & Bowers, John. (1996b). System dynamics in project management: A comparative analysis with traditional methods. *System Dynamics Review, 12*(2), 121-139. doi: 10.1002/(sici)1099-1727(199622)12:2<121::aid-sdr99>3.0.co;2-x

Rodrigues, Alexandre, & Williams, Terry M. (1998). System Dynamics in Project Management: Assessing the Impacts of Client Behaviour on Project Performance. *The Journal of the Operational Research Society, 49*(1), 2-15.

Rozenes, Shai, Vitner, Gad, & Spraggett, Stuart. (2006). Project control: literature review. *Project Management Journal, 37*(4), 5-14.

Saeed, K. (1992). Slicing a complex problem for system dynamics modeling. *System Dynamics Review, 8*(3), 251-261.

Sharp, JA, & Price, DHR. (1984). System dynamics and operational research: An appraisal. *European Journal of Operational Research, 16*(1), 1-12.

Shenhar, Aaron J. (2001a). Contingent management in temporary, dynamic organizations: The comparative analysis of projects. *Journal of High Technology Management Research, 12*(2), 239.

Shenhar, Aaron J. (2001b). One size does not fit all projects: exploring classical contingency domains. *Management Science, 47*(3), 394-414.

Shenhar, Aaron J. (2004). Strategic project leadership® toward a strategic approach to project management. *R&D Management, 34*(5), 569-578. doi: 10.1111/j.1467-9310.2004.00363.x

Shenhar, Aaron J., & Dvir, Dov. (1996). Toward a typological theory of project management. *Research Policy, 25*(4), 607-632.

Sherman, J. Daniel, & Rhoades, Richard G. (2010). Cycle time reduction in defense acquisition. *Research Technology Management, 53*(5), 46-54.

Singh, H., & Singh, A. (2002). Principles of complexity and chaos theory in project execution: A new approach to management. *Cost engineering, 44*(12), 23-33.

Söderlund, Jonas. (2004). Building theories of project management: past research, questions for the future. *International Journal of Project Management, 22*(3), 183-191.

Sterman, John D. (1994). Learning in and about complex systems. *System Dynamics Review (Wiley), 10*(2/3), 291-330.

Sterman, John D. (2000). *Business dynamics: systems thinking and modeling for a complex world* (Vol. 19): Irwin/McGraw-Hill New York.

Sterman, John D. (2002). All models are wrong: reflections on becoming a systems scientist. *System Dynamics Review, 18*(4), 501-531. doi: 10.1002/sdr.261

Sterman, John D. . (1989). Modeling managerial behavior: misperceptions of feedback in a dynamic decision making experiment. *Management Science, 35*(3), 321-339.

Stewart, John M. (1965). Making project management work. *Business Horizons, 8*(3), 54-68.

Sullivan, Michael J. (2011). DOD Cost Overruns: Trends in Nunn-McCurdy Breaches and Tools to Manage Weapon Systems Acquisition Costs. Washington, DC: Government Accountability Office.

Taylor, Tim, & Ford, David N. (2006). Tipping point failure and robustness in single development projects. *System Dynamics Review, 22*(1), 51-71. doi: 10.1002/sdr.330

Taylor, Tim, & Ford, David N. (2008). Managing tipping point dynamics in complex construction projects. *Journal of Construction Engineering and Management, 134*(6), 421-431.

Tishler, A., Dvir, D., Shenhar, A., & Lipovetsky, S. (1996). Identifying critical success factors in defense development projects: A multivariate analysis. *Technological Forecasting and Social Change, 51*(2), 151-171.

Vanhoucke, M. (2012). Measuring the efficiency of project control using fictitious and

empirical project data. *International Journal of Project Management, 30*(2), 252-263.

Vanhoucke, M., & Vandevoorde, S. (2006). A simulation and evaluation of earned value metrics to forecast the project duration. *Journal of the Operational Research Society, 58*(10), 1361-1374.

Vidal, Ludociv-Alexandre, & Marle, Frank. (2008). Understanding project complexity: implications on project management. *Kybernetes, 37*(8), 1094-1110.

Vidal, Ludovic-Alexandre, Marle, Franck, & Bocquet, Jean-Claude. (2011). Measuring project complexity using the Analytic Hierarchy Process. *International Journal of Project Management, 29*(6), 718-727.

