Exploring Performance Based Logistics Predictors of Earned Value Management Outcomes: A Quantitative Study

Dissertation

Submitted to Northcentral University

Graduate Faculty of the School of Business and Technology
in Partial Fulfillment of the
Requirements for the Degree of

DOCTOR OF PHILOSOPHY

by

JOSEPH S. CERRETA

Prescott Valley, Arizona
September 2012

APPROVAL PAGE

Exploring Performance Based Logistics Predictors of Earned Value Management Outcomes: A Quantitative Study

by

Joseph S. Cerreta

Approved by:

10/1/12

Chair: Robin Throne, Ph.D. Date

Member: Duane Benton, Ph.D.

Member: Steve Roussas, Ph.D.

Certified by:

10/4/12

School Dean: Arthur Lee Smith, Ph.D. Date

Abstract

The study addressed the problem that it is not known to what extent interdependency exists between earned value management and performance-based logistics service contracts. The purpose of the quantitative correlation study was to examine relationships between performance-based logistics metrics of operational readiness rate, reliability growth rate, and depot mean down time with the earned value management metrics of schedule performance index and the cost performance index. The study analyzed the census data from the Shadow 200 performance-based logistics program from November 2004 through February 2012. A quantitative hypothesis testing methodology comprised of intercorrelation and multiple linear regression to compare data from earned value management and performance-based logistics service contract metrics. Spearman's coefficient of correlation was used to identify the predictor variable's high versus low probability of correlation. A three-predictor multiple linear regression model using operational readiness rate, reliability growth rate, and depot mean downtime was used to examine the relationships with all three predictors as analyzed concurrently with the outcome variables. Three significant correlations were identified from the correlation analysis. A significant correlation was found between operational readiness rate and the schedule performance index (r_s=-0.212; p=0.048). The relationship between operational readiness rate and the reliability growth rate was found to be significant (r_s=-0.280; p=0.019), and the relationship between depot mean downtime and the cost performance index was also significant (r_s=0.497; p<.05). The operational readiness rate, reliability growth rate, and depot mean downtime combined did significantly predict the cost performance index (p=0.001). There was a significant interaction effect existed between

schedule and cost performance indices. There was a significant difference between the population means of the schedule and cost performance indices within the Shadow 200 performance-based logistics program. Additional research to quantify the influence of performance-based logistics monetary incentives may help researchers understand how these incentives effect performance metrics. Further research may also provide a better understanding for researchers examining the effect of incentives on performance metrics as comparative studies between performance-based logistics and traditional lifecycle support logistics programs.

Table of Contents

List of Tables

List of Figures

Chapter 1: Introduction

Program managers use earned value management processes and tools to measure cost and schedule performance for early forecasting of program performance (Storms, 2010). Earned value management is a business framework inclusive of the culture and discipline to apply a set of management processes for accurate reporting, problem analysis, variance analysis, corrective actions, evaluation of the effectiveness of the corrective action, and re-planning in extremely unpredicted circumstances. The use of an approved performance measurement baseline in earned value management is an effective technique managers apply for change control (Storms, 2010).

Contractors perform dynamic technical lifecycle support activities within performance-based logistics, which indicate trends in more efficient business practices (Owen, 2008). The objective of a performance-based logistics approach lifecycle is to support product readiness and availability performance. Performance-based logistics is designed to optimize operational availability, readiness, and reliability performance using resources such as spares, repairs, transportation, and service labor (Vitasek, 2008). Prediction models use meantime between failures, meantime to repairs, and cycle times to predict quantities of spare parts, consumables, obsolescence upgrades, product reliability improvements, and service-related tasks maintain the desirable operational availability rate (Nowicki, 2008).

Research specific to the effects of earned value management and performance-based logistics included many theories on these topics independently. Nowicki (2008) suggested further research to investigate optimization models for implementing earned value management in a performance-based rather than lifecycle-based context to improve existing analytical methods. Tremaine and Seligman (2010) recommended controlling life cycle cost management through predicting long-term sustainment costs for the operations in support of defense weapons systems. Variable interdependency was correlated and modeled to provide predictive capabilities and early warning signs to enhance the predictive nature of earned value management for program performance, employed in a performance-based logistics environment.

This chapter introduces a quantitative correlational study to investigate the relationships between earned value management metrics and performance-based logistics metrics. Background information will be presented regarding the principles of earned-value management within a performance-based logistics context. The research problem and purpose statements will be presented. The theoretical framework will reflect the significance of the study and precede objective research questions and hypotheses for each operationalized variable pair in this study. The nature and significance of the study will precede definitions of terms to conclude the chapter.

Background

Operations management for services, such as life cycle support services, incorporates more risk to balance sustainable growth and profitability with future customer needs (Spring, & Araujo, 2009). Early warning performance trends and predictors for future program outcome (Marshall, 2007) are required for success in managing program performance to produce a service, especially ambiguous service-related tasks such as performance-based lifecycle sustainment. Periodic analysis of the performance trends can be used to identify problems early in the program's execution stages and provide program managers with indicators of success to the outcome of the program (Kim, 2008).

Rodriguez-Candela (2007) suggested performance ambiguity challenges predicting cost and schedule performance. Failure analysis results may contradict existing lifecycle support models such as meantime between failures for component or subcomponent items, which may change the sparing requirements for those components. These influences may be implemented as policy changes, improvements in technical system or sub-system design, or management decision-making, which may adversely affect the cost and schedule performance (Spring, 2010). Performance-based logistics methods provide managers with multiple performance metrics to measure the efficiency of implementation. Performance-based metrics are optimized through contract administration by incentivizing profit and minimizing time, potentially inducing risk. Rodriguez-Candela (2007) reported contractors who seek to maximize incentives may create extremely lean infrastructure plans, incapable of supporting unpredicted failure results.

Vanhoucke and Vandevoorde (2007) were concerned with the inflexibility of earned value management in a performance-based logistics context because of the flexible nature of performance-based logistics' product lifecycle support for fleet sustainment. The adaptability of performance-based logistics' lifecycle support is responsive to analysis of predictive failures, product-user contributing failures, and various echelons of support (Spring, 2010). The adaptability may conflict with pre-established planning of earned value management's performance measurements from a cost and schedule baselined plan.

Performance-based logistics programs are employed on more than 72% of new weapon systems acquisition programs in the United States (DoD, 2006). The application of earned value management may hinder managers supporting the dynamic nature of performance-based logistics because cost and schedule performance measurements are based on established baseline plans, rather than performance metrics, to measure current effectiveness and provide early warning indications of problems. Miller (2006) suggested that logistics-specific programs such as performance-based logistics contracts are not applying earned value management because of its complexities and relevance.

This research included analysis of performance metrics for the Shadow 200 Unmanned Aircraft System. AAI Corporation, the original equipment manufacturer, had approved the use of data consisting of earned value and performance-based logistics metrics for this research. Additionally, the Shadow 200's customer, the United States Army Program Executive Office – Aviation also approved the use of metric data for the purpose of this research. The information release approval documents are found in Appendix B. The Shadow 200 unmanned aircraft system is used to provide intelligence, surveillance, and reconnaissance to US Armed Forces (Defense Update, 2006). Operators control the aircraft from ground control stations to conduct flight over areas of interest and observe activities with the optical payload onboard the aircraft. Earned value management and performance-based logistics metrics were simultaneously employed to manage the Shadow 200 unmanned aircraft system program. Managers at the system's prime contractor, AAI Corporation, fulfilled the predictor variables as product performance metrics (Owings, 2010).

Problem Statement

The problem is that it is not known to what extent interdependency exists between earned value management and performance-based logistics service contracts (Nowicki, 2008). According Sherman and Rhoades (2010) defense acquisition processes were developed during the 1960s and cannot be used flexibly, causing this problem to affect the ability for Department of Defense acquisition professionals to modernize to new weapons systems because of the high cost of sustaining current systems using traditional lifecycle sustainment methods. Officials at the United States Office of Management and Budget acknowledged this problem and issued mandates for cost, schedule, and technical integration required in federal programs by 2006 (Visitacion, 2007). Department of Defense analysts also acknowledged issues with implementing earned value for nonschedule-based service contracts (DoD, 2006). Sherman and Rhoades (2010) indicated cycle time is necessary to control costs for operations and maintenance of Department of Defense acquisition programs continues to increase annually, however the cost of sustaining system readiness is not performance-oriented and prohibits investment in new weapons technology.

A benefit of this research was to improve the predictive capabilities and early warning indications of cost and schedule performance for service-oriented programs. Thirty-eight percent of surveyed contractors abandoned earned value management reporting at the 80% project completion mark because of the inability to predict remaining cost and schedule performance using earned value management (Templin & Christianson, 2003). Discoveries to correlational relationships with metric performance will be useful for decision-making regarding earned value management and performance-based logistics implementation.

Purpose

The purpose of this quantitative correlational study was to explore the relationships between the outcome variables of cost and schedule performance indices as earned value management metrics with the predictor variables of Operational Readiness Rate (ORR), Reliability Growth Rate (RGR), and Depot Mean Downtime (DMDT) as performance-based logistics metrics. The predictor-outcome variable pairs were measured for association from statistical hypothesis testing including correlation and modeled using multiple linear regression. The interval-scaled outcome variables were analyzed with the predictor variables to determine if any covariance exists. Intercorrelations and Mann-Whitney testing was used to examine the effect of the predictor variables of ORR, RGR, and DMDT with the two factors of the outcome variables of Schedule Performance Index (SPI) and Cost Performance Index (CPI).

The data collection instrument for this study collected monthly contract deliverable cost performance report data using the monthly averaged cost and schedule indices. For the predictor variable data collection, the Shadow 200 performance-based logistics metric scoring tables were used consisting of monthly averaged variable data. Intercorrelations testing and multiple linear regression indicated the effect to lifecycle support with program cost and schedule performance metric. System performance and reliability metrics combined with cost and schedule performance trends may be used to decrease risk to the program for achieving the objectives of life cycle support (Rodriguez-Candela, 2007). Understanding the interdependency between earned value management and performance-based logistics for the Shadow 200 provided predictive solutions. The study consisted of data from the Northeastern region of the United States, specifically from the Shadow 200 original equipment manufacturer, AAI Corporation.

Theoretical Framework

Periodic analysis of cost and schedule trends can be used to identify problems early in the program's execution stages, and provide indicators of success of the outcome of the program (Kim, 2008). The objective of this study was to develop research specific to earned value management and performance-based logistics. Many researchers have studied these topics independently Kim (2007), Kim (2008), Nowicki (2008), Owen (2008), Rodriguez-Candela (2007), Spring (2010), Storms (2010), Vandevoorde, S., and Vanhoucke, S. (2007), and Visitacion (2007); however, there was little research on the effects of implementing earned value management with a performance-based rather than life cycle-based context. Additionally, Plumer (2011) determined an examination of the relationships during correlational studies contributed to improving the understanding of covariance, interdependency, and predictive capabilities from the relationships. This research, inclusive of both earned value management and performance-based logistics topics included analysis to correlate earned value management within a performance-based logistics context. The basis of research was based upon monthly contract deliverable cost performance reports (Johnson, 2006) from the reported monthly averaged cost and schedule indices related to the Shadow 200 performance-based logistics service contract as well as the monthly averaged performance-based logistics metric data from the Shadow 200 performance-based logistics metric scoring tables.

A quantitative research design for earned value management in a performance-based logistics context correlated pre-planned cost and schedule measurements with the dynamic metrics of performance-based logistics (Randall, Pohlen, & Hanna, 2010). Archived data was used to provide the structure necessary for data analysis to correlate and model the relationships. A quantitative method was implemented to support the effectiveness (Kim, 2007) in determining metrics performance using predictive capabilities of earned value management in a performance-based logistics context. The instrument in Appendix C was used to collect variable data.

A power analysis was performed, using fixed-predictor models of multiple regression to determine the sample size. G*Power version 3.1.3 was the statistical software used to calculate the *a priori* sample sizes from a linear multiple regression test: fixed model, R^2 deviation from zero (Faul, Erdfelder, Buchner, & Lang, 2009). A medium effect size of f^2 of 0.15 was used. Alpha was set at 0.05 with a power of 0.80 and the three predictors for ORR, RGR, and DMDT were used. The calculation from the input parameters rendered a sample size of 77 predictors was required for each output variable of schedule and cost performance indices in this research.

Research Questions

Owings (2010) asserted measurements for predictor variables of ORR, RGR, and DMDT were critical to an effective performance-based logistics program. Measurements for outcome variables of SPI and CPI were critical for forecasting project performance. Earned value management metrics lack the ability to indicate technical scope performance. Questions relevant to the predictor and outcome variables were used to collect data to examine the interactions and interdependencies (Vogt, 2007).

