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Advanced Earned Value Management: A Proposal for Extending Program Management Theory Through Value Centric Turbulence Flow Methods

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Advanced Earned Value Management: A Proposal for Extending Program Management Theory Through Value Centric Turbulence Flow Methods

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Abstract

Current methods of measuring acquisition project performance are based upon generations of old cost models that compare budgets with expenditures. These methods provide little in the way of forecasting, leaving the project manager to react to past performance rather than making decisions of future potential. The principal means of measuring project performance in large complex projects is earned value management (EVM), which measures actual work performed to budgeted work performed. While this method provides valuable insight into how well a project is doing relative to a predetermined plan, new methods of forecasting when projects begin to become volatile are needed. Knowing when a project will enter a phase of volatility will provide greater transparency and flexibility to decision-makers before critical events have occurred. This paper describes the state of current project management theory and how it has driven the project management community to a point of stagnation. Additionally, this paper will outline a new and innovative approach to forecasting when a project will become volatile long before current EVM and risk management tools can today. This research approach proposed in the paper intends to extend current theory and practice in project management by examining several information systems programs and providing new, more effective decision-making tools for future project managers. The methods defined in this research will be known as advanced earned value management (AEVM).

Introduction

When managers try to develop complex products with many interdependent subsystems, the high informational processing load can overwhelm the organization. Errors, poor decisions, and bad communication can result in additional levels of effort later in the development process leading to inefficiency or failure. Additionally, decision support systems currently being used in defense acquisition are focused on analysis of historical cost data rather than the effect the volatile environment has on future performance. This problem is particularly acute in information-centric acquisition programs in which the boundaries of hardware and software are less obvious and where the socio-technical boundaries are critical to successful performance of the system being developed.

Defense acquisition programs remain vulnerable to underperformance and excessive cost growth during times of increasingly constrained budgets. History suggests that the “normal” condition of complex programs is one of failure in that they typically exceed their preplanned cost, schedule, and performance targets. This phenomenon is especially true in large complex programs such as information systems and network acquisition programs. Since 1975, an annual array of acquisition reform studies, beginning with the Packard Commission, have had virtually no impact on the ever-increasing trend of cost growth and substandard program performance. The increasing need for complex artificial intelligence and networked technologies capability within the DoD portends even more challenges for the defense acquisition process. Current management theory reinforces classical approaches to project management in which development programs are viewed from a preplanned production process that can be controlled through a robust systems management approach. It is critical for the acquisition community to examine new analytical and decision-making approaches to managing the acquisition of these systems. It is also important to explore the theory of program management and assess if change is necessary to the existing paradigm of managing risk within the iron triangle paradox of cost, schedule, and performance.

Project planning is an output-oriented process that attempts to “decide” future events though rigorous advanced planning and process controls. Projects tend to be planned and executed using classical methods, in which a project follows a standard system model that requires an input, transformation, and output flow model intended to align resources with objectives (see Figure 1).

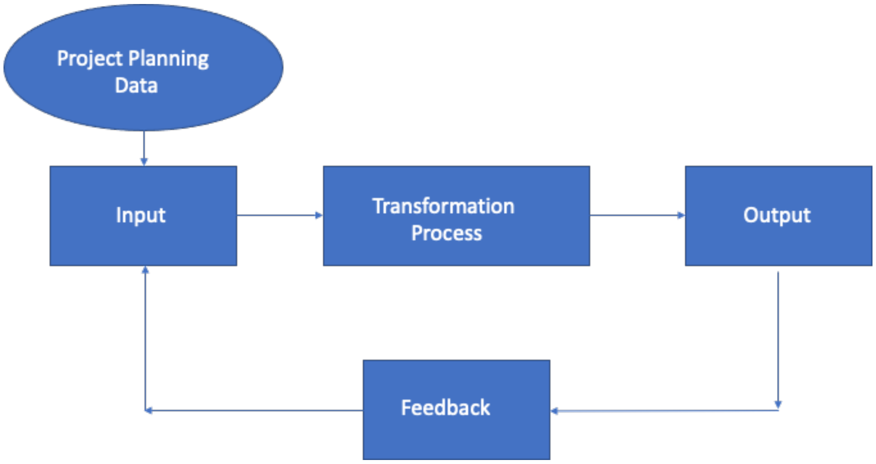


Figure 1. Standard System Feedback Process

The process involves problem-solving focusing on “what” and “how” the project will be accomplished. All activity in the project is devoted to the accomplishment of the objective through planned future time periods. Project performance is typically measured using techniques such as earned value management (EVM), which derives perceived “value” from planned work relative to actual work performed. While these processes provide historical perspectives of a program, they do not provide objective predictive insight by which a program management team can make better decisions that lead to higher probabilities of success of a development acquisition program.

Current program management methods are grounded in classical and system management theory, which is based on the belief that workers have physical and economic needs rather than social needs or job satisfaction and that projects are a system that is represented by a collection of parts brought together to accomplish some end goal or objective. Classical management theory advocates specialization of labor, centralized leadership and decision-making, and profit maximization. In the case of defense program management, program teams are focused on budget and cost optimization rather than profit maximization, resulting in an approach that assumes a development program can be executed in accordance with a centrally derived and executed cost and schedule baseline. Unfortunately, this view of project management prevents project teams from adequately anticipating future events that could lead to increasing project volatility. Project managers are left to deductive reasoning based upon regressive data and experience, significantly increasing the probability that complex programs will exhibit unacceptable levels of variability with regard to the planned program performance baseline.

Other scientific fields such as aerodynamics have analogous problems in that prediction and forecasting is necessary to improve system design and performance. Using aerodynamics as an analogous benchmark with which scientists have developed methods by which the turbulent and volatile fluid environment can be more accurately predicted, there may be an opportunity to extend this methodology into program management theory to better understand the turbulent and volatile project environment in which program's flow during the development phase of a project life cycle. If it is possible to more accurately forecast the chaotic environment in which a program must interact, than perhaps there is an opportunity to fundamentally advance the underlying theory upon which project management is based and develop new methods to better forecast project performance.

Statement of the Problem

The absence of a strong and inquisitive theoretical base in program management is perpetuating a management strategy that is grounded on historical cost accounting and traditional manufacturing models rather than methods that offer improved forecasting and decision-making approaches. Hence, *the problem is that current cost accounting and system thinking methods, based upon classical management and system theory, do not provide adequate forecasting opportunity for complex acquisition programs during the execution and control phase of the program life cycle.* Other disciplines such as fluid and thermodynamics have similar challenges in that they attempt to predict physical outcomes from complex and dynamic environments. This research will show how a complex business environment can be treated as a knowledge flow system that moves from calm laminar states to volatile turbulent states, much the same as other Newtonian fluid environments. The following research questions are proposed to address the problem.