Whitty, Stephen Jonathan, & Maylor, Harvey. (2009). And then came complex project management (revised). *International Journal of Project Management, 27*(3), 304-310.

Wideman, R Max (1989). Successful project control and execution. *International Journal of Project Management, 7*(2), 109-113.

Williams, Glen W. (1974). An Examination of the XM-1 Tank System Acquisition Program in a Peacetime Environment. Fort Belvoir, VA: DTIC Document.

Williams, Terry M. (1999). The need for new paradigms for complex projects. *International Journal of Project Management, 17*(5), 269-273.

Williams, Terry M. (2003). Assessing Extension of Time delays on major projects. *International Journal of Project Management, 21*(1), 19-26.

Williams, Terry M. (2005). Assessing and moving on from the dominant project management discourse in the light of project overruns. *Engineering Management,*

IEEE Transactions on, 52(4), 497-508.

Williams, Terry M., Eden, Colin, Ackermann, Fran, & Tait, Andrew. (1995). The Effects of Design Changes and Delays on Project Costs. *The Journal of the Operational Research Society, 46*(7), 809-818.

Wirthlin, Joseph R., Houston, Daniel X., & Madachy, Raymond J. (2011). *Defense acquisition system simulation studies.* Paper presented at the Proceedings of the 2011 International Conference on Software and Systems Process.

Wolstenholme, E. F. (1992). The definition and application of a stepwise approach to model conceptualisation and analysis. *European Journal of Operational Research, 59*(1), 123-136.

Wolstenholme, E. F. (1999). Qualitative vs Quantitative Modelling: The Evolving Balance. *The Journal of the Operational Research Society, 50*(4), 422-428.

Wolstenholme, E. F. (2003). Towards the definition and use of a core set of archetypal structures in system dynamics. *System Dynamics Review, 19*(1), 7-26. doi: 10.1002/sdr.259

Wolstenholme, E. F. . (1990). *System enquiry: a system dynamics approach*. New York, NY: John Wiley & Sons , Inc.

Wright, J. Nevan (1997). Time and budget: the twin imperatives of a project sponsor. *International Journal of Project Management, 15*(3), 181-186.

Yeo, K.T. (1993). Systems thinking and project management — time to reunite. *International Journal of Project Management, 11*(2), 111-117.

Yu, SB, & Efstathiou, J. (2005). Complexity in rework cells: theory, analysis and comparison. *Journal of the Operational Research Society, 57*(5), 593-602.

Appendix A- Cost Data

Table A-1: Future Combat System

Year	Yearly Budget ($B)	Cumulative Budget ($B)
2005	3.0	3.0
2006	3.16	6.16
2007	3.32	9.48
2008	3.48	12.96
2009	3.64	16.6
2010	3.8	20.4
2011	5.24	25.64
2012	6.68	32.32
2013	8.12	40.44
2014	9.56	50
2015	11	61
2016	10.4	71.4
2017	9.8	81.2
2018	9.2	90.4
2019	8.6	99
2020	8	107
2021	7.96	114.96
2022	7.92	122.88
2023	7.88	130.76
2024	7.84	138.6
2025	7.8	146.4

Source: (Francis, 2006)

Table A-2: Javelin Missile System

Year	Yearly Budget ($B)	Cumulative Budget ($B)
1993	0.018	0.018
1994	0.207	0.226
1995	0.212	0.438
1996	0.171	0.610
1997	0.191	0.800
1998	0.195	0.995
1999	0.241	1.236
2000	0.291	1.527
2001	0.367	1.894
2002	0.447	2.341
2003	0.474	2.815
2004	0.454	3.269
2005	0.014	3.283
2006	0.010	3.293

Source: (Buck, 1995)

Table A-3: Expeditionary Fighting Vehicle

Year	Yearly Budget ($B)	Cumulative Budget ($B)
2000	0.114	0.114
2001	0.138	0.252
2002	0.261	0.513
2003	0.316	0.829
2004	0.335	1.164
2005	0.305	1.468
2006	0.278	1.747
2007	0.457	2.204
2008	0.246	2.450
2009	0.314	2.763
2010	0.292	3.055
2011	0.243	3.298