Understanding the variable interdependency between earned value management and performance-based logistics provided the predictive analysis for life cycle support with program cost and schedule performance metric data (Kim, 2007). The quantitative focus of this study was to examine the relationships of earned value management metrics with performance-based logistics' metrics using the research questions provided to answer the following research questions.

Q1: To what extent, if any, is the relationship between Operational Readiness Rate and a Schedule Performance Index correlated?

Q2: To what extent, if any, is the relationship between Operational Readiness Rate and a Cost Performance Index correlated?

Q3: To what extent, if any, is the relationship between Reliability Growth Rate and a Schedule Performance Index correlated?

Q4: To what extent, if any, is the relationship between Reliability Growth Rate and a Cost Performance Index correlated?

Q5: To what extent, if any, is the relationship between Depot Mean Downtime and a Schedule Performance Index correlated?

Q6: To what extent, if any, is the relationship between Depot Mean Downtime and a Cost Performance Index correlated?

Q7: Do the performance-based logistics metrics of Operational Readiness Rate, Reliability Growth Rate, and Depot Mean Downtime have an effect on earned value metrics of Cost and Schedule Performance Indices?

Q8: Is there an interaction effect between the earned value metrics of Cost and Schedule Performance Indices?

Hypotheses

$H1_0$: There is no significant correlation between Operational Readiness Rate and a Schedule Performance Index.

$H1_1$: A significant correlation exists between Operational Readiness Rate and a Schedule Performance Index.

$H2_0$: There is no significant correlation between Operational Readiness Rate and a Cost Performance Index.

$H2_1$: A significant correlation exists between Operational Readiness Rate and a Cost Performance Index.

$H3_0$: There is no significant correlation between Reliability Growth Rate and a Schedule Performance Index.

$H3_1$: A significant correlation exists between Reliability Growth Rate and a Schedule Performance Index.

$H4_0$: There is no significant correlation between Reliability Growth Rate and a Cost Performance Index.

$H4_1$: A significant correlation exists between Reliability Growth Rate and a Cost Performance Index.

$H5_0$: There is no significant correlation between Depot Mean Downtime and a Schedule Performance Index.

$H5_1$: A significant correlation exists between Depot Mean Downtime and a Schedule Performance Index.

$H6_0$: There is no significant correlation between Depot Mean Downtime and a Cost Performance Index.

$H6_1$: A significant correlation exists between Depot Mean Downtime and a Cost Performance Index.

$H7_0$: The Operational Readiness Rate, Reliability Growth Rate, and Depot Mean Downtime have no significant multivariate main effects for Cost and Schedule Performance Indices.

$H7_1$: The Operational Readiness Rate, Reliability Growth Rate, and Depot Mean Downtime have significant multivariate main effects for Cost and Schedule Performance Indices.

$H8_0$: There is no significant interaction effect between the earned value metrics of Cost and Schedule Performance Indices.

$H8_1$: There is a significant interaction effect between the earned value metrics of Cost and Schedule Performance Indices?

Nature of the Study

In this quantitative study, the relationship between earned value management metrics of cost and schedule performance indices with the performance-based logistics metrics of ORR, RGR, and DMDT was explored with the use of a correlational design (Nowicki, 2008). The outcome variables were the SPI and CPI variables. The ORR, RGR, and DMDT were the predictor variables. The total population of earned value and performance-based logistics metric data for the Shadow 200 unmanned aircraft system history was available for statistical testing. Intercorrelations and Mann-Whitney testing was used to examine the effects of the combined predictor interactions to the outcome variables. Correlation and multiple linear regression were used to examine predictor-outcome relationship pairs. Because correlation does not determine causation, multiple linear regression analysis was performed to determine if modeling performance-based logistics metrics with cost and schedule performance metrics in a nonschedule-based program, such as the Shadow 200 program provided enhanced forecasting capabilities rather than earned value metrics of the Cost Performance Index or Schedule Performance Index (Alvarado, Silverman, & Wilson, 2004).

Significance of the Study

Lambert and Garcia-Dastugue (2006) stated that skills and knowledge enable cross-functional supply chain management processes; however, Nasr (2005), suggested that skills and knowledge are critical to understanding for effective decision-making from performance measurement information. A significant problem for managers is the ability to use earned value metrics within a performance-based logistics context to perform early forecasting of program performance or detect warnings of program cost and schedule performance issues. Performance-based life cycle sustainment tasks may benefit from early warning performance trends and predictors for future program performance (DoD, 2006). Analysis of performance trends can identify problems early in the program's execution stages and provide indicators of success for the outcome of the program (Kim, 2008). Life cycle cost management can be used to predict long-term costs for the operations and support of defense weapons systems for total ownership costs (Tremaine & Seligman, 2010). Predictive tools to forecast project cost and schedule may provide managers with methods for containing total ownership costs. Correlating, understanding the combined effects, and modeling performance-based logistics metrics with earned value metrics may provide managers with skills and knowledge to provide value in service support instead of component delivery (Randall, et. al., 2010).

Definitions

Critical and unique earned value management and performance-based logistics terms were defined. The specific variables relevant to earned value management in a performance-based logistics context included the SPI, CPI, ORR, RGR, and DMDT. These terms and other terms were identified in alphabetic order.

Cost Performance Index (CPI). The Cost Performance Index was defined as the ratio of the budgeted cost of work performed as a divided by the actual cost of work performed. The CPI indicated the efficiency of the cost during project execution. This index provided predictive measurement for the expected cost performance of an entire project (PMI, 2009). The Cost Performance Index calculation was represented as

$$\text{Cost Performance Index} = \frac{\text{Budgeted Cost of Work Performed}}{\text{Actual Cost of Work Performed}}$$

Depot Mean Downtime (DMDT). For the purposes of this study, Depot Mean Downtime was defined as a performance-based logistics metric depicting the measure the time, in hours or days, from component failure to repair or replacement. The metric was a sum of the repair, repair logistics time, and maintenance Downtime divided by total time (US Army, 2009). The metric was used to incentivize performance to meet an objective for which process improvement was implemented to achieve minimized repair turn-around time for improved life cycle cost. The DMDT is calculation was represented as

$$DMDT = \underline{\text{repair downtime} + \text{repair logistics time} + \text{maintenance downtime}}$$

Total time

Downtime. Downtime was defined as the measure of hours or days that a subsystem was not mission capable. This calculation began at the time of not mission capable status through system or subsystem failure or inspection required and continued until the system or subsystem was repaired or inspected for return to a mission capable status (Undersecretary for Logistics, 2007).

Maintenance Downtime. Maintenance Downtime was defined as the number of hours or days that a subsystem was undergoing preventative maintenance actions and included delays in logistics availability time of the replacement system or subsystem (US Army, 2009).

Not Mission Capable. Not mission capable was defined as any condition of a system or subsystem that required a corrective/repair maintenance action to return to a mission-capable status (US Army, 2009).

Operational Readiness Rate (ORR). For the purposes of this study, ORR was defined as a performance-based logistics metric to measure the function of a system's availability to perform the designed tasks compared to the expected operational availability time for the system. The metric was calculated as a total time minus Downtime divided by total time. The ORR was also known as System Status Readiness (SSR). The calculation was represented as

$$ORR = \frac{total\ time - downtime}{Total\ time}$$

Reliability Growth Rate (RGR). For the purposes of this study, RGR was defined as a performance-based logistics metric, which measured the effect of improvements to the average life expectancy of a component in a system. The RGR indicated the decrease in the failure rate of the component through improved system engineering, material design, and training as a result of failure analysis. The variable was depicted as a normalized period, typically 100,000 hours for aviation systems, multiplied by the number of failures, divided by amount of operational use of the failed component. The RGR calculation was represented as

$$RGR = \frac{\textit{normalized value in time X number of periodic system failures}}{\textit{Actual value in time}}$$

Repair Downtime. Repair Downtime was defined as portion of the DMDT metric for the number of hours or days that a subsystem had unscheduled maintenance actions and excluded any delays in logistics transportation or availability time (US Army, 2009).

Repair Logistics Time. Repair logistics Downtime was defined as the portion of the DMDT metric for the number of hours or days that a subsystem was delayed in performing unscheduled maintenance actions because of the logistics availability of a replacement component (US Army, 2009).

Schedule Performance Index (SPI). The Schedule Performance Index was defined as the ratio of the budgeted cost of work performed. This metric was used to evaluate and predict future schedule performance of a project (PMI, 2009). The calculation was represented as

$$SPI = \frac{\textit{budgeted cost of work performed}}{\textit{budgeted cost of work scheduled}}$$

Total Downtime. Total Downtime was defined as the portion of the DMDT metric for the number of hours or days that a subsystem required preventative or unscheduled maintenance actions and included delays in logistics availability time of the replacement system or subsystem (US Army, 2009).

Total Time. Total time was defined as the denominator in the calculation of the ORR metric to measure a time constant, in quarters, multiplied by the number of systems supported (US Army, 2009).

Summary

This quantitative correlational study was used to examine the relationships of detailed prior planning as earned value management metrics with the flexibility requirements for performance-based logistics metrics in the Shadow 200 program. The research may provide managers with methods to improve the predictive capabilities or early warning indications of cost and schedule performance for service-oriented programs. The result of this research may identify influential relationship metrics between earned value management and performance-based logistics context (Rodriguez-Candela, 2007).

This research was used to investigate the relationships between the outcome variables of SPI and CPI as earned value management metrics with the predictor variables of ORR, RGR, and DMDT as performance-based logistics metrics. Measurements of association between the predictor-outcome variable pairs indicated the level of existing covariance. The research provided managers with an understanding to what extent interdependency exists between earned value management and performance-based logistics service contracts (Nowicki, 2008).

Chapter 2: Literature Review

The objective of this study was to examine common measures for earned value management and metrics for performance-based logistics incentives to determine if any relationship exists. Synthesis of the literature on the fields of earned value management and performance-based logistics was used to correlate an influence between them. The literature review was organized into five sections: (a) earned value management implementation, (b) performance-based logistics implementation, (c) performance incentives, (d) forecasting, and (e) logistics support.

A literature search strategy was used to collect research from peer-reviewed and scholarly journals, dissertations, theses, conference papers, and books using keywords. Keyword selection search engines included ProQuest, Article Linker, and use Northcentral University's interlibrary loans. A particular focus was placed on research containing earned value management and performance-based logistics employment. The keywords included project management, earned value management, EVM, earned value analysis, earned-value management system, cost control, schedule management, metrics, forecasting, performance-based logistics, PBL, lifecycle support, logistics performance, and supply chain management.

The literature review was used to identify strengths and weaknesses for each section, which may be useful for program managers implementing earned value management with life cycle support strategies such as performance-based logistics to improve the predictive capabilities and early warning indications of cost and schedule performance for service-oriented programs. Russell (2009) recognized the necessity for earned value management within the acquisition process. In this study, Russell (2009) identified life cycle sustainment weaknesses within the acquisition process to use earned value management as an effective management tool to forecast program performance and identify early warning indications of problems. Nowicki, Kumar, Studel, and Verma (2008) identified performance-based logistics as a fundamental concept to implement frameworks, definitions, and structures for life cycle performance; however, they recognized weakness with optimizing the strategies and implementing best practice.

Earned Value Management Implementation

Administrators from the US government's Office of Management and Budget formalized policy for the methodological implementation to integrate cost, scope, and schedule performance with earned value management systems as a required management practice for government programs (Azizian, 2011). The policy, an enforcement of the Federal Acquisition Streamlining Act of 1994, required major acquisition programs to achieve 90% of cost and schedule performance (Azizian, 2011). Major acquisition programs included any program committing more than $500,000 annually. Mandates in the policy included the use of the American National Standards Institute/Electronic Industry's Alliance Standard, ANSI/EIA-748, as the guideline for earned value management implementation for performance-based acquisition management programs and certification compliance (Johnson, 2006).

The Office of Management and Budget administrators stated the requirements for successful validation of a contractor's earned value management system entailed demonstration of an Earned Value Management System (EVMS) that meets ANSI/EIA Standard 748, for both government and contractor costs requiring the effort and demonstrate variance from the planned schedule and performance goals (Kobren, 2009).

Russell (2011) stated that significant relevance between earned value management and weapon system lifecycle support, such as performance-based logistics, existed in three areas. First, earned value management had become synergistic with the defense acquisition process, focusing on management of metrics for program planning, execution measurements, and change control. Second, Russell suggested an increase in literature for earned value management within a performance-based logistics context demonstrated a growing need for development of industry best practices, and standardizing of processes. Third, logisticians who were the life cycle managers for weapons systems, lack the knowledge and experience to ensure the contractor's life cycle support plan is considered reasonable during the baseline process. Additionally, they could not understand the early warning identifiers (Russell, 2011), which can be used to minimize adverse cost and schedule conditions.