1. Do current project management and control methods lack the ability to adequately forecast project future performance during the developmental phase of the project life cycle?
2. Does the project environment display knowledge flow characteristics similar to other Newtonian fluids?
3. Is it possible to forecast project management performance using turbulent flow theory such as the Reynolds-averaged Navier Stokes (RANS)?

Objective

The purpose of this research is to advance program management theory and practice by applying knowledge flow and turbulence forecasting methods to traditional business decision support systems. While traditional decision support systems such as earned value management (EVM) provide an accurate accounting view of project performance, turbulent flow modeling will allow for improved forecasting, leading to an advanced EVM (AEVM) approach to project management. Turbulent flow methods have shown themselves to provide a more predictive construct to other disciplines such as weather forecasting, aerodynamics, and hydrodynamics. This approach is becoming more relevant to other fields outside of natural physics and is revealing itself as a potential framework by which human-centered organizational outcomes may be predicted. This research will also be grounded in an information science domain in that we will be using structured and unstructured project data in a new way that allows improved project forecasting. Additionally, within the information sciences paradigm, business intelligence and analytics is gaining an increasing role with regard to how data is transformed into actionable insights that inform an organization's strategic and tactical business decisions. Business analytics such as project cost data, lexical link analysis of key project reports, and turbulent flow methods may provide predictive project forecasting information, increasing the business intelligence environment of the project team and subsequently improve the project decision support strategy.

Why Is This Research Important?

This research is important because current methods of measuring project performance such as earned value management are not sufficient to adequately provide forecasting insight into project volatility, limiting decision-makers' ability to make informed decisions in a risk-based project environment. Current theory and practice are not well suited to managing the complex nature of programs intended to develop artificial intelligence and adaptive reality capability. As the DoD undertakes ever-increasing complex programs such as Project Overmatch and Project Convergence, the need to have more accurate forecasting methods is vital to ensuring success and preventing repeating the mistakes of the past.

Relying on current methods that are based upon a dearth of theoretical explanation is not an acceptable strategy if the United States intends to maintain its technological lead into the 21st century. This research will provide the project team a new tool by which they can more accurately predict the impact of planning decisions before the project exceeds its performance baseline metrics such as cost and schedule, resulting in a chaotic and volatile program. Current models, such as EVM and the risk management framework (RMF) are regressive in nature and do not provide adequate forecasting insight into project management performance. A project becomes unstable and volatile when it begins to vary off its predetermined performance baseline. While there will always be some level of variability relative to the program performance baseline, when project variability exceeds its ability to maintain project baseline convergence, the decision-making environment becomes chaotic, resulting in an increasingly turbulent project with increasing volatility. For the purpose of this research, increasing project volatility is considered to be a dynamic state in which project risk realization becomes oscillatory dynamic with regards to mitigation strategies. In other words, the risks begin to outpace the project's ability to mitigate them toward an acceptable project conclusion.

If project teams could accurately diagnose potential areas of failure through improved forecasting methods, proactive measures could then be employed to prevent program failure. Engineers use the Reynolds number in fluid mechanics as a metric that predicts whether the flow of a fluid will be smooth and stable (laminar flow) versus unstable and chaotic (turbulent flow). Knowledge flow in an organization acts in the same way. Fyall (2002) argues that sufficient organizational capacity may allow for good information flow through a team while an overwhelmed group will suffer from turbulent information flow and risk total failure. An organizational Reynolds number, for example, could determine if the information flow through an organization was going to be efficient and reliable versus volatile and chaotic. This would help project teams to better understand the project risk profile and make choices to mitigate risk realization. Reynolds number is a value that helps to predict viscous and inertia effects in Newtonian fluids in order to characterize the stability of the fluid environment under varying conditions.

Literature Summary

Organizations across many business sectors and geographic borders are steadily embracing project management as a way to control spending and improve project results. Executives emphasize that adhering to project management methods and strategies reduces risks, cuts costs, and improves success rates. As a profession, project management has gained increasing interest over the past several years for both its failures and its relevance (Morris, 2000). Often referred to as a means for dealing with change (Cleland & Ireland, 2007), project management has become a topic of real interest from both the practitioners' and researchers' perspective (Ika, 2009). Recent trends within the DoD suggest that project management is critical to effectively delivering key weapons capability to the warfighter. For example, the Defense Acquisition University (DAU) is currently attempting to fundamentally change the pedagogy by which project management training is delivered to the defense acquisition workforce. The DoD has identified six critical functional areas, one of which is project management, that are necessary as the DoD moves into the next century.

Additionally, Packendorff (1995) argues that project management is emerging as a true scientific discipline with its own academic journals, conferences, and language that are characteristic of claiming scientific status. Yet, despite the level of interest and significant amount of investment in the profession of project management, its effectiveness remains in question. Significant project delays, cost overruns, and underperformance seem to be the rule rather than the exception (Ika, 2009). This initial search of the literature will establish the current *state of project management theory*, provide an introduction *to the tools by which project managers* attempt to understand and control their programs, and offer a glimpse into how *turbulent flow model* can help move project management into a more productive management paradigm and why this is critical to improving project forecasting.

The State of Project Management Theory

There seems to be a growing realization that the fragmented theoretical foundation in the field of project management is contributing to the stagnant performance being observed in actual project performance (Cicmil, 2006). The prevailing practices that seem to embrace project management practices and research are grounded in traditional economic and manufacturing methods, which view cost as the dependent variable for project success. The foundation of project management theory goes back to Frederick Taylor, Max Weber, and Henry Fayol. Taylor's *The Principles of Scientific Management* introduced the concept that management can be viewed as a science in which deliberate scientific processes replaced the rule-of-thumb method and that work can be divided between workers and managers based upon their respective levels of training and responsibility (Taylor, 1911).

Additionally, Weber (1930) argued that organizations should be hierarchically based with decisions and processes that are based upon a prescribed set of rules. Weber argued that relationships within an organization should be impersonal and focused on the scope of their respective authorities. These classical views are critical to understanding current project management in that today's organizations fundamentally follow these principles of division of labor and hierarchical decision-making, which structures a project into discrete packages of work that are assigned to individuals in a project office. These work packages are subsequently allocated resources in the form of time and money and sequenced into a project schedule known as the performance measurement baseline (Brotherton, 2008). The effect of this hierarchical and linear management approach suggests that if work can be allocated and assigned to competent workers, then projects can be planned to the smallest level of effort, thus minimizing uncertainty and potential volatility as the project moves through its life cycle. While this is a generally accepted planning framework, this classical method provides little insight into uncertainty due to less tangible factors, such as individual behavior and changing environmental conditions.