Source: http://www.acq.osd.mil/ara/am/sar/

Table A-4: M1 Abrams Main Battle Tank

Year	Yearly Budget ($B)	Cumulative Budget ($B)
1972	0.020	0.020
1973	0.021	0.041
1974	0.054	0.095
1975	0.065	0.160
1976	0.053	0.213
1977	0.143	0.356
1978	0.300	0.656
1979	0.475	1.131
1980	0.760	1.891
1981	1.218	3.109
1982	2.089	5.198
1983	2.169	7.367
1984	1.878	9.245
1985	1.893	11.138

Source: http://www.acq.osd.mil/ara/am/sar/

Appendix B- Model Results

Table B-1: Future Combat System

	Total Budget ($B)		Year Complete		Performance (%)	Change in Performance	Number of Systems	Total Work		Maximum Work Year	%		Total Years (from 2005)
						Normal Approach							
Baseline	156		2021.75		97		15	100		2018	15		16.75
1% Rework	167	7%	2022	0.01%	97	0.0%	15	101	1%	2018.25	16	7%	17
2% Rework	181	16%	2022.5	0.04%	97	0.0%	15	103	3%	2018	17	13%	17.5
3% Rework	198	27%	2023.25	0.07%	96	-1.0%	14	105	5%	2018.75	19	27%	18.25
4% Rework	217	39%	2024	0.11%	96	-1.0%	14	108	8%	2019	21	40%	19
5% Rework	240	54%	2025	0.16%	95	-2.1%	13	111	11%	2018.75	22	47%	20
6% Rework	269	72%	2026.25	0.22%	94	-3.1%	12	116	16%	2019.25	25	67%	21.25
7% Rework	306	96%	2027.75	0.30%	93	-4.1%	11	121	21%	2019.25	27	80%	22.75
8% Rework	364	133%	2030.5	0.43%	91	-6.2%	9	130	30%	2019.5	30	100%	25.5
9% Rework	447	187%	2035	0.66%	87	-10.3%	5	137	37%	2019.5	37	147%	30
10% Rework	586	276%	2049.25	1.36%	78	-19.6%	0	200	100%	2019.75	37	147%	44.25
11% Rework	Sustained Growth.												
						Ignore Schedule							
Baseline	156		2021.75		97		15	100		2018	15		16.75
1% Rework	168	8%	2022	0.01%	97	0.0%	15	101	1%	2018.25	16	7%	17
2% Rework	181	16%	2022.5	0.04%	97	0.0%	15	103	3%	2018	17	13%	17.5
3% Rework	197	26%	2023.5	0.09%	96	-1.0%	14	105	5%	2018.5	19	27%	18.5
4% Rework	216	38%	2024	0.11%	95	-2.1%	13	108	8%	2019	21	40%	19
5% Rework	241	54%	2025	0.16%	95	-2.1%	13	111	11%	2019.25	23	53%	20
6% Rework	270	73%	2026.25	0.22%	94	-3.1%	12	116	16%	2019.25	25	67%	21.25
7% Rework	308	97%	2028	0.31%	92	-5.2%	10	122	22%	2019.25	27	80%	23
8% Rework	362	132%	2030.5	0.43%	91	-6.2%	9	121	21%	2019.5	30	100%	25.5
9% Rework	444	185%	2035	0.66%	87	-10.3%	5	147	47%	2019.5	33	120%	30