Effective organizational processes were written to enforce compliance with earned value guidelines for the structure of an earned value management system (Johnson, 2006); an effective implementation of earned value management adhered to detailed organizational processes, which were compliant with the ANSI standard (Russell, 2011). The system was used to employ best practices to manage change control, standardize cost, and schedule performance metrics, and provided early warning indications for future program performance (Azizain, 2011). Regan (2006) determined that a contractor's earned value management system used guidelines and processes to standardize and control the organizational application of accounting practices, analysis, and management reporting, data maintenance, and change control. As stated by Azizain (2011), administrators at the General Services Administration suggested the benefits to earned value management included a set of control techniques and processes to document the planned work, the amount of work completed, and the cost to complete that work.

The ANSI/EIA 748 standard is composed of 32 guidelines affinitized into five main categories of organization, planning and budgeting, accounting, managerial analysis and reporting, and baseline management to integrate the elements of cost, scope, and schedule with organizational processes (Regan, 2006). Table 1 contains a brief description of the 32 guidelines. Appendix A provides a detailed guideline description. These industry guidelines have become government requirements for defense acquisition programs through Department of Defense instruction 5000.01 and 5000.02. Additionally, acquisition professionals established the Defense Federal Acquisition Regulation Supplements to introduce compliance requirements for earned value management implementation (Buchanan, & Klingner, 2007).

Table 1
Abbreviated Earned Value Management System Guidelines

EVMS Category	Guideline Description
Organization	1 - Define the authorized work elements for the program in a work breakdown structure. 2 - Identify an organizational breakdown structure. 3 - Integrate planning, scheduling, budgeting, work authorization and cost accumulation processes. 4- Identify the organization for controlling overhead (indirect costs). 5 - Integrate the work breakdown structure and organizational structure for cost and schedule performance measurement.
Planning, Scheduling and Budgeting	6 - Schedule the authorized work. 7 - Identify performance goals to measure progress. 8 - Establish and maintain a time-phased budget baseline. 9 - Establish budgets for authorized work.

	10 - Identify the authorized work in discrete work packages. 11 - Sum the work package budgets and planning package budgets within a control account. 12 - Identify and control level of effort activity by time-phased budgets. 13 - Establish overhead budgets. 14 - Identify management reserves and undistributed budget. 15 - Reconcile target costs with internal budgets and management reserves.
Accounting Considerations	16 - Record direct costs in a manner consistent with the budgets.
	17 - Summarize direct costs from control accounts into the work breakdown structure.
	18 - Summarize direct costs from the control accounts into organizational elements. 19 - Record all indirect costs. 20 - Identify unit, equivalent, or lot costs. 21 - Accumulate accurate material costs.
Analysis and Management Reports	22 - Generate planned budget and the amount of budget earned for work accomplished at the control account level. Also, compare of the amount of the budget earned and the actual costs. 23 - Identify differences between both planned and actual schedule performance and planned and actual cost performance.
	24 - Identify budgeted indirect costs and significant variances.
	25 - Summarize the data elements and associated variances.
	26 - Implement managerial actions from earned value information. 27 - Develop revised estimates of cost at completion.
Revisions and Data Maintenance	28 - Incorporate authorized changes in a timely manner.
	29 - Reconcile current budgets to prior budgets. 30 - Control retroactive changes to sustain baseline integrity and accuracy. 31 - Prevent revisions to the program budget except for authorized changes. 32 - Document changes to the performance measurement baseline.

Note. Adapted from "Earned Value Management in a Data Warehouse Project," by J. Gowan, M. Mathieu, and M. Hey, 2006, *Information Management and Computer Security*, 14, p.37.

Regan (2006) stated each guideline required distinctive organizational processes for compliance. An earned value management system description (Monius, 2011) was the regulatory collection of organizational processes and procedures for when to use them. Each organizational process provided guidance to managers to produce documentation, demonstrating guideline compliance within the organization category. In example, a work breakdown structure, organizational breakdown structure, and the responsibility assignment matrix are output documents used to assign and authorize the scoped work, contributing to guidelines one, two, and three, providing a framework for reporting and control (Kuehn, 2007).

The planning and budgeting category of the 32 ANSI/EIA-748 guidelines allowed managers to focus on program integration (Plumer, 2010). The development of the program plan incorporated an integrated master schedule to identify milestone objectives from the control account managers. The General Services Administration Earned Value Management System Compliance Review Guide also described this category (Azizian, 2011) as the framework for establishing time-phased budget accountability necessary to evaluate risk, cost, and schedule performance.

Lukas (2008) suggested program integration as the framework for successful implementation of earned value management. Managers lacked program management integration and relied upon normative methodologies instead, as reported by Bower (2009). Normative methodologies used qualitative, rather than quantitative techniques in program management (Bower, 2009), which led to organizational cultural deficiencies and implementation failures.

The accounting category included guidelines for integration between the organizational cost accounting system and cost data reporting (Azizian, 2011). Russell (2011) imparted cost data that was collected by the accounting system must accurately collect direct and indirect costs for cost types, including labor, material, other direct costs, and subcontract costs. Cost integration for maintenance, repair, and overhaul services, which was fundamental to performance-based logistics (MacDonnell & Clegg, 2007) required integration within the accounting system as a business model to provide early warnings of cost or schedule problems. Lukas (2008) suggested mitigating the potential inaccuracy of delays in invoicing by adjusting or estimating costs as accruals until the costs were collected. A process of estimating actuals was an acceptable business practice and within the guideline intent (Monius, 2011), provided a process standardized the method, personnel were trained on the process, and the process was part of the organizational system description.

Officials from the General Services Administration identified requirements for the managerial analysis and reporting category to provide evidence of correctly reporting program earned value, including customer and subcontractor performance (Azizian, 2011). Data item description DI-MGMT-81466A was used to describe a standardized format for cost reporting for defense contracts (Zimmerman, 2006). Monius (2011) suggested implementation also required a method to document and standardize corrective action plans for the monthly variance analysis corrective actions to ensure timely and accurate closeout. The reporting requirements were fundamental to providing evidence of controlling costs.

The baseline management guideline category described sets of processes to manage change control (Johnson, 2006). Kuehn (2007) recommended baseline changes occur after completing a formal change control process to demonstrate the intent of the guideline category. Lukas (2008) disclosed program managers had performed unauthorized changes to a performance measurement baseline to minimize the bad-news effect of undesirable program performance.

In 1998, the Under Secretary of Defense for Acquisition, Technology, and Logistics authorized the Defense Contracts Management Agency with the responsibility as the Department of Defense cognizant federal agency for earned value management (Regan, 2006). The agency established an earned value management center to certify organizational earned value management systems (Owen, 2008). The certification process was a joint effort between a defense contractor and the Defense Contracts Management Agency's earned value center. The certification process included internal audits, contractor self-assessments, corrective action reports, management process maturation, readiness assessments, and a formal on-site validation review.

Buchanan and Klingner (2007) stated in 1991, the Office of Federal Procurement Policy mandated performance-based contracting for Federal acquisition programs. Performance-based contracting used metrics, standards, and objectives to motivate defense contractors to perform at desired levels with increased requirements. Buchanan and Klingner (2007) suggested the policy was used to focus on work to be performed, similar to earned value management. In 2005, the policy was replaced with performance-based service acquisition including Defense Federal Acquisition Regulations (DFARS) such as notification of an earned value management requirements, which were written into the contract language as a notice of Earned Value Management System, DFARS 252.234-7001, Earned Value Management System, DFARS 252.234-7002, or an EVM Clause Usage (Buchanan & Klingner, 2007). A document package consisting of checklists, forms, templates, and instructions to perform the self-assessment was sent from the center (Monius, 2011). The notification package also included requirements for a data call to prepare and submit specified financial, schedule, and programmatic reports for a fiscal period.

Data call documentation was evaluated for traceability and evidence that the defense contractors earned value management system operated within the ANSI guidelines (Lukas, 2008). Monius (2011) reported that a data call was composed of two data sets. First, a one-time submittal including the organizational earned value management system description, a compliance cross reference matrix, a risk matrix, documentation on metrics for schedule assessments, and metrics for earned value cost data. Monius suggested the earned value management system description references specific processes within the document for guidance to managers for when to apply them.

Owen (2008) suggested incorporating the processes within the system description, including processes to organize program management; processes to establish the integrated master schedule; processes to authorize scope, schedule, and functional resources requirements; processes for cost collection and accounting; processes to report cost and schedule performance; processes to manage a change control program; processes to manage material items and subcontracts; and processes to sustain documentation currency and system surveillance. Changes to an organization's system description required Defense Contracts Management Agency approval. Monius (2011) suggested using references to the processes within the system description; however, the processes were maintained external to the system description to maintain and control change independently, expediting the change control process.

The second data call consisted of 12 months of cost data including cost performance reports, schedule data, work authorization documents, work breakdown structure dictionaries, and responsibility assignment matrices delivered incrementally (Monius, 2011). Monius (2011) also suggested incremental deliveries in four installments. The first installment included the contract and modifications, contractual deliveries listing, statement of work, and cost data from historical records. The second installment included cost performance reports with each fiscal period closeout to supplement the first data call, which included integrated master schedules, baseline change requests, and contract logs such as an undistributed budget and management reserve logs. The third installment consisted of one-time document submittals. The fourth installment consisted of the defense contractor's self-assessment findings.

The earned value center conducted an initial visit to defense contractors seeking validation (Monius, 2011). The contractor communicated corporate and program overviews, identified the training programs used to prepare program managers, cost account managers, cost analysts, and schedulers for compliance to the system description and processes. Participants in the initial visit included organizational senior leaders, organizational earned value integration team, Defense Contracts Management Agency earned value certification representatives, and the government customer holding the contract requiring earned value management (Monius, 2011). A presentation of the organizational processes within the context of the earned value management system was provided to status the current state of the organization for the initial visit team.

The earned value self assessment performed at AAI Corporation for the Shadow 200 unmanned aircraft system program involved the organization earned value team, program managers, cost account managers, business managers, cost analysts, and schedulers to analyze the existing processes for compliance to the ANSI/EIA-748 standard. The self-assessment report described a plan to improve sub-standard processes, train new processes, and methods to monitor additional improvement requirements to ensure the organization's processes and people met the earned value guideline intent (Monius, 2011). A system description cross reference checklist aligned requirements to each paragraph of the system description with the ANSI/EIA-748 guideline requirements. Monius (2011) suggested maturing the organizational system description prior to receiving notification of earned value from the customer.

AAI Corporation's self-assessment included interviews of program managers, cost account managers, business managers, cost analysts, and schedulers to determine process understanding and compliance. Monius (2011) suggested documenting interviews via interview-minutes forms to include questions from guideline categories as well as lessons learned input from Defense Contracts Management Agency representatives and the earned value center. Monius (2011) also suggested using screenshots to demonstrate both evidence of compliance as well as noncompliance. The self-assessment used data traces of single cost accounts across documents required by the system description to demonstrate guideline compliance and noncompliance. The system description cross reference checklist, programmatic personnel interviews, and data traces were used to generate discrepancy reports for noncompliance findings. AAI's earned value self-assessment team categorized the discrepancy reports at two levels, significant and minor. Significant levels were used if the discrepancy added risk to the earned value certification and affected measurements in program performance.

Minor levels were used if the discrepancy did not risk validation or performance measurements (Monius, 2011). The earned value center received the self-assessment results and corrective action plans. Guideline compliance and deficiencies incident percentages were required as part of the submitted documents. The methods to determine compliance provided evidence from the data traces, interviews, and analysis of metrics (Monius, 2011).

According to Everage (2006), the earned value management certification process was used to evaluate the defense contractor's system description and organizational processes for guideline compliance, implementation plan, system description, processes training plans, self-assessment results, corrective action plans, results from progress assistance visits, processes to sustain process currency and personnel proficiency levels. Officials at the Defense Contracts Management Agency reported the evaluations process included progress assistance visits and a validation review by experts at the center (Owen, 2008). The audits were performed to validate process visibility and data integrity throughout management processes. An advance agreement or letter of acceptance from the Administrative Contracting Officer certifies the contractor has an earned value management system, affirming government contract requirements requiring earned value management systems have been met (Owen, 2008).