Classical theories of management needed to be extended to allow for a more human-centric influence that accounted for human behavior. Behavioral theorists such as Follet, Maslow, and McGregor extended the more classical theories by arguing that employees must be considered active participants in the decision-making process, thus introducing a new dimension of ambiguity into management decision outcomes (Prietto, 2015). McGregor in particular theorized that people work for inner satisfaction and are not necessarily driven by materialistic rewards (McGregor, 1960). His Theory X and Theory Y introduced the concept that a manager's assumptions about human nature influences how that manager manages the workforce (Prietto, 2015). From a program management perspective, the notion that individuals within a project environment do not comply with the "economic man" principle and that outputs can be influenced by the bias of both the manager and the worker, opens up the potential for arguing that the knowledge flow within a project organization cannot be precisely predicted based upon discrete planning processes as suggested in the more classical management theories and methods. This leaves us with the dilemma of trying to manage a project based off of precise pre-project planning information that could be significantly influenced by less tangible factors such as human behavior and project environmental changes.

Karl Ludwig von Bertalanffy introduced the idea that a system could be thought of from a more biological perspective which is self-correcting and is made up of processes that transform inputs to outputs (Prietto, 2015). From a management perspective, this seems to extend the underlying classical theory in that it provides the necessary rigor by which to explain the socio/managerial relationship between a hierarchical and human-centered process. His work sought to demonstrate the pervasiveness of open systems in nature and the potential of reducing human thought into a systems concept (Lopreato, 1970). The idea of viewing organizations as systems was not new. The trend, however, was to view management processes as closed systems with predictable outcomes. Pareto's 1897 law, for example, had demonstrated a system-like behavior in society by showing how 80% of the wealth belonged to 20% of the population, regardless of the total amount of available capital (Newman, 2006). A systems approach to project management suggests that the boundaries are closed and clearly delineated, allowing for well-defined interdependencies (Lorreato, 1970). By suggesting that organizations and acquisition projects behave like systems, one must accept the premise that the structure and components of an organization are interdependent and therefore affect one another.

If an organization, however, were more like a biological open system, as Bertalanffy suggested (Prietto, 2015), then one is left with the challenge of capturing random interdependent relationships of highly complex networks within an organization. By entertaining the possibility that organizations behave like biological open systems in which people and processes impact the preplanned nature of a project, we are able to accept the potential of neo-classical approaches that provide better real forecasting of project behavior and outcomes.

Path analysis is used to describe the directed dependencies among a set of variables and used to try to understand organizational behavior with regard to independent and depend variables. By viewing an organization as a system, path analysis could be considered a viable technique by which causal inference can be explored. With regard to organizational analysis, however, path analysis is often plagued by intervening variables that significantly influence the organizational model's highest path coefficients. This would suggest that systems modeling of project management organizations need additional tools and methods by which to more accurately capture the uncertainty of external intervening variables that impact the knowledge flow through an organization.

Classical and systems theory provide a relevant framework by which to begin understanding how a project management organization makes decisions and how knowledge flows through the organization, but may be limited in its ability to forecast future activities in that the complex nature of the project organization appears to behave more like an open system that is influenced by a complex network of intervening pathways and variables. The more we understand all the pathways of knowledge flow and how they affect the productivity of an acquisition project, the more relevant other analogous engineering and physics models could help us to improve project performance forecasting. Knowing how to improve the flow of knowledge requires a framework that considers all the pathways within a project (Cohen & Prusak, 2001). Pathways for knowledge flow are similar to networks in organizations. Within a project management structure, knowledge flow can be correlated with the work breakdown structure and how efficiently the preplanned work breakdown structure (WBS) is being executed relative to the *planned performance measurement baseline* (PMB). The use of network ties stimulates innovation as an interactive process and represents the main source of competitive advantage for an organization (Swan et al., 1999). Viewing WBS productivity as a knowledge flow network provides us with the opportunity to explore other models of forecasting within the engineering domain. These analogies could allow us to apply theories such as chaos, thermodynamics, and fluid dynamics to problems that have heretofore been characterized as social constructions measured through the lens of economics and accounting.

Current Project Management Measurement and Control

As information-centric projects become more complex, project management must become more effective and dynamic in order to keep up with the ambiguity and speed of technology. Sociotechnical systems and artificial intelligence will require new ways of understanding how future needs will be transformed into real and virtual capability. Cost-based manufacturing methods will not provide the necessary agility and insight into how capabilities are evolving to meet customer needs and how resources are being optimized to achieve maximum return on investment (ROI) within predefined budget constraints.

Project management methods that are used to control programs are based upon a cost management that provides little insight into project value or volatility. Changes in a project's requirements, stakeholders, schedule, and budget can cause changes in the broader environment just as desperate business processes impact project deliverables. Changes in key project metrics such as cost and schedule that vary off the original project baseline create a project environment that has the potential to be uncontrollable and results in increasing cost and schedule delays (Pitagorsky, 2018). Variance off the PMB is reflected in terms of cost and is considered to be increasing in volatility the larger the variance. Degrees of project volatility follow a continuum from rapid and unpredictable to infrequent and predictable. Changes in project certainty can be the result of many factors such as people, requirements, policies, and budget changes. While monitoring cost is an important metric, it does little in terms of improving a project manager’s ability to forecast future performance, particularly in terms of future volatility.

There are several methods by which project teams attempt to manage and reduce uncertainty in a project. The literature, however, supports the argument that there are principally only five tools that are considered most relevant for managing complex acquisition programs (Housel & Mun, 2020). These include techniques such as PERT, Lean Six Sigma, balanced score card, knowledge value-added (KVA), earned value management (EVM), and integrated risk management (IRM). The only methods that seem to suggest some level of forecasting is IRM and EVM.

Project managers typically follow an ongoing risk management process that helps them identify, understand, and respond to threats and opportunities (O’Conner, 2020). IRM is a forward-looking, risk-based decision support system incorporating various methods such as Monte Carlo Risk Simulation, Parametric Forecast Models, Portfolio Optimization, Strategic Flexibility, and Economic Business Case Modeling. Economic business cases using standard financial cash flows and cost estimates, as well as non-economic variables such as expected military value and strategic value (Housel & Mun, 2020). These metrics are often forecasted using system dynamic models based upon preplanned hierarchical structures, assumptions, and probabilistic models that make assumptions based upon the uniqueness of the project under consideration. They generally do not consider the dynamic nature of mediating variables over time such as human performance, requirements variability at both the operational and project level, and impacts of the bureaucratic and political environment.