10% Rework	Sustained Growth.												
						Ignore Budget							
Baseline	78		2014		98		16	100		2012.5	15		9
1% Rework	81	4%	2014.25	0.01%	98	0.0%	16	101	1%	2012.5	15	0%	9.25
2% Rework	83	6%	2014.25	0.01%	98	0.0%	16	101	1%	2012.5	16	7%	9.25
3% Rework	86	10%	2014.25	0.01%	98	0.0%	16	102	2%	2012.25	16	7%	9.25
4% Rework	89	14%	2014.25	0.01%	98	0.0%	16	103	3%	2012.25	17	13%	9.25
5% Rework	92	18%	2014.5	0.02%	98	0.0%	16	104	4%	2012.5	18	20%	9.5
6% Rework	95	22%	2014.5	0.02%	98	0.0%	16	105	5%	2012.5	18	20%	9.5
7% Rework	99	27%	2014.75	0.04%	98	0.0%	16	106	6%	2012.5	19	27%	9.75
8% Rework	103	32%	2014.75	0.04%	98	0.0%	16	107	7%	2012.5	20	33%	9.75
9% Rework	107	37%	2014.75	0.04%	98	0.0%	16	108	8%	2012.5	21	40%	9.75
10% Rework	112	44%	2015	0.05%	97	-1.0%	15	110	10%	2012.5	21	40%	10
11% Rework	117	50%	2015	0.05%	97	-1.0%	15	111	11%	2012.5	22	47%	10
12% Rework	122	56%	2015.25	0.06%	97	-1.0%	15	113	13%	2012.5	23	53%	10.25
15% Rework	142	82%	2015.75	0.09%	97	-1.0%	15	119	19%	2012.5	26	73%	10.75
20% Rework	198	154%	2017.5	0.17%	95	-3.1%	13	137	37%	2012.75	33	120%	12.5
25% Rework	397	409%	2024.25	0.51%	90	-8.2%	8	208	108%	2012.75	41	173%	19.25
26% Rework	Sustained Growth.												
						Ignore Everything							
Baseline	159		2022.75		99		17	100		2019.5	15		17.75
1% Rework	170	7%	2023	0.01%	99	0.0%	17	101	1%	2019.5	16	7%	18
2% Rework	181	14%	2023.25	0.02%	98	-1.0%	16	103	3%	2019.5	17	13%	18.25
3% Rework	194	22%	2023.5	0.04%	98	-1.0%	16	105	5%	2020	19	27%	18.5
4% Rework	208	31%	2024	0.06%	97	-2.0%	15	107	7%	2019.5	20	33%	19
5% Rework	225	42%	2024.5	0.09%	97	-2.0%	15	110	10%	2020	22	47%	19.5
6% Rework	245	54%	2025	0.11%	96	-3.0%	14	113	13%	2020	24	60%	20
7% Rework	268	69%	2025.75	0.15%	96	-3.0%	14	117	17%	2020	26	73%	20.75
8% Rework	297	87%	2026.5	0.19%	95	-4.0%	13	122	22%	2019.75	28	87%	21.5
9% Rework	333	109%	2027.75	0.25%	94	-5.1%	12	128	28%	2020	31	107%	22.75
10% Rework	382	140%	2029.25	0.32%	92	-7.1%	10	137	37%	2019.75	33	120%	24.25
11% Rework	452	184%	2031.75	0.44%	90	-9.1%	8	152	52%	2020	37	147%	26.75
12% Rework	566	256%	2036.75	0.69%	87	-12.1%	5	180	80%	2020	41	173%	31.75
13% Rework	Sustained Growth.												