Once a defense contractor obtained a certified earned value management system, routine government surveillance was performed to ensure management processes, decision-making, and performance assessments sustain accuracy, validity, and credibility of performance measurement data within the ANSI/EIA-748 guidelines (Owen, 2008). Defense Federal Acquisition Regulation Supplement clause 252.234-

7002 required surveillance on government contracts requiring earned value management (Johnson, 2006). Subject matter experts at the Defense Contracts Management Agency developed a Standard Surveillance Operating Manual to establish roles and responsibilities, standardized process steps, and provided guidelines for development of a standard surveillance plan (Monius, 2011). The Standard Surveillance Plan was the defense contractor-government agreement to establish a framework, member participation, frequency, and risk approach to administering surveillance requirements.

Joint surveillance consisted of government and contractor participation, and defense contractor members must have been independent of the program under surveillance (Johnson, 2006). Owen (2008) discovered the Defense Contracts Management Agency performed surveillance to verify the contractor's implementation of processes, procedures, tools, and techniques within the organizational earned value system description and process to disseminate the surveillance results both to the center and defense contractor. Monthly assessments of the surveillance requirements included data analysis of program cost and schedule performance.

The surveillance was performed to verify training of program management personnel, comprehensive planning for an integrated baseline review, baseline integration of cost schedule and technical planning, authorization and allocation of work, cost and schedule variance reporting, and management systems integration (Johnson, 2006). Noncompliance or unapproved deviations from the validated system description resulted in corrective actions reports. In a joint surveillance environment, either the government or the independent defense contractor participants issued corrective action reports for discrepancies identified during the surveillance (Monius, 2011).

Policy changes at the earned value management center are anticipated for 2011, which may affect the government's system surveillance program (Infanti, 2010). A revised system surveillance instruction will contain a shift in surveillance responsibilities to regional contract management offices for weapon systems programs with acquisition category level one. Subject matter experts at the earned value management center will continue responsibilities for category levels two, three, and four (Infanti, 2010). However, Monius (2011) indicated the center's officials remain responsible for programs at critical levels two and three as well as level four programs; subject matter experts at the local defense contracts management agency office would also remain responsible for noncritical level two and three programs. Revisions to the corrective action reporting system and trip wire instructions are also planned for release (Infanti, 2010), which increases the center's focus on early warning forecast accuracy.

Regan (2006) reported the certification process required multiple years to complete. Regan (2006) also suggested applying lessons learned significantly improved the contractor's ability to achieve certification. Regan (2006) reported that most defense contractors failed to appoint an earned value manager, who had the responsibility and authority to affect changes to the processes for certification. This failure caused an increase in the preparation time required for certification. The absence of an earned value manager caused delays with developing processes used to control and standardize an earned value management system via a system description document and management processes designed to maintain data integrity across programs.

Regan (2006) also reported that program management personnel had an influence on the organizational culture with a resistance to change, causing a hindrance to process maturation and training. Senior management buy-in into earned value management certification requirements decreased delays with certification. Senior management buy-in also decreased time lost from the resistance to change and identified improvement opportunities in operational processes, resulting in leaner and less expensive process steps (Regan, 2006).

Lukas (2008) suggested organizational process maturity was required to implement earned value management. Stratton (2006) indicated earned value management system process maturity levels affected the level of compliance within the ANSI guidelines. Lukas (2008) reported that organizations with at least a Capability Maturity Model Integration level three had the minimum process maturation to sustain an earned value management system, and at level four, the processes indicated optimization to improve the organization's business model with earned value management. Lukas (2008) determined many organizations failed to implement an earned value management system because of a lack of documentation requirements. The lack of documentation led to program team failures to document customer requirements; inability to integrate of the scope within a program, leading to incomplete requirements; inability to integrate program planning, scheduling, and budgeting into a work breakdown structure; inability to manage change control; and an inadequate cost collection system. Lukas (2008) also stated the lack of process maturity increased the likelihood for qualitative rather than quantitative management techniques. Qualitative techniques were used to amplify bias during progress reporting and reduced early warning problem detection during programmatic forecasting (Lukas, 2008).

Johnson (2006) cautioned that a lack of earned value management practices contributed to poor integrated planning and program performance visibility, loss of scope control, and inadequate risk management, contributed to an 18% failure rate in information technology projects. Bower and Finegan (2009) advised that earned value management practices did not significantly improve program performance alone; however, earned value was concentric to the aerospace and defense industry. Managers in the non-aerospace and defense industries were adverse to the acronym-based language associated with earned value management and had a perception that earned value management was associated only with defense acquisition (Bower & Finegan, 2009). Cicmil and Hodgson (2006) determined program managers lacked the practical experience necessary to manage customer and organizational expectations within strict compliance of an earned value management system.

Congruent with Bower and Finegan (2009), the use of metrics in earned value management narrowly measured program performance with respect to cost and schedule elements and failed to measure the effect on other factors such as environmental, quality, or societal needs, limiting the use of earned value management for some industries. Kim (2007) suggested a narrow focus toward quantitative performance measurements provided the information necessary to forecast early indications of program performance and final anticipated program costs.

Common errors with implementing earned value management resulted from a lack of integrated program planning, including initial baseline planning, accuracy, and evaluation of variances during earned value analysis (Lukas, 2008). Lukas (2006) identified five classes of estimating for baseline planning. Lukas (2008) also reported an inverse relationship between the scope definition and estimating accuracy.

For high technology programs, a class five category was described as strategic order of magnitude planning with 5% to 10% of the defined scope correlated with an estimating variation of ±100%; class four had between 10% and 35% of the scope defined to maintain ±50% variation, which Lukas defined as conceptual; class three, described as budgetary, had between 35% and 60% scope definition for ±30% variation; class two classified a definitive estimate with 60% to 90% of the scope defined for ±30% variation; class one, which detailed the baseline plan critical to successful earned value management implementation required 90% to 100% of the scope defined and had a ±5% variation in estimation. Lukas (2008) indicated fewer baseline plan changes were required when more up-front detailed plan occurred prior to establishing the baseline plan.

Lukas (2008) asserted some attributes of earned value management, such as the schedule performance index could not determine the schedule health of the program because the schedule performance index did not differentiate schedule performance against critical or noncritical path schedule activities. Kim (2007) suggests using alternative methods of measuring and forecasting schedule performance, such as the critical path method to increase the validity of the program schedule performance and forecasted completion date. Stratton (2006) researched 700 completed projects in a three-year period to determine that earned value could predict a program's schedule health performance after completing only 15% of the total work. Stratton (2007) also maintains when a project was 66% completed, earned value's schedule variance and schedule performance index metric became unreliable for predicting project completion performance.

As a project nears completion, the schedule earned value metric began to normalize the efficiency of spending time. This occurred because the schedule performance index must be equal to 1.0 at the completion of the project, regardless of when the project completed (Stratton, 2007). Stratton (2007) suggested using earned schedule instead of the schedule performance index to predict project completion. Lukas (2008) reported earned schedule was used to indicate performance based upon the schedule for work completed rather than the value of work completed. Stratton (2007) reported project performance using earned schedule measured against the planned duration for the project provided the anticipated project completion date in time instead of dollars. Using an earned value schedule performance index with additional tools such as earned schedule (Stratton, 2007) or critical path methods (Vandevoorde & Vanhoucke, 2006) increased the validity of predicting project performance.

Vandevoorde and Vanhoucke (2006) determined earned value management had systematic errors when used to predict schedule performance under certain situations. Error situations included projects with noncritical paths such as service-type projects, and under conditions with multiple changes to the baseline plan. Vandevoorde and Vanhoucke (2006) indicated three fundamental flaws identified with schedule variance using a schedule performance index. The schedule variance did not identify the variance in time (Vandevoorde & Vanhoucke, 2006). Schedule variance was a comparison of the monetary amount of work performed with the monetary amount of work scheduled; the variance was indicated in a monetary value instead of a time value. A schedule performance index of 1.0 indicates the task was complete or on schedule. As a program neared completion, the schedule performance index begins to normalize to 1.0, even if the project were behind schedule (Vandevoorde & Vanhoucke, 2006).

Kuehn (2007) suggested the work breakdown structure was the most important tool for integration of product or service scope into a program. Product-oriented work breakdown structures provided the central focus necessary for decomposition from requirements analysis to execution (Kuehn, 2007). In January 2011, a revision to defense handbook MIL-STD-881-C modernized the Department of Defense guidelines to standardize product-oriented work breakdown structures for defense acquisition programs (Monius, 2011). The decomposition of a work breakdown was structured into major scope areas from the defense handbook to standardize the framework of major elements, such as electronics, ordinance, or unmanned aircraft systems (Kuehn, 2007). The revision to the defense handbook improved work breakdown structure definitions, integrated cost, scope, and schedule management, and incorporated policy changes compliant to DODI 5000.02 (Infanti, 2010). DODI 5000.02 also referenced the requirement for performance-based logistics for lifecycle support (Azizian, 2011).

Performance-Based Logistics Implementation

In 1998, officials from the Department of Defense required performance-based logistics as a life cycle support strategy to reduce the sustainment costs of weapon systems' life cycle support (DoD, 2006). Performance-based logistics was a methodology centered on sustainment of readiness levels rather than quantities of spares component availability as in traditional logistics support structures. According to

Devries (2005), performance-based logistics was used to focus elements of integrated logistics support toward a consolidated approach to weapon system's operational readiness.

Sols, Nowicki, and Verma (2008) compared the operational availability of the F/A-18E/F supported by the PBL approach at 85% readiness versus 73% for the C/D model aircraft, which used a traditional logistical support model. Similarly, the US Navy's Aegis missile cruisers increased operational readiness from 62% with traditional logistics support to 94% after implementing performance-based logistics as the support structure (Geary, 2006). Department of Defense officials had implemented more than 215 performance-based logistics programs, which supported life cycle sustainment and part of the annual $125 billion spent by the department (Kratz, 2007). Fowler (2008) reported increasing performance-based logistics contracts because of historical success since 1997. Torcomian (2008) indicated the success of defense-related performance-based logistics attracted nondefense industries, such as the trucking industry with similar readiness results. Devries (2005) asserted performance-based logistics integrated initial acquisition processes with total life cycle system management concepts to achieve warfighter requirements for ready and available systems.

Kobren (2009) related the framework of requirements for performance-based logistics began in 1998 with Section 912(c) from the National Defense Authorization Act and the 1998 report titled *Secretary of Defense Report to Congress: Actions to Accelerate Movement to the New Workforce Vision.* Devries (2005) reported the implementation of performance-based logistics was mandated during the 2001 Quadrennial Defense Review. Devries (2005) also suggested total lifecycle system management was used to focus program managers to consider complete lifecycle support from the beginning of the acquisition process (Devries, 2005). Kobren (2009) also reported three additional documents had preceded the Department of Defense directive 5000.01, *The Defense Acquisition System* and directive 5000.02, and the *Operation of the Defense Acquisition System.* These three preceding reports included *Product Support for the 21st Century: Report of the Department of Defense Product Support Reengineering Implementation Team Section 912(c)* written in 1999; the 2000 report of *Product Support for the 21st Century*; and the 2001 report *Product Support for the 21st Century.* Kobren (2009) also emphasized guidance entitled *Performance-Based Logistics: A Program Manager's Product Support Guide* reinforced policy memoranda issued from the Office of Secretary of Defense. Kobren (2009) cited experts from the Defense Acquisition University that the purpose of the guide was to provide product support managers with roles and responsibilities to implement performance-based logistics prior to the 2010 National Defense Authorization Act, which formally established product support managers in the Department of Defense. The *Defense Acquisition Guidebook,* issued in 2006, was used to provide guidance for Department of Defense agencies to implement performance-based logistics (Kobren, 2009).

The use of performance-based logistics leveraged best value and industry best practices as a combination of organic and commercial support (Devries, 2005). Performance-based logistics shifted reliability and continuous improvement for increasing system reliability with Total Quality Management, Six Sigma, variation reduction, and Theory of Constraints. Doerr, Lewis, and Eaton (2005) suggested profit incentivized the supplier of the performance-based logistics, whereas service performance incentivized the customer. Because the customer's objectives were ambiguous between acquisition objectives, strategies, and limitations within the acquisition process (Doerr, et. al., 2005), tangibility for the supplier was used to determine the benefits as a return on investment; however, the customer's goals and performance requirements as a function of cost were subjective and difficult to measure. Figure 1 identifies the theoretical perspective differences between the customer and service provider.