Risk analysis, real options analysis, and portfolio optimization techniques are enablers for estimating ROI and estimating the risk-value of various strategic options. These techniques are favored in portfolio management approaches to project management and attempt to provide greater insight into future performance in order to optimize project investment. Real options theory informs the risk management process in that it provides insight into how to make decisions regarding investments in tangible assets when the future is uncertain (Hayes, 2020). Current statutory guidance such as the Clinger–Cohen Act of 1996 mandates the use of portfolio management for all federal agencies. The GAO (1997) requires that IT investments apply ROI measures, and DoD Directive 8115.01, issued October 2005, mandates the use of performance metrics based on outputs, with ROI analysis required for all current and planned IT investments. The DoD (2017) Risk Management Guidance Defense Acquisition Guidebook requires that alternatives to the traditional cost estimation need to be considered since cost models do not adequately address costs associated risks across complex projects. This admission by the DoD and GAO reinforces the weakness of current risk-based methods with regard to understanding project uncertainty, requiring new methods of forecasting. Unfortunately, current risk-based methods, including real options methods, are still based upon underlying cost analysis techniques, in that risk management processes require mitigation steps that show cost potential of each step that is proposed to reduce the potential of the underlying risk.

Risk is the probability that an adverse or opportunistic event will occur sometime in the future. Risks are characterized as both the probability and consequence that this event will happen and how much it will cost if the risk is realized as well as mitigated (DoD, 2014). To better understand the overall risk of a project, the project is reduced into packages of work, each having some level of risk associated with its execution. The risk in each package of work is represented in terms of the cost and time that is required to mitigate the risk. These packages of work are commonly referred to as cost accounts within a project WBS (DoD, 2005). Following classical management theory, the WBS represents a hierarchical structure that is subsequently aligned within an organization to the various work units and cost account managers. The cost and schedule elements for each task are modeled and risk identified within the WBS to determine the total cost and schedule risk of a certain program.

The WBS represents a product-oriented grouping of project work elements shown in graphical display to organize and subdivide the total work scope of a project. A WBS is the cornerstone of effective project planning, execution, controlling, statusing, and reporting. All the work contained within the WBS is identified, estimated, scheduled, and budgeted from product start to first article delivery. The WBS is the structure and code that integrates and relates all project work with regard to scope, schedule, and cost. Therefore, the WBS contains the project's scope baseline necessary to achieve the technical objectives of the work described. The WBS is used as a management tool throughout the life cycle of a project to identify, assign, and track its total work scope. The WBS allows the project team to manage a project within the framework of EVM, the principal management tool used to assess work performed relative to work planned (DoD, 2019). Within the project management profession, EVM is perceived to provide the project team with some level of predictivity and is the principal decision support system for project management. As we will see, however, forecasting within the EVM framework is based upon recursive cost data, and actually provides little insight into future project performance or more importantly, the intangible variables that influence a program's stability and performance.

Earned Value Management

Current program management practices suffer from deficiencies in its theoretical base, creating self-inflicted problems in program execution in addition to hampering the effective professionalization of program management. The predominant metric by which acquisition projects are measured based on the belief that complex programs can be precisely planned and executed using a classically informed linear cumulative labor curve. The budget at complete (BAC) for a project is used as the objective by which resources are acquired and the project plan is developed and subsequently put-on contract to a competent developer. The closer the actual cost gets to the ubiquitous BAC determines the overall success of the program. As projects deviate from BAC, a new cost number to tracked and the variance off the BAC determines how well the project is performing. Decisions are made based upon current expenditures and future estimates (estimate at complete [EAC]) based upon preplanned remaining work. Koskela and Howell suggest that this approach is flawed and is the result of overly “narrow" project management theory based upon implicit linearity, which is used but rarely acknowledged (Koskela & Howell, 2002).

Earned value management is a method that allows the project manager to measure the amount of work actually performed on a project relative to the amount of work planned (DoD, 2019). EVM provides a method that permits the project to be measured by progress achieved. The project manager is then able, using the progress measured, to forecast a project’s total cost and date of completion, based on trend analysis. The relative relation to work performed to work planned is known as “Earned Value (EV)” (Reichel, 2006). Value in this sense should not be construed as value from an economic perspective. Economically, value is assessed as the ratio between revenue and cost. In this context, earned value is simply a misleading analogy that suggests that the allocated work on schedule and to cost results in some sort of value to the project. Earned value provides very limited insight into future performance and yet project managers rely on this process as their principal decision support system.

EVM is used for providing a disciplined, structured, objective, and quantitative method to integrate performance, cost, and schedule objectives for tracking contract performance. The term *earned value* is also defined as the “budgeted cost of worked performed” or BCWP. BCWP allows the project manager to calculate performance indices for cost and schedule, which provides information on how well the project is performing relative to its original plans. These indices, when applied to future work, are used by project managers to forecast how the project will do in the future, assuming the cost and schedule indices do not fluctuate. The basis of EVM is an accurate plan with completion rates and budgeted costs (Reichel, 2006). This plan begins with the program work breakdown structure, in which the estimated cost and schedule is allocated to the performance measurement baseline (PMB). Once the PMB is approved, this becomes the project Integrated Master Schedule (IMS) from which the project is measured. EVM would be most effective to monitor a stable process that has minimal complexity or uncertainty. It is not an effective forecasting method for complex programs such as hardware/software artificial intelligence or networking projects. Commonly used methods such as risk and EVM do not reveal causal chains responsible for management actions, or the socio-political complexities and interconnectedness within the project environment (Williams, 2018).

The assumption is that if project volatility is adequately managed, then costs can be controlled and therefore preplanned budgeting methods continue to remain a valid technique for embarking on projects regardless of their complexity. In other words, if we espouse the belief that a project can be decomposed into its smallest unit of value, then we can apply a cost and risk variable to these units and manage them accordingly. According to the PMBOK® Guide (the Project Management Body of Knowledge), project control is a “project management function that involves comparing actual performance with planned performance and taking appropriate corrective action (or directing others to take this action) that will yield the desired outcome in the project when significant differences exist.” The belief is that management and control keep projects on a predetermined track. The PMBOK does not, however, provide an explanation or insight into reliable forecasting; rather, it focuses on measuring planned performance relative to actual performance, accurate reporting of cost and schedule data, and updating cost information based upon trending information.