Comparison to Baseline

Table B-2: Javelin Missile System

	Total Budget ($B)		Year Complete		Performance (%)		Number of Systems	Total Work		Maximum Work Year	%		Total Years (from 1993)
					Normal Approach								
Baseline	3.011		2004.5		100		34435	100		2000	26		11.5
1% Rework	3.289	9%	2005	0.02%	100	0.0%	34435	102	2%	2001	28	8%	12
2% Rework	3.578	19%	2006	0.07%	100	0.0%	34435	104	4%	2001	29	12%	13
3% Rework	3.929	30%	2006.5	0.10%	99	-1.0%	34434	106	6%	2001.25	30	15%	13.5
4% Rework	4.354	45%	2007.25	0.14%	99	-1.0%	34434	109	9%	2001.25	31	19%	14.25
5% Rework	4.782	59%	2008	0.17%	98	-2.0%	34434	112	12%	2001.25	33	27%	15
6% Rework	5.459	81%	2009.25	0.24%	97	-3.0%	34432	117	17%	2001.5	35	35%	16.25
7% Rework	6.221	107%	2010.75	0.31%	96	-4.0%	34431	123	23%	2001.5	36	38%	17.75
8% Rework	7.308	143%	2012.5	0.40%	95	-5.0%	34430	131	31%	2001.75	38	46%	19.5
9% Rework	9.459	214%	2016.25	0.59%	92	-8.0%	34427	145	45%	2001.75	41	58%	23.25
10% Rework	13.773	357%	2023.75	0.96%	87	-13.0%	34422	175	75%	2001.75	43	65%	30.75
11% Rework	Sustained Growth.												
					Ignore Schedule								
Baseline	2.398		2003.75		100		34434	100		2000.25	30		10.75
1% Rework	2.545	6%	2004	0.01%	100	0.0%	34434	102	2%	2000.25	32	7%	11
2% Rework	2.891	21%	2004.75	0.05%	100	0.0%	34434	104	4%	2000.25	33	10%	11.75
3% Rework	3.218	34%	2005.5	0.09%	100	0.0%	34434	107	7%	2000.5	35	17%	12.5
4% Rework	3.774	57%	2007.5	0.19%	100	0.0%	34434	111	11%	2000.5	36	20%	14.5
5% Rework	4.331	81%	2008.75	0.25%	99	-1.0%	34434	115	15%	2000.75	38	27%	15.75
6% Rework	5.024	110%	2010.25	0.32%	98	-2.0%	34433	121	21%	2001	40	33%	17.25
7% Rework	5.859	144%	2012.25	0.42%	97	-3.0%	34432	129	29%	2000.75	41	37%	19.25
8% Rework	7.465	211%	2015.75	0.60%	94	-6.0%	34429	142	42%	2001	44	47%	22.75
9% Rework	10.428	335%	2022	0.91%	90	-10.0%	34425	167	67%	2001	46	53%	29
10% Rework	Sustained Growth.												
					Ignore Budget								
Baseline	1.934		2001		100		34435	100		1998.75	26		8
1% Rework	1.995	3%	2001	0.00%	100	0.0%	34435	101	1%	1998.75	28	8%	8
2% Rework	2.058	6%	2001	0.00%	100	0.0%	34435	102	2%	1998.75	28	8%	8
3% Rework	2.13	10%	2001.5	0.02%	99	-1.0%	34434	103	3%	1998.75	28	8%	8.5
4% Rework	2.204	14%	2001.5	0.02%	99	-1.0%	34434	105	5%	1998.75	29	12%	8.5
5% Rework	2.285	18%	2001.5	0.02%	99	-1.0%	34434	106	6%	1998.75	30	15%	8.5
6% Rework	2.372	23%	2001.5	0.02%	99	-1.0%	34434	107	7%	1998.75	31	19%	8.5
7% Rework	2.465	27%	2001.75	0.04%	99	-1.0%	34434	109	9%	1998.75	32	23%	8.75
8% Rework	2.567	33%	2001.75	0.04%	99	-1.0%	34434	111	11%	1998.75	33	27%	8.75
9% Rework	2.679	39%	2002	0.05%	99	-1.0%	34434	113	13%	1998.75	33	27%	9
10% Rework	2.799	45%	2002	0.05%	99	-1.0%	34434	115	15%	1998.75	34	31%	9
11% Rework	2.935	52%	2002.25	0.06%	99	-1.0%	34434	117	17%	1998.75	35	35%	9.25
12% Rework	3.084	59%	2002.5	0.07%	99	-1.0%	34434	119	19%	1998.75	36	38%	9.5
15% Rework	3.654	89%	2003.25	0.11%	98	-2.0%	34433	129	29%	1998.75	40	54%	10.25
20% Rework	5.511	185%	2005.5	0.22%	97	-3.0%	34432	158	58%	1998.75	46	77%	12.5
21% Rework	6.236	222%	2006.25	0.26%	96	-4.0%	34431	169	69%	1999	48	85%	13.25
22% Rework	7.286	277%	2007.5	0.32%	96	-4.0%	34431	185	85%	1999	50	92%	14.5
23% Rework	9.066	369%	2009.5	0.42%	94	-6.0%	34429	211	111%	1998.75	50	92%	16.5
24% Rework	14.042	626%	2015.25	0.71%	89	-11.0%	34424	281	181%	1999	53	104%	22.25
25% Rework	Sustained Growth.												
					Ignore Everything								
Baseline	3.597		2009.25		100		34434	100		2004	31		16.25
1% Rework	3.866	7%	2009.5	0.01%	95	-5.0%	34434	102	2%	2004	33	6%	16.5
2% Rework	4.178	16%	2010	0.04%	99	-1.0%	34434	105	5%	2004	34	10%	17
3% Rework	4.554	27%	2010.75	0.07%	99	-1.0%	34434	110	10%	2004	36	16%	17.75
4% Rework	4.997	39%	2011.5	0.11%	98	-2.0%	34433	114	14%	2004	38	23%	18.5
5% Rework	5.549	54%	2012.25	0.15%	98	-2.0%	34433	119	19%	2004	41	32%	19.25
6% Rework	6.217	73%	2013.5	0.21%	97	-3.0%	34432	126	26%	2004	43	39%	20.5
7% Rework	7.147	99%	2014.75	0.27%	96	-4.0%	34431	135	35%	2004	46	48%	21.75
8% Rework	8.576	138%	2017	0.39%	94	-6.0%	34429	148	48%	2004	49	58%	24
9% Rework	10.819	201%	2020.25	0.55%	92	-8.0%	34427	169	69%	2004	52	68%	27.25
10% Rework	15.825	340%	2027.5	0.91%	86	-14.0%	34421	214	114%	2000.75	55	77%	34.5
11% Rework	Sustained Growth.												