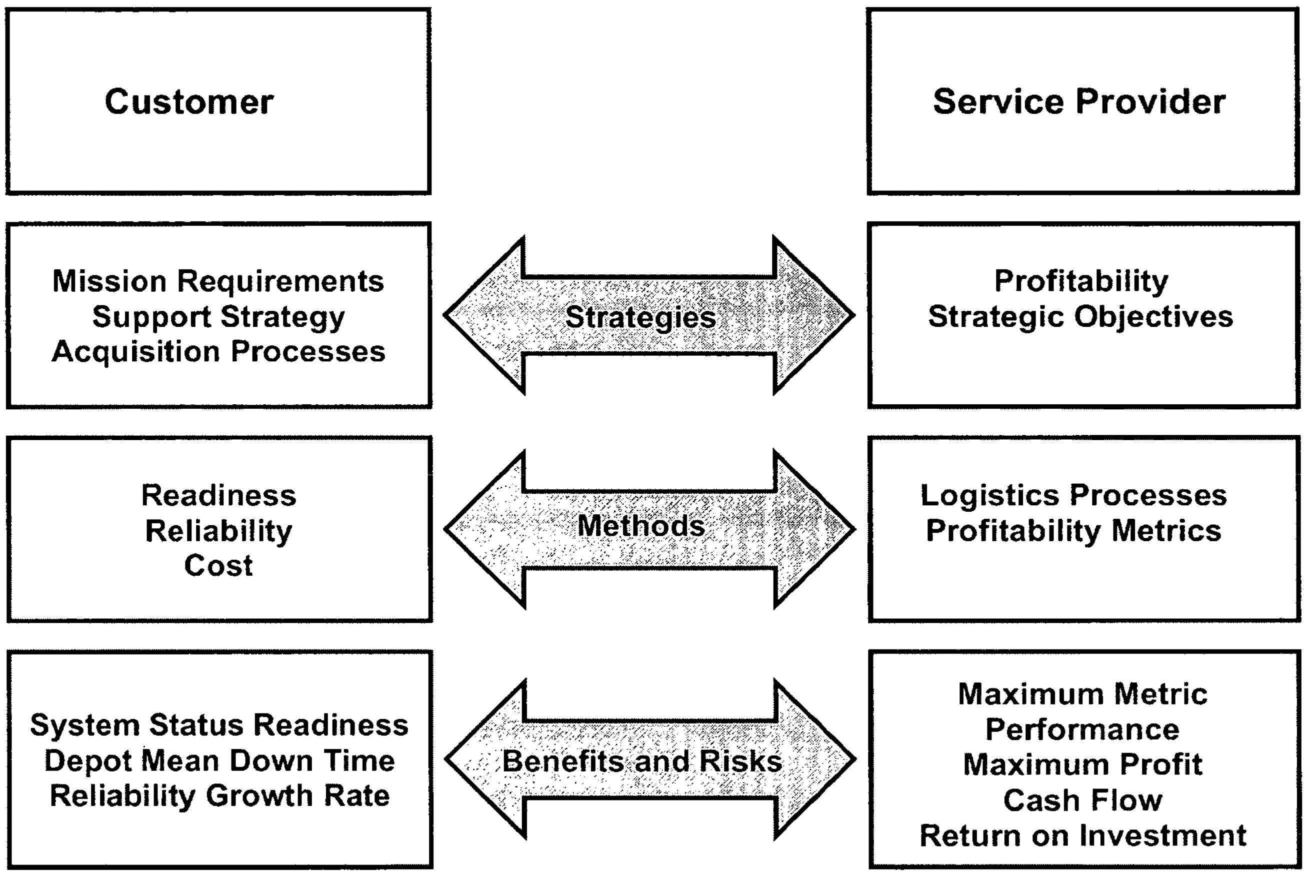

Figure 1. Theoretical Perspectives in a Performance-Based Logistics Context. Adapted from "Measurement Issues in Performance-Based Logistics," by K. Doerr, I. Lewis, and D. Eaton, 2005, *Journal of Public Procurement*, 5, pp.171.

Silva and Disano (2007) suggested requirements definitions may be defined with increased performance characteristics maturity. In the case study, nine performance characteristics were considered important maturity matrix inclusion (Silva & Disano, 2007) for defining outcome-based performance requirements. The categories were performance definition, performance achievement, organizational mechanics, information management, value chain integration, process innovation, product improvement, critical management capability, and financial management. A maturity model was used to identify weaknesses to administrators developing outcome-based performance requirements such as performance-based logistics.

Performance definition was a category used by Silva and Disano (2007) to describe the ability for acquisition professionals and user representatives to align outcome to strategic objectives and mature characteristics synchronize performance outcome with objective requirements. Rodriguez-Candela (2007) suggested that ill-defined contract requirements demonstrated less mature methods and led to implementation failures for performance-based logistics support strategies. Randall, Pohlen, and Hanna (2010) described mature performance definitions as processes required to obtain profitability, regardless of increasing product performance and reliability. Murphy and Beach (2010) suggested mature performance definitions described the ability to obtain the best value for a solution to a problem. Murphy & Beach (2010) also suggested using analytical tools such as matrices and models to identify best value and incorporated a top-down approach for strategic planning.

Organizational alignment and stakeholder perspectives were used to reinforce strategic objectives, defined the culture, and developed business models (Vitasek &

Geary, 2008). Organizational alignment described the process to flow top-level objectives to the lowest resource elements. Vitasek and Geary (2008) determined resistance to implementing performance-based logistics existed because the lower echelons did not realize the benefits of the strategy.

Spring and Araujo (2009) emphasized a business model alignment within the context of providing nondefense related services such as automotive painting, shifted from production, to performance; in example, quantities of automotive paint produced shifted to quantities of autos painted. A shift also drove innovative design, such as improvements in painting applications to use as little automotive paint as possible and still painting as many autos as possible. Chance (2010) revealed organizations with limited experience with performance-based logistics failed to align business objectives and failed to use industry best practice to accelerate the development of their business model.

Silva and Disano (2007) described mature characteristics for achieving performance using profit-centric measurements for incentivizing the service provider to meet the level of performance desired. Rodriguez-Candela (2007) also suggested the use of metrics to incentivize performance; however, mature approaches were demonstrated when multiple metrics were used to prevent situations when monetary awards for minimal performance achieved maximum profit existed.

Randall, Pohlen, and Hanna (2010) suggested that mature levels of performance achievement were demonstrated when the service provider flowed performance requirements to downstream suppliers. Similar to obtaining performance achievement, Randall, Pohlen, and Hannah (2010) suggested both upstream and downstream supplier network relationships were important for demonstrating maturity in organizational mechanics and value chain integration. Silva and Disano (2007) described mature organizational mechanics as organizations with senior managers focused on process improvement and employee empowerment, and limited the use of stovepipe departments to meet the organizational objectives. Barber (2008) reported mature organizations had managers who continuously changed their people, processes, and procedures to sustain organizational value.

Commensurate with Silva and Disano (2007), information management were methods used with more mature processes to communicate information internally and externally across multiple integrated systems. Barber (2008) suggested productive information management systems were used to show the linkage to strategic objectives, models, communicated success, and risk. Spring and Araujo (2009) reported full integration of information technology was established when a network infrastructure could be used to exhibit how transactions occurred, how models interacted, and a capabilities assessments could be made from the information.

Barber (2008) suggested that managers who focused on sustaining organizational value chain made continuous changes to the organization and constantly improved the product performance. Kobren (2009) stated that performance-based logistics required innovation-oriented approached in lieu of traditional lifecycle support. Innovative concepts included public-private partnering to share the risk of facilities investment; a financial construct designed to incentivize service suppliers minimized cost and used best value approaches to maximize operational readiness; added increased reliability, maintainability, while reduced obsolescence (Kobren, 2009).

Silva and Disano (2007) described mature critical capabilities management processes had robust processes and were proactive. Plumer (2010) suggested customer satisfaction was positively correlated to cost and schedule control as well as the ability to predict future performance. In a performance-based logistics context, critical capabilities management was essential when the customer was not informed of poor program performance in time to apply corrective measures. Poor program performance may be caused by scope requirements changes and the inability for managers to control the scope change. In example, technology improvements had been ineffectively implemented in time (Plumer, 2010), requiring a reactive critical capabilities solution.

The final performance characteristic to Silva and Disano's (2007) case study was financial management. A mature financial management system had processes, tools, and procedures used by managers to understand the factors driving cost into the value chain. The more mature systems had an earned value management system for providing the framework to managers to understanding cost and early warnings of problems (Kim, 2007). Kuehn (2007) suggested that when comprehensive program planning used earned value management during the planning phase of a project, costs were better controlled and scheduled delays were more easily communicated to customers using quantitative measurements.

Jones and Zsidisin (2008) reported that more than 70% of a major acquisition program total ownership costs were associated with life cycle sustainment, leaving 30% of the cost accrued during the research, development, and procurement activities. As sustainment costs increased, budgetary constraints challenged fleet modernization. Dr. Jacques Gansler, former Under Secretary of Defense for Acquisition, Technology, and

Logistics described fleet modernization challenges as a death spiral. Specifically he defined a death spiral as:

> A situation where reduced readiness requires us to keep moving more and more dollars from equipment modernization and putting it into daily O&M [Operations & Maintenance], thus further delaying modernization, causing the aging equipment to be over-used, further reducing readiness, and increasing O&M – a vicious circle. (Kobren, 2009, pp. 256)

The integration of systems engineering also increased product reliability through analysis such as Failure Mode Effects and Criticality Analysis, and Fault Tree Analysis (Nowicki, 2008). Implementation of reliability improvements facilitates on-site support to perform system upgrades and field training, increased system operational availability because the sustainment activities were performed at the equipment's current location instead of moving them to centralized repair or modification facilities (Nowicki, 2008). Performance-based logistics system-based inventory models were used to reduce the cost of sparing through a focus on repairs rather than spares.

Performance-based logistics inventory management was used to leverage supplier-owned inventory spares rather than government-owned. Randall, Pohlen, and Hanna (2010) suggested managers for performance-based logistics providers analyzed current organizational processes, infrastructure capabilities, relationships with suppliers, employee skills, and knowledge to understand weaknesses that inhibit effective solutions to the performance-based logistics framework. A reduction in transactional costs for sustaining the service performance benefitted the customer; however, transactional costs for contracting to industry considered contracts management, negotiation, and performance monitoring (Doerr, et. al., 2005).

Melese, Franck, Angelis, and Dillard (2007) suggested that defense contractors increased opportunistic behaviors as components, locations, and service specificity isolated their competitors. Opportunistic behavioral changes monopolized the scope of work, losing affectivity with best practice and best value, normally realized with competitive procurement (Melese, et. al., 2007). Cipicchio (2008) and Fowler (2008) asserted performance-based logistics transferred transaction costs for spares replacement for an investment in improved reliability and life cycle cost reduction. This approach was used to place a focus on maintaining a system's readiness level through reliability improvement instead of levels of spare parts as well as component obsolescence management, keeping inventory levels at cost efficient levels.

Villanueva (2009) suggested management software can be used to model enhanced performance-based logistics capabilities to increase an organization's performance in supplying performance-based services and allows managers to focus the reliability aspect of total cost of ownership. Software was used to model multi-indentured, multi-echelon scenarios (Nowicki, Kumar, Studel, &Verma, 2008) to determine the most cost effective system configuration for spare parts and consumable items to achieve the performance target. Owings (2010) suggested periodic reviews and model assessments for performance-based logistics metric was used to increase the efficiency of providing life cycle support services. Modeling the optimal quantity of spare parts to meet the performance objectives enhanced the managers' ability to make provisioning decisions to sustain the desired performance level using multi-objective problem solving to optimize performance levels (Villanueva, 2009).

Vitasek and Geary (2008) stated scholars at the University of Tennessee had benchmarked 24 Department of Defense performance-based logistics programs. The study suggested that four principal factors were instrumental to the successful implementation of performance-based logistics. The factors were business-partnering commitments, similar interests, contractual structure, and management for performance (Vitasek & Geary, 2008). This study also identified 15 attributes to successful implementation of performance-based logistics. These attributes included performance definition; performance measurement; performance-based logistics knowledge base; organizational alignment; risk alignment; stakeholder perspectives; work scope; workload allocation; workload flexibility; supply chain integration; contract length; contract type and terms; performance incentives; financial enablers; and product and process improvement.

Vitasek and Geary (2008) described performance definition as the customer requirements to meet a readiness level. Sols, Nowicki, and Verma (2007) described defining criteria for system readiness and effectiveness was essential to satisfy government requirements for high-cost life cycle product support for long-term defense weapons systems. Performance metric agreements for the levels of performance desired and the monetary incentive to achieve the performance must also align the performance definition (Sols, Nowicki, & Verma, 2007). Silva (2007) described the performance definition as desired outcomes.