The tools and methods used by project teams are fundamentally grounded in classical and system theory that emphasizes planning and cost management rather than data driven forecasting of projects that are informed by complex and chaotic environments. With this understanding, the nature of the research problem becomes even more relevant. Our problem stated that, *current cost accounting and system thinking methods, based upon classical management and system theory, do not provide adequate forecasting of complex acquisition programs during the execution and control phase of the program life cycle.* This problem, exacerbated by the relative lack of project management theory that focuses on project forecasting and future performance, creates a wonderful opportunity to extend theory as well as potential opportunities for more advanced processes that will help project management grow as a profession. Up to this point, we have examined the theoretical foundation on which project management is based. This foundation in classical and systems management theory is reflected in the fundamental tools used to plan, resource, and execute acquisition projects designed to provide unique products to meet a customer’s needs. We have also introduced the concept of network knowledge flow from which more robust theoretical positions can be claimed and methods introduced. In the next section of this literature review, we will extend this line of reasoning to explore possible physics-based applications that might allow use to develop theory and methods that will provide enhanced forecasting in complex and highly volatile project environments. Relevant readings and thought into how theories from other fields such as fluid dynamics and knowledge value might be used to provide improved forecasting models in project management based upon turbulent flow analogies will be introduced. We shall also examine the necessary relationship the field of information science has with project forecasting and turbulent flow theory.

Forecasting Project Management Performance

Project managers need new practices that incorporate data analytics and information from the complex and chaotic environments with which to make decisions. These practices should also be forward looking with intent to capture future events from a more deliberate and information-informed strategy, rather than extrapolation based predominately upon historical data. In her article “Making Fast Strategic Decisions In High-Velocity Environments” Kathleen Eisenhardt revealed that fast decision-makers use more, not less, information than slow decision-makers (Eisenhardt, 1989). Additionally, the greater number of alternatives considered simultaneously, the greater the speed of the strategic decision. Her research showed that executives immersed themselves in real-time information on their environment and the firm operations. The result of this, according to Eisenhardt, was a deep personal knowledge of the enterprise allowing for rapid decision-making. Consequently, the greater the speed of the strategic decision process, the greater the performance in high-velocity environments (Eisenhardt, 1989). Developing methods that incorporate structured and unstructured data into a more predictive decision-making process provides similar information immersion that Eisenhardt identified in her qualitative research on how key business leaders made effective decisions. The knowledge-based decision-making required these executives to consider the effects of the volatile environment and not just cost and revenue data. In effect, the successful leaders were able to quickly integrate and forecast based upon structured and unstructured data. New methods by which more information provides better insight into project integrity through better volatility management is necessary in order to improve project outcomes.

While the business community recognizes that project management is critical to providing a competitive advantage, the lack of program management theory seems to reveal a lack of theoretical thought in the profession of program management. A sound theoretical basis is critical to moving a profession forward, and an absence of theoretical explanation and curiosity has the potential of rendering a profession stagnant and task oriented. Defense department leadership and non-project management communities within the DoD still regard project management as a branch of operations management, and therefore believe that it is simply a series of management tasks that are structured within a system engineering construct where projects are instruments used to achieve higher-level organizational goals and objectives (Kwak & Anbari, 2009). Within industry, however, there is still a belief that project management helps create a strategic value chain that gives companies an edge on their competitors, particularly in high-risk sectors and markets. Being able to deliver projects on time and within budget often determines whether a company will get the next job or whether its new product hits the market. Without new theory, project management will reach a natural limit with regard to its effectiveness.

Complex products with many interdependent subsystems and high information processing load requirements can cause organizational failure. While there are many decision support systems that are designed to interpret historical project data, there is currently no way for managers to forecast when the demands placed upon a project have exceeded the risk tolerance level of the project team, resulting in projects moving from a somewhat stable state to a more volatile and turbulent state. Engineers use the Reynolds number in fluid mechanics as a metric that predicts whether the flow of a fluid will be smooth and stable versus turbulent and chaotic. Reynolds number is a dimensionless parameter widely used in fluid dynamics and is defined as the ratio of inertia force to the viscous force of a fluid. The concept of Reynolds number was introduced by George Stokes in 1851 in the development of the Navier-Stokes equation intended to solve the complex nature of turbulent flow (Anderson, 2017).

Fyall (2002) argues that it is possible to establish an organizational Reynolds number that estimates when a project approaches a turbulent region, alerting the project team to apply proactive measures before project turbulent behavior occurs. Using project workflow networks, subtask interdependency can be seen as exhibiting fundamental fluid properties exhibiting probabilistic behavior. Routine tasks, for example, may exhibit a higher probability of success, whereas more innovative and complex tasks could have a lower degree of success, suggesting that the knowledge flow between tasks may vary based upon their relative level of complexity. Establishing a metric similar to Reynolds number could provide insight into the nature of information flow in an acquisition project, allowing a project team to more reliably forecast if the information flow through an organization resulted in a stable predictable environment or one approaching turbulence as manifested in increasing project volatility.

Determining the tripping point at which a developmental program moves from a smooth predictable state to a chaotic and turbulent state is conceptually similar to predicting the turbulent flow characteristics across an airfoil in flight. By constraining the boundary conditions and identifying and measuring the multitude of dynamic variables within the project frame of reference, one can begin to define the nature of how these variables transition from a laminar (smooth) controlled state, to a turbulent state**.** The Reynolds number is the ratio of inertial forces to viscous forces and is a convenient parameter for predicting if a flow condition will be laminar or turbulent. It can be interpreted that when the viscous forces are dominant, they are sufficient enough to keep all the fluid particles in line, or in laminar flow (Batchelor, 1967, pp. 211–215). The ratio between viscous and inertia properties of a fluid establishes the relative volatility of the fluid. A low velocity fluid tends to be more stable than a high velocity fluid, indicating that there are increasing eddies being created as a result of specific environmental variables. As the fluid increases in velocity, failure to dampen or control these eddies causes the fluid to move from a laminar to a turbulent state (Anderson, 2017). Analogously, when a program is moving in a controlled fashion with little unpredictable external or internal variance from the original estimates, one could say a program is in a laminar state. However, as the program activity begins to increase in both speed and numbers of interdependent and unanticipated inputs, the program begins to move toward a turbulent and volatile state. However, stable business environments, which control for extraneous factors, could provide stability for acquisition projects, leading to less project volatility and a higher probability of success.