Comparison to Baseline

Table B-3: Expeditionary Fighting Vehicle

	Total Budget ($B)		Year Complete		Performance (%)		Number of Systems	Total Work		Maximum Work Year	%		Total Years (from 2000)
Normal Approach													
Baseline	15		2025.75		92		565	100		2019.25	17		25.75
1% Rework	17	13%	2026.5	0.04%	92	0.0%	565	102	2%	2020.25	19	12%	26.5
2% Rework	19	27%	2027.75	0.10%	91	-1.1%	564	103	3%	2019.75	20	18%	27.75
3% Rework	22	47%	2029	0.16%	89	-3.3%	562	108	8%	2020.25	22	29%	29
4% Rework	26	73%	2031	0.26%	88	-4.3%	561	113	13%	2020.5	25	47%	31
5% Rework	31	107%	2033.75	0.39%	85	-7.6%	558	121	21%	2020.5	27	59%	33.75
6% Rework	40	167%	2037.75	0.59%	82	-10.9%	555	132	32%	2020.75	30	76%	37.75
7% Rework	58	287%	2046.5	1.02%	75	-18.5%	548	157	57%	2020.75	33	94%	46.5
8% Rework	Sustained growth.												
Ignore Schedule													
Baseline	15		2025.75		92		565	100		2019.5	17		25.75
1% Rework	17	13%	2026.75	0.05%	92	0.0%	565	102	2%	2020	19	12%	26.75
2% Rework	19	27%	2027.5	0.09%	91	-1.1%	564	105	5%	2019.5	20	18%	27.5
3% Rework	22	47%	2029.5	0.19%	89	-3.3%	562	109	9%	2020.25	22	29%	29.5
4% Rework	26	73%	2031	0.26%	88	-4.3%	561	113	13%	2020.5	25	47%	31
5% Rework	31	107%	2033.75	0.39%	85	-7.6%	558	121	21%	2020.75	28	65%	33.75
6% Rework	40	167%	2037.5	0.58%	82	-10.9%	555	132	32%	2021	31	82%	37.5
7% Rework	60	300%	2046.75	1.04%	75	-18.5%	548	159	59%	2021	34	100%	46.75
8% Rework	Sustained growth.												
Ignore Budget													
Baseline	7		2015.75		99		572	100		2013.5	17		15.75
1% Rework	7	0%	2016	0.01%	98	-1.0%	571	101	1%	2013.25	17	0%	16
2% Rework	8	14%	2015.75	0.00%	98	-1.0%	571	102	2%	2013.25	18	6%	15.75
3% Rework	8	14%	2016	0.01%	98	-1.0%	571	103	3%	2013.5	19	12%	16
4% Rework	8	14%	2016	0.01%	98	-1.0%	571	104	4%	2013.5	20	18%	16
5% Rework	9	29%	2016	0.01%	98	-1.0%	571	105	5%	2013.5	21	24%	16
6% Rework	9	29%	2016.25	0.02%	98	-1.0%	571	107	7%	2013.75	22	29%	16.25
7% Rework	10	43%	2016.5	0.04%	98	-1.0%	571	108	8%	2013.75	23	35%	16.5
8% Rework	10	43%	2016.5	0.04%	98	-1.0%	571	110	10%	2013.75	24	41%	16.5
9% Rework	11	57%	2016.75	0.05%	97	-2.0%	570	112	12%	2013.5	25	47%	16.75
10% Rework	11	57%	2017	0.06%	97	-2.0%	570	114	14%	2013.75	26	53%	17
11% Rework	12	71%	2017.25	0.07%	97	-2.0%	570	117	17%	2013.5	27	59%	17.25
12% Rework	13	86%	2017.5	0.09%	97	-2.0%	570	120	20%	2013.75	29	71%	17.5
15% Rework	17	143%	2018.75	0.15%	95	-4.0%	568	131	31%	2013.75	33	94%	18.75
20% Rework	37	429%	2026	0.51%	89	-10.1%	567	197	97%	2013.75	43	153%	26
21% Rework	Sustained growth.												
Ignore Everything													
Baseline	14		2025.75		94		567	100		2021.75	17		25.75
1% Rework	15	7%	2026	0.01%	94	0.0%	567	102	2%	2022	19	12%	26
2% Rework	16	14%	2026.75	0.05%	93	-1.1%	566	104	4%	2022	20	18%	26.75
3% Rework	18	29%	2027	0.06%	92	-2.1%	565	107	7%	2022	22	29%	27
4% Rework	20	43%	2027.75	0.10%	92	-2.1%	565	110	10%	2022	24	41%	27.75
5% Rework	22	57%	2028.75	0.15%	91	-3.2%	564	114	14%	2022	27	59%	28.75
6% Rework	25	79%	2029.75	0.20%	90	-4.3%	563	120	20%	2021.75	29	71%	29.75
7% Rework	30	114%	2031.25	0.27%	88	-6.4%	561	127	27%	2022	32	88%	31.25
8% Rework	36	157%	2033.5	0.38%	86	-8.5%	559	138	38%	2022	36	112%	33.5
9% Rework	46	229%	2037.25	0.57%	83	-11.7%	556	156	56%	2022.25	40	135%	37.25
10% Rework	71	407%	2046.5	1.02%	76	-19.1%	549	199	99%	2022	44	159%	46.5
11% Rework	Sustained growth.												