Performance measurements were used to incorporate methods and techniques to develop and measure performance-based logistics metrics (Vitasek & Geary, 2008). Rodriguez-Candela (2007) indicated considerable attention to the development of metrics to ensure the metrics represented effectiveness of the services provided and established a significance weighting. Kim (2007) suggested the accuracy of metrics was critical to risk management. Vitasek and Geary (2008) described the performance-based logistics knowledge base as a key fundamental to successful implementation. The basis included previous experience, management systems, and business models capable of supporting the strategy. Randall, Pohlen, and Hanna (2010) asserted skills and knowledge was value-added toward implementation and was competitively advantageous because the value included cost savings and lower risk.

The performance-based logistics strategy was used to transfer risk from customer to the service provider delivering the performance on firm fixed price contracts (Nowicki, 2008). Melese, Franck, Angelis, and Dillard (2007) suggested a direct relationship with complexity, cost, and risk. As the complexity for a system level support effort increased, the cost, and risk proportionally increased (Melese, et.al., 2007). Vitasek and Geary (2008) disclosed risk alignment employed organizational acceptance of risk and flowed risk to levels of the organization for implementation of the appropriate mitigation strategies. Effective acceptance of risk included a comprehensive understanding of the work scope and levels of services provided. Vitasek and Geary (2008) revealed risk mitigation was shared throughout the organization by various risk-level dependent authority levels. Risk transferred to subcontractors was an effective mitigation strategy (Melese, et.al., 2007).

Vitasek and Geary's (2008) research maintained workload allocation and flexibility were critical attributes to effective implementation of performance-based logistics. Performance metrics were used to identify the objective requirements for the outcome expected from the customer; however, the nature of performance-based logistics provided the service provider with the methods to achieve the requirements. Vitasek and Geary (2008) also asserted work sharing through depot-industry collaborations effectively distributed work to decrease lead-time and reduced cost. Owings (2010) suggested depot partnering reduced risk to the contractor because the depots already invested the infrastructure necessary for some of the work scope.

Supply chain integration methods included optimization for modeling, asset visibility, and availability (Nowicki, 2008), whereas shorter lead-time required less capital investment for quantities of spares to maintain the minimum safety stockage levels necessary for system readiness. Lead-times and failure rates were used to determine adequate quantities of spare parts and reorder points. Kim (2008) suggested employing model maturation factors of lead-time, replenishment, delivery rates from suppliers, meantime between failures, shipping, and transportation cycle times throughout the life cycle of the system. Kim (2008) suggested uncertainty and risk was reduced as the model matured. Supply chain integration, as reported by Kim (2008), was used to integrate risk and organizational alignment as decentralized management decision-making occurs during periods of uncertainty. Vitasek and Geary (2008) asserted product improvements increased reliability, while process improvement decreased the time and cost associated with servicing the component.

As the contract length extended and the contract type changed from cost reimbursable to firm-fixed price, the defense contractor was more likely to make significant investments in infrastructure and risk acceptance because the contractor believed the investment costs would be recovered during the contract period of performance (Melese, Franck, Angelis, & Dillard, 2007). Defense contractor investments reduced cost to the customer; however, increased the risk of monopolization as component and infrastructure specificity increases. Sustaining a performance-based logistics strategy via a cost reimbursable-type contract shared the risk of sparing model immaturity if the supported system or technology was new and unproven (Owings, 2010).

Devries (2005) determined that barriers to implementing an effective performance-based logistics system included a lack of available funding, regulatory guidance, training, infrastructure, technical data, incentives, and cultural impediments. Effective implementation benefited from industry best practices and improvements in supply chain management (Devries, 2005). Effective implementation of performance-based logistics begins during establishment of the performance-based agreement to determine performance requirements (Torcomian, 2008).

Scope analysis, organizational processes, and controls integrated program planning within established performance requirements. Integration steps also required a cost analysis to determine the sustainable cost of achieving the required performance levels prior to entering a performance-based logistics type of agreement (Kim, 2007). Performance-based logistics implementation within the trucking industry caused service providers to focus on performance, reliability, and maintainability to achieve profitable margins, which was similar to the defense-based approach for performance-based logistics contracts (Torcomian, 2008).

Performance Incentives

Performance incentives and financial enablers were benefits of performance-based logistics. Rodriguez-Candela (2007) reported profitability incentivized contractors to exceed desired performance levels. Penalty zones had a positive effect on system performance because the loss of profitability also incentivized the service provider to focus on process and component reliability improvements to minimize the risk of profit loss resulting from possible penalties (Rodriguez-Candela, 2007). Incentivizing contractor performance affected cultural and organizational behavior (Vitasek & Geary, 2008). Kim (2008) asserted penalties served as an effective motivator to increase the contractor's attention to issues. The effects of motivation included faster management-decision making, faster forecast modeling, and increased component reliability rates.

Managers who successfully employed performance-based logistics received compensation and incentive awards for providing the support (Rodriguez-Candela, 2007). Monetary awards incentivized defense contractors to achieve or exceed performance objectives in a performance-based logistics context (Kim, 2008). Conversely, a failure to achieve performance metrics provided negative reinforcement and monetary penalties for the inability to maintain a minimum performance threshold desired by the customer. Kim (2008) researched penalties for poor performance tied to system availability. His research reported induced rapid problem solving minimized downtime, established frequency, and type of failure monitoring techniques to improve the results.

Kautz's (2009) perspective of an economic theory of incentives described the agent-principal relationship. The agent was responsible for the production of the incentivized output, while the principal had ownership of the output (Kautz, 2009). In modeling this relationship, a certain amount of work was determined to establish a performance threshold. The incentive was derived from a calculation of value for the level of performance exceeded, which the agent and principal had agreed. The value was paid to the agent in periodic increments.

In the context of incentivizing for performance-based logistics, the agent, AAI Corporation for the Shadow 200 unmanned aircraft system, was the supplier responsible to maintain system availability or other performance-based logistics metrics, and the government realized the benefits from the exceeded metrics (Owings, 2010). The agreement was the contract, which included quantitative incentive criteria for determining value for exceeding the performance-based logistics metric performance thresholds. The incentive was paid based upon quarterly scoring conferences.

The flexibility in performance-based logistics provided the defense contractor with the ability to determine the methodology for fulfilling the performance objectives to achieve the incentive (Kim, 2007). Incentives were used to motivate the defense contractor to improve methods of managing reliability improvement, inventory levels, and on-site support. Nowicki (2008) suggested defense contractors used higher skilled technicians to perform more repairs, which reduced spare parts, decreasing overhead costs for stocking inventory and shipping replacement components. The additional cost of using highly skilled technicians offset the reduction in inventory levels as well as improved system availability rates.

The defense contractor burdened the risk to balance the methodology of implementing performance-based logistics to maximize incentive awards. The incentive from the government to the defense contractor, as an agent-principal relationship, depended upon the level of performance met or exceeded. Factors such as environmental effects may have caused variation in component failure rates and fluctuated predictive failure analysis for new components or supply chain, thus adversely affected the organization's profitability for maintaining the metric (Kim, 2007).

Forecasting

When the outcome was variable and uncertain, the ability to predict future program performance using tools for cost, scope, and schedule performance enhanced management decision-making (Kim, 2008). Managers used earned value management had a deterministic approach to forecasting program cost and schedule performance; however, earned value management was based on the assumption that future performance would be identical to past performance (Lukas, 2008). Past-performance did not adequately predict future performance or early warning indications if future performance changes because of management decision-making (Kim, 2007).

Contrary to Kim's (2007) and Stratton's (2007) research, Fleming and Koppelman (2006) determined the cost performance could be identified within ±10% for the remainder of the project, once the project was at the 20% completion point. Stratton (2007) and Kim (2007) reported a project's cost and schedule performance could be determined as early as 15% into a project, while Stratton (2007) suggested at 66% of completion, earned value schedule performance metrics became unreliable.

In the context of performance-based logistics, ambiguous logistical support to maintaining a performance metric such as operational readiness required managers to stray from an earned value management baseline plan. Earned value methods, such as level of effort, was used to manage tasks based upon the ambiguity and flexibility required to meet the requirements of maintaining performance-based logistics metrics. Level of effort did not measure differences in schedule variance and the SPI is constantly at 1.0, even if the task were behind schedule (Stratton, 2007). Therefore, earned value management had limitations in providing early warning indications to schedule performance in a performance-based logistics environment with a substantial amount of level of effort (Vandevoorde & Vanhoucke, 2006).

Kim (2007) determined that accuracy was the most important criteria in forecasting and indicated the use of a variety of forecasting methods for the most appropriate method for the situation. Further, Kim (2007) recognized the benefits of using earned value management for cost forecasting, while the critical path method provided improved accuracy in predicting schedule performance. LeBlanc, et. al, (2009) indicated probabilistic forecasting was used to identify a prediction range as an interval around an estimated forecast. Early forecasting and management decision-making was used to ensure supply chain availability when unpredictable future conditions exist with long lead items.

Lukas (2006) asserted some barriers to accuracy in program forecasting and estimation that included deficiencies during the initial phases of defining scope, problematic communications, unrealistic customer expectations, and excessively optimistic program management team. Immature or nonexistent processes within the earned value management system contributed to inaccurate forecasting and poor practices when applying the scope requirements to a work breakdown structure for estimating and forecasting cost and schedule (Lukas, 2008). Managers using inadequate processes also failed to ensure comprehensive scope planning, while managers using mature processes stated assumptions and out-of-scope exclusions for customer review to mitigate risk of an incomplete scope definition or communications with customer expectations (Lukas, 2006).

Logistics Support Optimization

Nowicki (2008) suggested maintaining the optimal stockage levels of repair component inventory would maximize profitability in a performance-based logistics context. Optimal stockage levels required in-depth analysis of availability, maintainability, and supportability of replacement parts. Nowicki (2008) also indicated analysis models were beneficial to item-based or system-based inventory models. Failures to implement industry best practices for spares provisioning prevented managers from obtaining the fidelity to plan spare parts and incorporate revenue in a performance-based logistics context (Nowicki, Kumar, Studel, & Verma, 2008).

An item-based inventory model was used as a simple approach to take into account frequency of failure, item cost, and replacement lead-time. Item-based models were not used for analysis of component relationships within a system, only the demand of the individual components (Nowicki, 2008). Nowicki, et.al. (2008) indicated multiitem inventory models at multi-echelons minimized cost with operational readiness performance measurements or maximized operational readiness with minimal cost.

Graves (1999) identified the benefits of the item-based inventory model using a weighted average of repair demand, over time, accommodated for a random failure rate. Nowicki (2008) considered two basic methods for item-based inventory models, Economic Order Quantity (EOQ), and stochastic. The EOQ method was used when with assumption that a known and constant failure rate exists, which contrasted Grave's (1999) approach. Establishment of stock replenishment policies in bulk quantity purchasing maintained enough stock to meet demand; however, it also considered the economy of scale in purchasing to minimize cost of procurement. This method was used when it was assumed that capacity was always available to meet the demand (Nowicki, 2008).

A stochastic, item-based model was an elementary form of inventory management (Drzymalski, 2008). Stock replenishment occurred as a one-for-one demand of inventory. The stochastic model was used with the consideration that a random demand rate and repair time existed, which was similar to Grave's approach. This newsvendor-type model was used for a replenishment trigger point, *S*, to order replenishment stock (Nowicki, 2008). Ordering maintained the current inventory level based on trigger points and did not consider varying lead-time or demand (Lu & Song, 2005). In addition, measurements for deterministic lead-times to replenishment derived a minimum stockage policy.

Systems-approach inventory models were used to account for an entire system, inclusive of the sub-components (Kim, 2007). The approach was used when multiple logistical support structures such as facilities and level of repair for sub-components exist. Each military branch supported weapons systems at different echelon supply levels (Kim, 2008).

The US Air Force maintained a two to three tier system, from the depots to distribution centers to installations or depots to installations directly; The US Army maintained a five-tier system to reach the lowest level of maintenance support; The US Navy's approach varied, based on the weapon system, such as submarines (Kim, 2008). Submarines maintained spare parts as a one-tier system. Supply ships supported four-tier levels as distribution centers and depots for other systems (Kim, 2008). Nowicki (2008) suggested using the systems approach concept with next higher echelon tiers to provide the logistical support for sparing and repairs to the subordinate echelons for subsystems. Peer echelon tiers supported as the next higher echelon should the dedicated higher-level echelon not have availability of parts or repair capability (Nowicki, 2008). Kim (2008) identified multiple inventory model requirements were necessary to meet the demand of a systems approach.