If we consider information flow in an organization to be analogous to fluid flowing through a pipe and if the capacity of the organization is large enough to manage and control the information flowing through it, then project stability is more likely. However, when an organization becomes overwhelmed and demand exceeds capacity, information flow throughout the organization becomes less controlled and more ambiguous, resulting in program volatility and greater risk of failure. Continued research is necessary to determine whether or not information flow through an organization changes from laminar to turbulent at a predictable point. Additionally, if an organizational Reynolds number exists, which variables and characteristics would define the capacity of the organization and the nature of the information being processed? If we are able to identify an analogous Reynolds number for an acquisition project, perhaps the project organization and strategy can be designed to produce the greatest amount of work in the most efficient way possible without risking chaotic information flow. Determining an organizational Reynolds number would provide enhanced understanding of the current EVM methods, allowing us to extend both project management practices and theory.

Method and Scope

This paper argues for a quantitative study that will use project data from EVM and selected acquisition reports (SAR) and correlate these data with Reynolds Averaged Navier Stokes (RANS) turbulent flow variables in order to better predict acquisition program performance. RANS is a mathematical technique that decomposes flow variables of the Navier-Stokes equations into their mean and fluctuating components. The Reynolds number is a dimensionless number used to categorize fluid systems in which viscosity controls the flow pattern of the fluid.

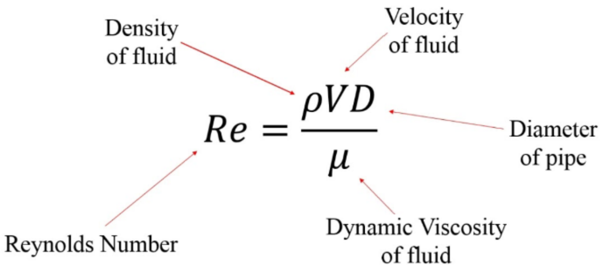
EVM is a project management methodology that integrates schedule, costs, and scope to measure project performance. Based on planned and actual values, EVM provides the project team an understanding of how well the project is performing but does not provide any real predictive power. The project is expected to perform according to the future plan if the project is within a reasonable variance of the project performance baseline.

Data Sources

Data will be obtained from the DoD Defense Acquisition Visibility Environment (DAVE). This data repository provides a consolidated source for programmatic data, including earned value management and selected acquisition report data. The DAVE database is a registered site that requires CAC entry. It can be accessed at: https://dave.acq.osd.mil/. Specific data that will be required for this research will be EVM, schedule, and budget data for acquisition category I (ACAT I) information technology programs. ACAT I programs are defined to have a research and development budget over $250 million. SAR data will provide the qualitative descriptions for these programs and will allow the researcher to develop a category that can be subsequently correlated to knowledge flow variables.

Variables

The Reynolds number helps predict flow patterns in different fluid flow situations. At low Reynolds numbers, flows tend to be dominated by laminar flow, while at high Reynolds numbers, flows tend to be turbulent. Reynolds number is a measure of volatility. For the purpose of this research the independent variables are velocity, distance, density, viscosity, and force. In addition to defining a Reynolds number for the project, the research will identify the project drag coefficient (Cd) by which Re will be compared and plotted, creating a Project “Moody” plot that reveals the predicted laminar and turbulent regions for the project.



Equation 1. Reynolds Number

$$C_D = \frac{2F_D}{\rho A V^2}$$

Equation 2. Drag Coefficient

The dependent variables for this research are the Re and Cd, which provide the foundation for project turbulent forecasting via the project “Moody” plots. Figure 2 represents a notional view of the project “Moody” plot that would clearly identify when a project begins to enter the critical zone between a smooth, well-managed project and a turbulent volatile project that could become unmanageable.

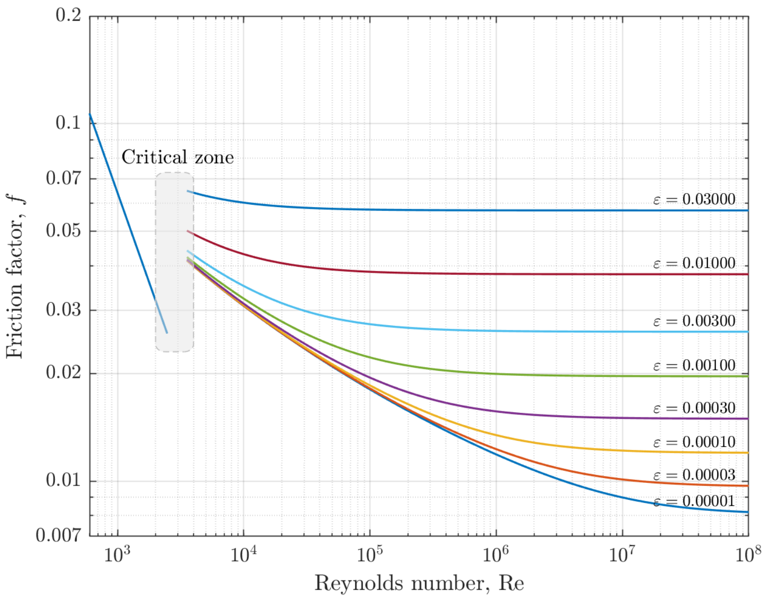


Figure 2. Sample Moody Plot

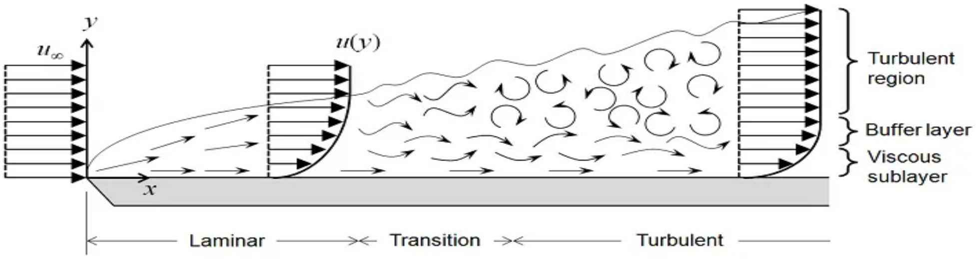
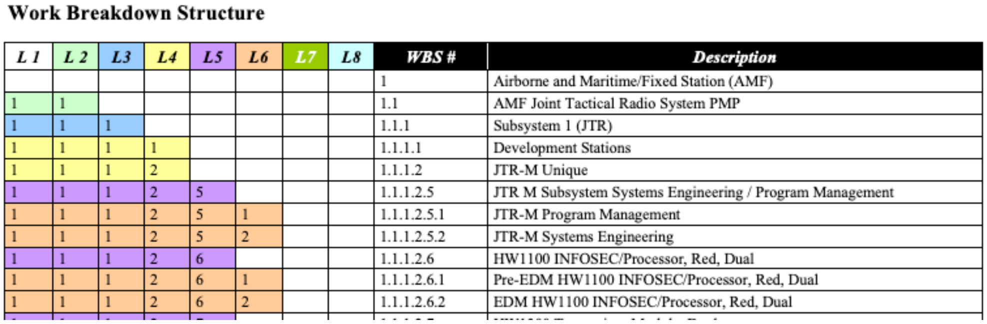