Comparison to Baseline

Table B-4:M1 Abrams Main Battle Tank

	Total Budget ($B)		Year Complete		Performance (%)		Number of Systems	Total Work		Maximum Work Year	%		Total Years (from 2000)
					Normal Approach								
Baseline	11		1985		93		3266	100		1983.25	15		13
1% Rework	12	9%	1985.25	0.01%	93	0.0%	3266	101	1%	1983.25	16	7%	13.25
2% Rework	12	9%	1985.25	0.01%	93	0.0%	3266	102	2%	1982.75	16	7%	13.25
3% Rework	13	18%	1985.5	0.03%	93	0.0%	3266	103	3%	1983.5	18	20%	13.5
4% Rework	14	27%	1986	0.05%	93	0.0%	3266	105	5%	1983.5	19	27%	14
5% Rework	15	36%	1986	0.05%	92	-1.1%	3265	107	7%	1983.5	20	33%	14
6% Rework	16	45%	1986.25	0.06%	92	-1.1%	3265	109	9%	1983.5	21	40%	14.25
7% Rework	18	64%	1986.75	0.09%	92	-1.1%	3265	111	11%	1983.5	23	53%	14.75
8% Rework	19	73%	1987.25	0.11%	92	-1.1%	3265	114	14%	1983.75	25	67%	15.25
10% Rework	23	109%	1988.25	0.16%	91	-2.2%	3264	121	21%	1983.75	28	87%	16.25
12% Rework	30	173%	1990.25	0.26%	89	-4.3%	3262	133	33%	1984	33	120%	18.25
15% Rework	68	518%	2000	0.76%	82	-11.8%	3255	194	94%	1984	42	180%	28
16% Rework	Sustained growth.												
					Ignore Schedule								
Baseline	11		1985		93		3266	100		1983.25	15		-15
1% Rework	12	9%	1985	0.00%	93	0.0%	3266	101	1%	1983.25	16	7%	-15
2% Rework	12	9%	1985.25	0.01%	93	0.0%	3266	102	2%	1983.25	17	13%	-14.75
3% Rework	13	18%	1985.5	0.03%	93	0.0%	3266	104	4%	1983.25	18	20%	-14.5
4% Rework	14	27%	1985.75	0.04%	92	-1.1%	3265	105	5%	1983.5	19	27%	-14.25
5% Rework	15	36%	1986	0.05%	92	-1.1%	3265	107	7%	1983.25	20	33%	-14
6% Rework	16	45%	1986.25	0.06%	92	-1.1%	3265	108	8%	1983.5	22	47%	-13.75
7% Rework	18	64%	1986.75	0.09%	92	-1.1%	3265	111	11%	1983.5	23	53%	-13.25
8% Rework	19	73%	1987.5	0.13%	91	-2.2%	3264	114	14%	1983.5	24	60%	-12.5
9% Rework	24	118%	1987.75	0.14%	91	-2.2%	3264	117		1983.75	27	80%	
10% Rework	24	118%	1988.25	0.16%	90	-3.2%	3263	121		1983.75	29	93%	
12% Rework	31	182%	1990.5	0.28%	89	-4.3%	3262	133		1984	33	120%	
15% Rework	71	545%	2000.75	0.79%	81	-12.9%	3254	200		1984	43	187%	
16% Rework	Sustained growth.												
					Ignore Budget								
Baseline	14		1977.75		95		3268	100		1976.25	23		-22.25