Research in systems approach inventory modeling was used to analyze the total cost of ownership from acquisition through complete lifetime sustainability of major and expensive components (Nowicki, 2008). Should these major components fail in the field, they rendered the entire weapon system not mission capable. Factors such as lifetime supplies, cost of development, procurement, and cost of maintaining lifetime inventory levels were considered to determine the system total life cycle cost (Heneveld & Teunter, 1997).

Nowicki, Kumar, Studel, and Verma (2008) developed a spares provisioning model, which was used to evaluate linear, exponential, or step incremental functions of revenue for system level performance-based logistics sustainment using an operational availability performance metric. The model also was used to evaluate minimum revenue thresholds at the minimum availability rates to sustain minimum metric performance, just above penalty levels. The model was used when the assumption of a known failure rate exists as well as known subcomponent repair turnaround times, which was not be valid for new weapons systems (Kim, 2008). An output of the model produced an anticipated operational availability rate and calculated anticipated monetary incentives. Nowicki, Kumar, Studel, & Verma (2008) suggested applying lessons learned for customer-designed performance metrics for defense contractor incentives that allowed maximum profit percentages while still in the penalty zone range of performance.

Optimization for a spares provisioning model required using two independent techniques, mathematical modeling and metaheuristic approaches (Villanueva-Jaquez, 2009). Villanueva-Jaquez (2009) agreed with Nowicki's (2008) mathematical modeling techniques measured supportabity, reliability, and maintainability while focusing on deviations from minimum or maximum objective criteria. Metehueristic approaches had been used to evaluate optimization models from the perspectives of facilities efficiencies; however, these approaches did have advantages when evaluating production, supply chain management, spare parts inventory, and schedule maintenance process improvements from experienced systems (Villanueva-Jaquez, 2009).

LeBlanc, et. al. (2009) determined a lead-time add-on percentage calculation factors demand in a systems approach inventory model when lead-time is significant.

The consideration of a future stockage level at early demand prediction minimized cost and maximized availability of lead-time items to ensure component availability (Nowicki, 2008). LeBlanc indicated the cost benefits of improving forecasting accuracy led to reducing the cost of excess inventory and also minimized idleness of the workforce.

Summary

This literature review was used to focus the investigation of combined implementation of earned value management and performance-based logistics for variable influence between the respective metrics. Lessons learned and industry best practices provide a comprehensive understanding of the complexity of the combined contexts and the challenges to successful implementation. A synthesis of the research establishes the foundation to question if influential relationships develop when earned value management and performance-based logistics coexist. Service support incentive methods determine performance levels and output to life cycle logistical support, effectiveness in forecasting to minimize cost and schedule impacts, and logistics support optimization used to identify inventory models. These may correlate with contractual performance employing earned value management.

Chapter 3: Research Method

A quantitative hypothesis testing methodology comprised of intercorrelation and multiple linear regression to compare data from earned value management and performance-based logistics service contract metrics. Azizian (2011), Plumer (2010), and Stratton (2006) correlated relationships of earned value management with program success and customer satisfaction. Drzymalski (2008), Kim (2007), King (2007), LeBlanc, et.al., (2009), Nowicki, et. al., (2008), Randall, et. al., (2010), Rodriguez-Candela (2007), and Vandevoorde and Vanhoucke (2006) researched the relationships for incentivization, optimization, and model development within a performance-based logistics support sustainment strategy. Previous correlational and statistical hypothesis testing studies were not conducted for examining interdependency of earned value management within the context of performance-based logistics. This study was conducted to test for interdependency between these topics.

Sherman and Rhoades (2010) indicated this problem affects the ability for the Department of Defense to modernize to new weapons systems because of the high cost of sustaining current systems using traditional lifecycle sustainment methods. Executives from the United States Office of Management and Budget addressed this problem through mandates for cost, schedule, and technical integration required in federal programs by 2006 (Visitacion, 2007). Department of Defense personnel also acknowledged issues with implementing earned value management for nonschedule-based service contracts (DoD, 2006). Sherman and Rhoades (2010) also indicated the defense acquisition process was inflexible and used for types of projects, regardless of size. An industry best practice approach may be used to provide flexibility reducing the total ownership costs for operations and maintenance of Department of Defense acquisition programs.

Gronholdt and Martensen (2009) suggested in their correlational study of essential management practices that specific hypotheses in earned value management in a performance-based logistics context could not be obtained because there was a lack of research in these consolidated fields. A benefit of this research was to improve the predictive capabilities and early warning indications of cost and schedule performance for service-oriented programs. Thirty-eight percent of surveyed contractors abandoned earned value management reporting at the 80% project completion mark because of the inability to predict remaining cost and schedule performance using earned value management (Templin & Christianson, 2003). Multiple linear regression was used to provide modeling indications for product performance in the performance-based logistics environment associated with earned value management metrics.

Research Questions

The research questions addressed in this study were concentric to understanding the relationships between earned value management and performance-based logistics metrics. The outcome variables of SPI and CPI will be assessed against the multi-dimensional predictor variables performance of ORR, RGR, and DMDT (Owings, 2010). Earned value management metrics do not provide managers with the ability to evaluate the technical scope performance in a performance-based logistics environment. Questions relevant to the outcome and predictor variables provided the basis for collecting data to examine the interactions for predictions to lifecycle support with program cost and schedule performance metric data (Kim, 2007).

Q1: To what extent, if any, is the relationship between Operational Readiness Rate and a Schedule Performance Index correlated?

Q2: To what extent, if any, is the relationship between Operational Readiness Rate and a Cost Performance Index correlated?

Q3: To what extent, if any, is the relationship between Reliability Growth Rate and a Schedule Performance Index correlated?

Q4: To what extent, if any, is the relationship between Reliability Growth Rate and a Cost Performance Index correlated?

Q5: To what extent, if any, is the relationship between Depot Mean Downtime and a Schedule Performance Index correlated?

Q6: To what extent, if any, is the relationship between Depot Mean Downtime and a Cost Performance Index correlated?

Q7: Do the performance-based logistics metrics of Operational Readiness Rate, Reliability Growth Rate, and Depot Mean Downtime have an effect on earned value metrics of Cost and Schedule Performance Indices?

Q8: Is there an interaction effect between the earned value metrics of Cost and Schedule Performance Indices?

Hypotheses

$H1_0$: There is no significant correlation between Operational Readiness Rate and a Schedule Performance Index.

$H1_1$: A significant correlation exists between Operational Readiness Rate and a Schedule Performance Index.

$H2_0$: There is no significant correlation between Operational Readiness Rate and a Cost Performance Index.

$H2_1$: A significant correlation exists between Operational Readiness Rate and a Cost Performance Index.

$H3_0$: There is no significant correlation between Reliability Growth Rate and a Schedule Performance Index.

$H3_1$: A significant correlation exists between Reliability Growth Rate and a Schedule Performance Index.

$H4_0$: There is no significant correlation between Reliability Growth Rate and a Cost Performance Index.

$H4_1$: A significant correlation exists between Reliability Growth Rate and a Cost Performance Index.

$H5_0$: There is no significant correlation between Depot Mean Downtime a Schedule Performance Index.

$H5_1$: A significant correlation exists between Depot Mean Downtime and a Schedule Performance Index.

$H6_0$: There is no significant correlation between Depot Mean Downtime and a Cost Performance Index.

$H6_1$: A significant correlation exists between Depot Mean Downtime and a Cost Performance Index.

$H7_0$: The Operational Readiness Rate, Reliability Growth Rate, and Depot Mean Downtime have no significant multivariate main effects for Cost and Schedule Performance Indices.

$H7_1$: The Operational Readiness Rate, Reliability Growth Rate, and Depot Mean Downtime have significant multivariate main effects for Cost and Schedule Performance Indices.

$H8_0$: There is no significant interaction effect between the earned value metrics of Cost and Schedule Performance Indices.

$H8_1$: There is a significant interaction effect between the earned value metrics of Cost and Schedule Performance Indices?

This chapter substantiated the research method and design. A description of the population was provided to estimate size and relevant characteristics of the research as well as to identify explain selection of participants. Materials and instruments were provided, describing constructs measured and evaluative properties to address reliability and validity. Operational definitions of variables were defined for the purpose of this study. The study data collection, processing, and analysis procedural steps was explained for consistency in repeatability. This chapter included a coding scheme and software used for the statistical analysis. An explanation of the methods, limitations, and delimitations was used to present the assumptions about the population and design. Finally, the chapter concludes with ethical assurances that were used during this research.

Research Method and Design

A quantitative research methodology was used in this study. A correlational study using correlation analysis and multiple linear regression was appropriate for understanding interdependency to improve the predictive capabilities and early warning indications of cost and schedule performance for service-oriented programs within the context of earned value management and performance-based logistics. Intercorrelations, regression, and Mann-Whitney testing were used to examine two factors from the outcome variables with three levels of predictor variables to test for variable interaction. Both outcome and predictor variables were measured on an interval scale and statistically tested (Black, 1999). The total population of earned value and performance-based logistics metric data for the Shadow 200 unmanned aircraft system was available with earned value management metrics to manage program cost and schedule performance in relation to the effects on technical scope performance metrics in the performance-based logistics context. Nowicki (2008) suggested conducting research to address the extent of interdependency that exists between earned value management and performance-based logistics service contracts. The data were tested using multiple linear regression to develop a predictive capabilities model from predictor variables to the outcome variables. The quantitative characteristics of observation and collection of statistical data for the data population provided the structure necessary for timely data analysis as well as demonstrated external validity when generalizations to larger populations were developed (Vogt, 2007). The selected hypotheses for each research question were determined from the statistical test results.

Since 2004, the Shadow 200 unmanned aircraft system used performance-based logistics and earned value management to sustain the product lifecycle (Owings, 2010). This correlational design was a cost-effective method of analyzing the data because the variable data was available from the historic longevity of the program. A census of the data was available for random sampling to statistically to test the outcome and predictor relationships. A data validity evaluation was performed to remove nonsampling errors. The use of census data from the entire population eliminated sampling errors or bias.

The continuous-scaled outcome variables of CPI and SPI were analyzed to perform a measurement of association with the predictor variables to determine the amount of covariance. The predictor variables were tested using intercorrelation and multiple linear regression analysis to determine the relationship between predictor and output variables. The test results were analyzed for significance between predictor interactions and between predictor-to-output variable relationships. High or low probability of linear covariance as well as direct versus inverse direct correlation to the outcome variables was analyzed. A lack of significant relationships determined during multiple linear regression analysis, using p greater than or equal to α at 0.05 for each variable pair was used to accept each null hypothesis. Significant relationships determined by p, which was less than α at 0.05 for each variable pair was used during multiple linear regression analysis to fail to reject each null hypothesis.

Intercorrelations between each variable pair relationship were derived from the measurement of covariance divided by their variability around the mean value. The covariance, measured by Spearman's coefficient of correlation was used to identify the predictor variable's high versus low probability of correlation with CPI (Y_1) and SPI (Y_2) as outcome variables to the predictor variables for ORR (X_1), RGR (X_2), and DMDT (X_3). The statistical significance detected medium-sized effects. The confidence level was established at α= .05. The statistical power will be set at 0.80, however because of limitations with the available census data, the power varied from 0.57 to 0.99. The scale for the correlation coefficient was from -1.0 to +1.0 with zero indicating there is no correlation between the variables. A positive value indicated a positive correlation between the variable pair, while a negative value indicated an inverse relationship between the variable pair. The coefficient of determination, r^2 was used to determine the magnitude of correlation (Black, 1999) and the proportion that variance in one variable affected the other. A coefficient value from 0.01 to 0.30 was considered as a weak correlation between the variable pair. Values from 0.31 to 0.60 were considered as a medium correlation, and values from 0.61 to 1.0 were considered as strong correlation between the variable pairs.

Multiple linear regression analysis was used to model a predictive relationship of the predictor variables of DMDT, RGR, and ORR. The linear relationships were used as an indicator to predict future cost and schedule performance. Each coefficient was tested during the multiple linear regression analysis in the analysis of variance table produced by Minitab 15 to determine if there is any significance to the relationship. Any coefficient with a *p*-value of less than alpha at 0.05 was considered a significant coefficient in the model. The adjusted R^2 was used determine the predictive capability of the model. The Y_1 or Y_2 represented SPI or CPI as the outcome variable, while X_1, X_2, or X_3 represented the predictor variable of ORR, RGR, or DMDT.

Intercorrelations, regression analysis, and Mann-Whitney testing was used to examine two factors from the outcome variables of SPI and CPI and the three levels of predictor variables from ORR, RGR, and DMDT to test for variable interaction and equality of the means. Because there were multiple observations of each set of predictor-outcome variable pairs with varying quantities of observations, testing to determine variable paired interactions between outcome variables was performed.