Figure 3. Flow Transition from Laminar to Turbulent Volatility Begins in Transition Region

Knowledge Flow

A necessary component of EVM is the work breakdown structure. Breaking work into smaller tasks is used to make the work more manageable and provides insight into the complexity of each task and its associated risks. The Project Management Institute (PMI) PMBOK defines the WBS as a “deliverable oriented hierarchical decomposition of the work to be executed by the project team.” If work packages can be viewed as units of knowledge, then as work packages are completed, the flow of knowledge can be mapped across the project as the various tasks are completed. For the purpose of this research, a task within a WBS work package is considered to be the smallest unit of measurable knowledge, or value, within a project, allowing us to measure knowledge flow over time. Figure 4 represents a sample WBS with individual task units representing units of knowledge value.



Work Breakdown Structure

L 1	L 2	L3	L4	L5	L6	L7	L8	WBS #	Description
								1	Airborne and Maritime/Fixed Station (AMF)
1	1							1.1	AMF Joint Tactical Radio System PMP
1	1	1						1.1.1	Subsystem 1 (JTR)
1	1	1	1					1.1.1.1	Development Stations
1	1	1	2					1.1.1.2	JTR-M Unique
1	1	1	2	5				1.1.1.2.5	JTR M Subsystem Systems Engineering / Program Management
1	1	1	2	5	1			1.1.1.2.5.1	JTR-M Program Management
1	1	1	2	5	2			1.1.1.2.5.2	JTR-M Systems Engineering
1	1	1	2	6				1.1.1.2.6	HW1100 INFOSEC/Processor, Red, Dual
1	1	1	2	6	1			1.1.1.2.6.1	Pre-EDM HW1100 INFOSEC/Processor, Red, Dual
1	1	1	2	6	2			1.1.1.2.6.2	EDM HW1100 INFOSEC/Processor, Red, Dual

Figure 4: Sample Work Breakdown Structure, AMF JTRS

As work packages are completed, the knowledge flow of the project increases either positively or negatively depending on whether or not the tasks were completed consistent with the planned performance baseline. A project completed on time and within its budget profile is considered to reflect optimal knowledge flow with no viscous effects, while projects that deviate from their baseline are considered to have achieved less than optimal knowledge flow.

Using basic EVM metrics from existing information technology programs, these metrics will be compared to actual work progress as represented by the workflow plan in the project WBS. For example, the cost performance and schedule performance indices represent how well a project is accomplishing previously planned work. As work begins to fall behind, the CPI/SPI reflect the variance and the project’s cost and schedule begins to deviate from the original plan. CPI and SPI calculations are represented by

Schedule Performance Index = Earned Value/Planned Value
Cost performance Index = Earned Value/Actual Cost

Where:

Earned Value = Budgeted Cost of Work Performed
Planned Value = Budgeted Cost of Work Scheduled

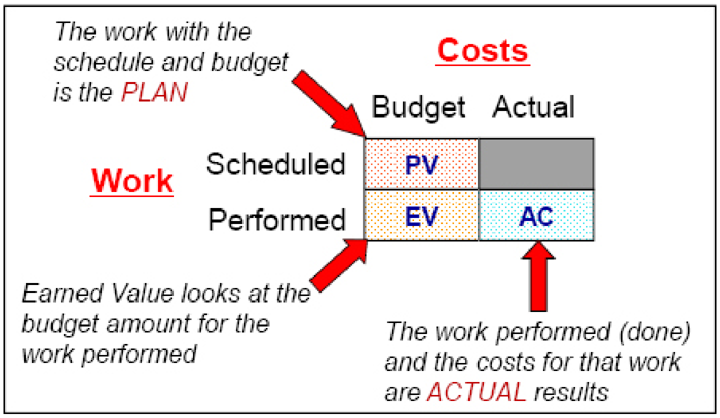


Figure 5: EVM Metrics (PMI.org)

The results of this comparison will represent a knowledge value (KV) variable by which knowledge flow can begin to be visualized. Since each task within the WBS represents a unit of knowledge, knowledge flow can be accurately determined throughout the project life cycle within the context of the accepted performance measurement baseline. Consequently, knowledge velocity (KVv) is the speed of actual knowledge value (KVa) relative to planned knowledge value (KVp). Additionally, KVv represents the property of the "fluid" environment within the developmental phase of the acquisition program.

Lexical Link Analysis

While characterizing the knowledge flow provides interesting insight and initial variable characterization, it is not sufficient to understanding future performance. Characterizing knowledge flow simply provides a visual into a moment in time with little understanding underlying nature of the knowledge flow state. In order to gain increased understanding into the nature of the knowledge flow, a method known as lexical link analysis (LLA) will be used to interpret the nature of the fluid environment at discrete points in time. This will begin to provide the researcher with a more coherent understanding of "why" the KVv is behaving in a particular manner. Lexical Link Analysis (LLA) is a form of text mining in which word meanings represented in lexical terms are treated as if they are in a community of a word network. LLA can provide automated awareness for analyzing text data and reveal previously unknown, data-driven themed connections (Zhao, 2016).