1% Rework	14	0%	1977.75	0.00%	95	0.0%	3268	101	1%	1976.25	23	0%	-22.25
2% Rework	15	7%	1977.75	0.00%	95	0.0%	3268	101	1%	1976.25	24	4%	-22.25
3% Rework	15	7%	1977.75	0.00%	95	0.0%	3268	102	2%	1976.25	24	4%	-22.25
4% Rework	15	7%	1978	0.01%	95	0.0%	3268	103	3%	1976.25	25	9%	-22
5% Rework	16	14%	1978	0.01%	95	0.0%	3268	104	4%	1976.25	25	9%	-22
6% Rework	16	14%	1978	0.01%	95	0.0%	3268	104	4%	1976.25	26	13%	-22
7% Rework	17	21%	1978	0.01%	95	0.0%	3268	105	5%	1976.25	26	13%	-22
8% Rework	17	21%	1978	0.01%	95	0.0%	3268	106	6%	1976.25	26	13%	-22
9% Rework	17	21%	1978.25	0.03%	95	0.0%	3268	107	7%	1976.25	27	17%	-21.75
10% Rework	18	29%	1978.25	0.03%	95	0.0%	3268	108	8%	1976.25	28	22%	-21.75
12% Rework	19	36%	1978.25	0.03%	95	0.0%	3268	110	10%	1976.25	29	26%	-21.75
15% Rework	21	50%	1978.5	0.04%	95	0.0%	3268	114	14%	1976.25	31	35%	-21.5
20% Rework	25	79%	1979	0.06%	94	-1.1%	3267	132	32%	1976.25	34	48%	-21
25% Rework	31	121%	1979.75	0.10%	94	-1.1%	3267	135	35%	1976.25	38	65%	-20.25
30% Rework	42	200%	1981	0.16%	92	-3.2%	3265	159		1976.5	43	87%	-19
35% Rework	90	543%	1988.25	0.53%	88	-7.4%	3261	249		1976.5	49	113%	-11.75
36% Rework	Sustained growth.												
					Ignore Everything								
Baseline	10		1983		93		3266	100		1980.25	23		-17
1% Rework	10	0%	1983	0.00%	93	0.0%	3266	101	1%	1980.25	24	4%	-17
2% Rework	11	10%	1983.25	0.01%	93	0.0%	3266	103	3%	1980.25	25	9%	-16.75
3% Rework	11	10%	1983.5	0.03%	93	0.0%	3266	104	4%	1980.25	26	13%	-16.5
4% Rework	12	20%	1983.5	0.03%	93	0.0%	3266	106	6%	1980.25	27	17%	-16.5
5% Rework	12	20%	1983.75	0.04%	93	0.0%	3266	108	8%	1980.25	28	22%	-16.25
6% Rework	13	30%	1984	0.05%	92	-1.1%	3265	110	10%	1980.25	30	30%	-16
7% Rework	14	40%	1984.25	0.06%	92	-1.1%	3265	113	13%	1980.25	31	35%	-15.75
8% Rework	15	50%	1984.75	0.09%	92	-1.1%	3265	116	16%	1980.75	32	39%	-15.25
9% Rework	16	60%	1985	0.10%	92	-1.1%	3265	119	19%	1980.25	34	48%	-15
10% Rework	17	70%	1985.5	0.13%	92	-1.1%	3265	123	23%	1980.5	35	52%	-14.5
12% Rework	20	100%	1986.5	0.18%	91	-2.2%	3264	132	32%	1980.25	39	70%	-13.5
17% Rework	48	380%	1995.5	0.63%	84	-9.7%	3257	212	112%	1980.25	49	113%	-4.5
18% Rework	Sustained growth.												

Comparison to Baseline