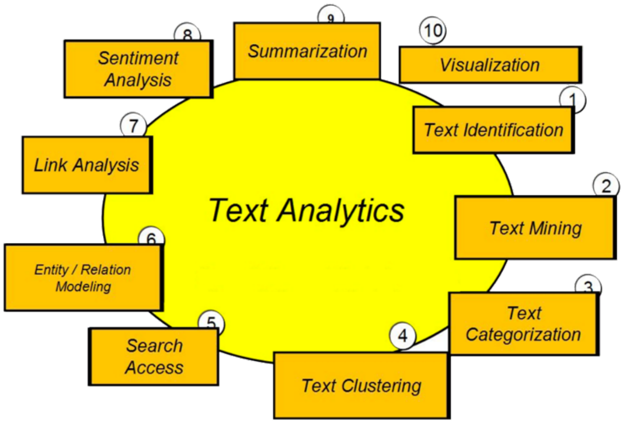


Figure 6: Graphical Representation of Lexical Link Analysis

Data for LLA will be obtained from the selected acquisition reports (SAR) from the projects under consideration for this research. A SAR is a comprehensive summary of a Major Defense Acquisition Program (MDAP) ACAT I program that is required for periodic submission to Congress by the Secretary of Defense. It's mandated by Title 10 USC § 2432 "Selected Acquisition Reports" (Acqnotes.com)

The SAR will provide the researcher with a rich understanding of the nature of the project's KVv by identifying key events through LLA that influence the nature of the knowledge value fluid. LLA can be mapped similar to scale free networks in which critical hubs that influence the network are easily identified.

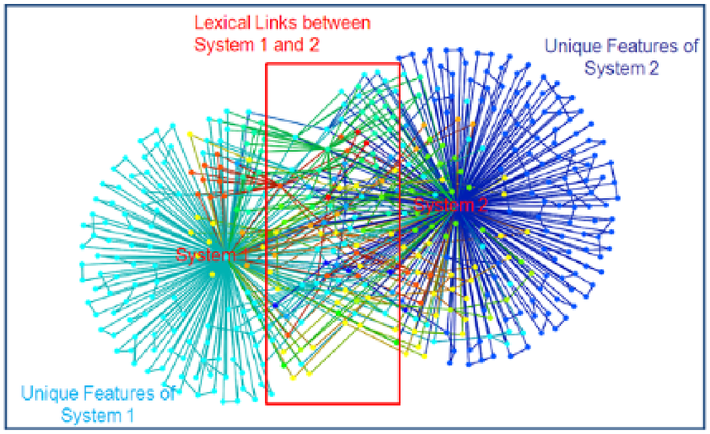


Figure 7: Nodal Relationship Using Lexical Link Analysis

Using the Pareto principle, which specifies that 80% of consequences come from 20% of the causes, the dominant hubs identified at each phase of the life cycle in conjunction with the KVv, key variables can be identified and chosen as candidates for inclusion into a project turbulence prediction model known as the Reynolds-averaged Navier Stokes (RANS) equation.

Finally, an ANOVA and a sensitivity analysis will be conducted to analyze how the different values of the independent variables affect the dependent variables at specific times in the project life cycle and will compare the variation among the means for the various programs studied. This analysis will improve our confidence in how accurately the turbulent flow advance EVM method measures what is intended to be measured.

Research Scope

The research scope will be limited to information technology programs that are in the developmental stage of their project life cycle. In the DoD acquisition framework, this is defined as being a program in the Post Milestone B phase known as the Engineering Manufacturing and Development phase. The EMD phase is the start of an official program. The purpose of this phase is the development of a capability. This phase starts after a Milestone B review and consists of two efforts, Integrated System Design (ISD) and System Capability and Manufacturing Process Demonstration (SC&MP) (Acqnotes.com). Figure 8 represents this phase graphically.

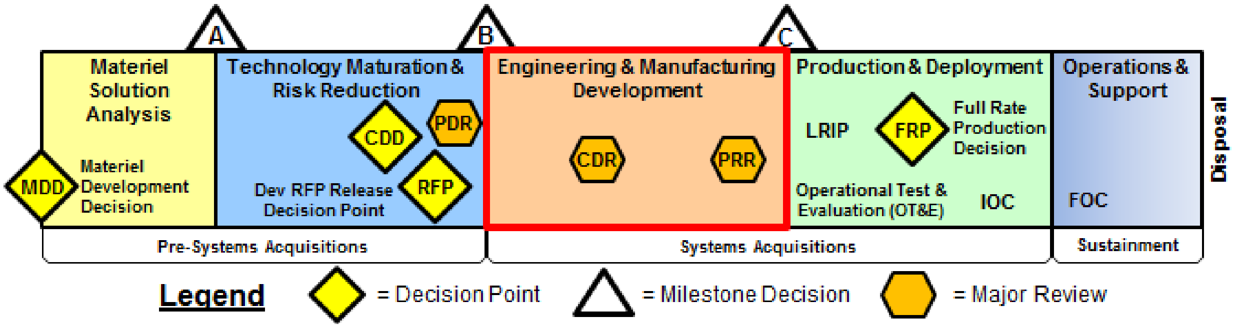


Figure 8: Defense Acquisition Life-Cycle Framework

The EMD phase is the phase in which EVM data is collected for a program in that the specific requirements are clearly delineated in a statement of work in the awarded contract. This phase requires that a performance measurement baseline be developed and EVM data collected for designated programs.

Potential Outcomes and Limitations

Two potential outcomes are the focus of this research. The first and perhaps most important is to extend current project management theory from a classical cost-based view of management into a more dynamic physics-based view that will more readily lend itself to improved forecasting and prediction. The second outcome is to provide a new model for project management forecasting and control that will improve decision-making for complex projects such as those typically found in information technology systems. Early analysis of this new fluid dynamics-based approach provides positive indications that the fundamental theory and method are sound. Notional data shows indications of increasing volatility significantly earlier than traditional EVM methods. Since this research methods uses traditional EM data and further refines the data with novel insight derived from LLA and fluid dynamics theory and methods, the methods for this improved measurement approach will be defined as Advanced Earned Value Management (AEVM).

The results of this research will be the basis upon which a library of Reynolds number “Moody” plots can be generated that will provide the initial planning tools by which complex projects can be architected. Reynolds number “Moody” plots reflect the fully developed flow of a fluid within the boundary conditions established for the project. By having these plots, projects can more accurately be structured and monitored for conditions that might create instability and turbulence or volatility resulting in projects that are difficult to manage.

Potential limitations for this project are data quality. The data for this research is available in multiple databases across the DoD, and obtaining access requires coordinating with multiple organizations willing to release program-specific data. Additionally, defining the independent variables will be based upon subject matter expertise and concurrence, leaving open the possibility for continued debate from external experts. This debate will subside as more data is used to validate the turbulent flow models and the library of Moody plots begins to grow over time.

Follow-on research can focus on moving from a more advanced form of project measurement developed in this research effort to application and policy development. As project volatility is better understood through this research, project managers will be able to more accurately management their projects with increased transparency in budgetary and technical decision-making. This increased transparency could provide the basis of fundamental reform in how budgets are determined and the flexibilities a project manager can be afforded with regard to financial and technical management.

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