Intercorrelations and regression with the three levels and two factors enabled six groups to be examined. The data was not balanced with an equal number of observations within the six groups. The interaction *F* test with a *p*-value of less than alpha at 0.05 was considered a significant. The Y_1 or Y_2 represented the two factors for SPI or CPI as the outcome variable, while the three levels represented as X_1, X_2, or X_3 from the predictor variables of ORR, RGR, or DMDT.

Participants

This study had no human participants. A power analysis was performed, using fixed-predictor models of multiple regression to determine the sample size. G*Power version 3.1.3 was the statistical software used to calculate the *a priori* sample sizes from a linear multiple regression test: fixed model, R^2 deviation from zero (Faul, Erdfelder, Buchner, & Lang, 2009). A medium effect size of f^2 of 0.15 was used. Alpha was set at 0.05 with a power of 0.80 and the three predictors for ORR, RGR, and DMDT were used. The calculation from the input parameters rendered a sample size of 77 predictors should be used for each output variable of schedule and cost performance indices in this research.

Materials/Instruments

The data collection instrument in Appendix C was used to collect the variable data correlating earned value management in a performance-based logistics context. Monthly averaged earned values from SPI and CPI were collected from a monthly financial report, generated from the organizational enterprise resource planning system imported into project management solution software known as Deltek wInsight (White, 2005) software application for the Shadow 200 performance-based logistics program.

Earned value management indices of cost performance were measured against the baselined plan to compare costs to identify areas that fail to meet a required threshold, a 10% variation from the plan or costs, was considered out of control (Kuehn, 2007). The performance-based logistics archival data for ORR, RGR, and DMDT was collected from the monthly scoring table report for the Shadow 200 performance-based logistics program (Owings, 2010). The data range of values consisted of interval scales for both predictor and outcome variables. Appendix C consisted of an original instrument for data collection.

Inferential statistical analysis considering power, effect size, and significance maximized the validity of the instrument's design. A content validity ratio (CVR) analysis was performed to test the instrument. CVR testing occurred prior to data collection and prior to Institutional Review Board approval. To facilitate the CVR analysis, the data collection instrument was reviewed by eight members of a panel, who have at least three years of experience in earned value management and performance-based logistics metric analysis. The panel members were asked to rate each variable pair to determine the validity to the research context. Individual ratings will be coded as essential or nonessential to each research question. The CVR analysis was used to determine if each survey question is valid for the research. The CVR calculation consists of the number of experts (Ne) who found a data pair to be essential as a function of the number of experts (N) on the panel. Based upon a panel of 11 members, a minimum content validity ratio value of 0.59 must be achieved for each variable pair to be accepted as valid for the research. Research question Q1 has a CVR of 0.64, Q2 was

0.82, Q3 was 0.64, Q4 was 1.0, Q5 was 0.64, Q6 was 0.82, Q7 was 0.64, and Q8 was 0.82. The responses to the CVR indicate all eight questions were valid to this research.

Operational Definition of Variables

Cost Performance Index (CPI). The CPI depicted a ratio of the budgeted cost of work performed as a function of the cost of work performed to determine the efficiency of the cost during program execution (PMI, 2009). This index was an evaluative and predictive tool to measure the expected cost performance of a program. A ratio of 1.0 indicated the budget spending is according to the budget plan and therefore, considered to be on budget. A ratio greater than 1.0 indicated the efficiency of budget spending was better than planned and considered under budget. A ratio of less than 1.0 indicated the budget spending efficiency was worse than planned and considered to be over budget. For example, if the earned value for a task was $100, while the cost to complete the task was $110, the ratio would be 0.9. This ratio indicated the task efficiency was less than expected and considered over budget. The CPI was collected from the monthly financial report, exported the organizational enterprise resource system into Deltek wInsight project management software (White, 2005) software application for the Shadow 200 performance-based logistics program. For the purpose of this correlational study, the CPI was an interval-scaled outcome variable. The data collection instrument in Appendix C was used to collect the CPI.

Depot Mean Downtime (DMDT). For the purposes of this study, Depot Mean Downtime depicted a performance-based metric to measure the time in days from component failure to repair or replacement. The metric was a calculation of the repair Downtime, repair logistics time, and maintenance Downtime as a sum of the total time

(US Army, 2009). For example, a failed engine on an aircraft rendered the aircraft system as not mission capable. The failure was not capable of repair on site and required an extensive overhaul. The date of failure was recorded before an unscheduled maintenance action was performed for the removal of the engine and the return to the depot for overhaul. A replacement engine was delivered from an intermediate inventory location within two days and installed on the aircraft. The replacement engine procedure require one day to install plus one additional day for maintenance operational checks. The original non-operating engine was shipped to the depot and arrived three days after failure. The overhaul required 35 days to complete. The overhauled engine was returned to the intermediate inventory location as a spare one-day later. The repair Downtime was two days (one day for installation, and one day for maintenance operational checks). The repair logistics time was two days (two days for delivery from the intermediate inventory location to the aircraft). The maintenance Downtime was 39 days (three days for delivery from the aircraft to the depot, 35 days for the overhaul, and one day for delivery from the depot to the intermediate inventory location). The total time was four days (two days for repair Downtime and two days for repair logistics time). The DMDT metric will be calculated as 10.75 days. The DMDT was collected from the monthly scoring table report for the Shadow 200 performance-based logistics program. For the purpose of this correlational study, the DMDT was a predictor variable. The data collection instrument in Appendix C was used to collect the DMDT metric.

Operational Readiness Rate (ORR). For the purposes of this study, the ORR depicted a performance-based logistics metric to measure the function of the system's availability to perform the designed tasks compared to the expected time available for the system to be operational. The rate was calculated as a total time minus Downtime divided by total time. Referencing the DMDT not mission capable aircraft scenario, the aircraft realized a Downtime of four days (two days for delivery from the intermediate inventory location to the aircraft, one day for replacement engine installation, and one day for maintenance operational checks). The metric is evaluated quarterly or every 90 days. The ORR for this period will be 95.5%. The ORR was collected from the monthly scoring table report for the Shadow 200 performance-based logistics program. For the purpose of this correlational study, the ORR was a predictor variable. The data collection instrument in Appendix C was used to collect the ORR metric.

Reliability Growth Rate (RGR). For the purposes of this study, the RGR depicted a performance-based logistics metric to measure the effects of improvements on the average life expectancy of a component. RGR was used to indicate the decrease in the failure rate of the component through improved system engineering, material design, and training from the failure analysis. The RGR metric calculation consisted of a normalized period, 100,000 hours for aviations systems, multiplied by the number of failures divided by the amount of operational use of the failed component. US Army aviation, mishap categories consist of classification categories A to E. Class A mishaps would include mishaps involving more than $2,000,000 in damage, total aircraft system loss, or loss of life. Class B mishaps were defined as damage in excess of $500,000 but less than $2,000,000, or an injury of three or more people relating to that mishap. Class C mishaps were defined as damage from $50,000 to $499,999, or more than a week of work lost due to personnel injury. Class D mishaps were defined as damage from

$5,000 to $49,999, or personnel injury resulting in restricted work duty or first aid. Finally, class E mishaps were defined as damage of less than $2,000 (De Lorenzo, Freid, & Villarin, 1999). For example De Lorenzo, Freid, & Villarin (1999) suggested that US Army manned aviation class A mishap rates across aircraft systems averaged 1.86 mishaps per 100,000 hours. The RGR was collected from the monthly scoring table report for the Shadow 200 performance-based logistics program. For the purpose of this correlational study, the RGR was a predictor variable. The data collection instrument in Appendix C was used to collect the RGR metric.

Schedule Performance Index (SPI). The SPI depicted a ratio of the budgeted cost of work performed to the budgeted cost of work scheduled. This index was used to evaluate and predict future schedule performance on a program (PMI, 2009). A ratio of 1.0 indicated the schedule performance was executed according to the plan and considered to be on budget. A ratio greater than 1.0 indicated the schedule performance was better than planned and considered to be ahead of schedule. A ratio of less than 1.0 indicated the schedule performance is worse than planned and considered to be behind schedule (Lukas, 2008). For example, if the earned value for a task was $100, while the planned value to complete the task at the same given period was $80, the SPI would be 1.25. This ratio indicated the task was not performed within the timeframe planned and was considered behind schedule. The SPI was collected from the monthly financial report, exported the organizational enterprise resource system into Deltek wInsight project management software (White, 2005) software application for the Shadow 200 performance-based logistics program. For the purpose of this correlational study, the SPI was an interval-scaled outcome variable

Data Collection, Processing, and Analysis

The data collection instrument for this quantitative correlational research was used to compile the data from two formal contractor-to-government submittal reports The data range of values consisted of interval scales for both predictor and outcome variables. Appendix C consisted of an original instrument for data collection. The CPI and SPI outcome variable data was collected from wInsight. The six-period summary data report was used to export the cumulative to date CPI and SPI for the Shadow 200 performance-based logistics program. The wInsight software formatted the monthly contract deliverable cost performance reports in accordance with data item description DI-MGMT-81466A (Johnson, 2006). Data collection for the predictor performance-based logistics variables for ORR,RGR, and DMDT data were retrieved from the monthly scoring table report for the Shadow 200 performance-based logistics program (Owings, 2010). The Army's integrated logistics support metrics policy required monthly scoring reports for developing performance outcomes (US Army, 2009). Owings (2010) suggested data requirements for this report in contractor format have been used since 2004 in accordance with the Shadow 200 performance-based logistics sustainment contract with the US Army Unmanned Aircraft Systems Project Office.

The data collection instrument in Appendix C was used to record the values. Monthly performance values for CPI and SPI was exported from the wInsight six-period summary into the data collection instrument. The collection instrument also was used to retrieve the values for ORR, RGR, and DMDT metrics from the Shadow 200 monthly scoring report.

Minitab version 15 was used as the statistical analysis software tool. The data from Appendix C was imported into Minitab's worksheet with each column representing a variable for the corresponding monthly period. Minitab's correlation, regression, and multiple regression were produced for each outcome-predictor variable pair and predictor variables combined to identify outliers that may affect the correlation coefficient (Hendersen, 2007). Correlation tests were performed to determine the type of relationship as well as association. Regression and multiple linear regression analysis was used to determine the covariance of distribution of the ORR, RGR, and DMDT predictor variables combined to the outcome variable of SPI or CPI to develop a predictive model. The regression model produced a predictor coefficient for each predictor variable independently and combined with all three predictor variables. Each coefficient was examined for significance to the outcome variable using the *p*-value compared to alpha. A *p*-value of less than alpha indicated the predictor has a significant effect on the other predictor variables or the outcome variable.

To address research question (Q1), to what extent is the relationship between ORR and a SPI correlated, the ORR data was compared to the SPI values. A correlation test within SPSS version 16 was exercised to determine Spearman's rank order correlation as well as the magnitude and type of correlation (Black, 1999). A two-tailed test was used to validate the correlation. The confidence level was established at $\alpha = .05$ and the degrees of freedom is N-2. Linear regression analysis was used to analyze the variance and data normality. The ORR predictor coefficient was examined for significance to the SPI outcome variable using the *p*-value compared to alpha. A *p*-value of less than alpha will indicated the predictor had a significant effect on the outcome variable. A regression model was examined to determine if any predictive attributes exist between the variable pair.

To address research question Q2, to what extent, if any, is the relationship between ORR and a CPI correlated, the ORR was compared to the CPI values. A correlation test within SPSS was exercised to determine Spearman's rank order correlation as well as the magnitude and type of correlation (Black, 1999). A two-tailed test was used to validate the correlation. The confidence level was established at $\alpha = .05$ and the degrees of freedom is N-2. Linear regression analysis was used to analyze the variance and data normality. The ORR predictor coefficient was examined for significance to the CPI outcome variable using the p-value compared to alpha. A p-value of less than alpha will indicated the predictor had a significant effect on the outcome variable. A regression model was examined to determine if any predictive attributes exist between the variable pair.

To address Q3, to what extent, if any, is the relationship between RGR and a SPI correlated, the RGR was compared to the SPI values. A correlation test within SPSS was exercised to determine Spearman's rank order correlation as well as the magnitude and type of correlation (Black, 1999). A two-tailed test was used to validate the correlation. The confidence level was established at $\alpha = .05$ and the degrees of freedom is N-2. Linear regression analysis was used to analyze the variance and data normality. The RGR predictor coefficient was examined for significance to the SPI outcome variable using the p-value compared to alpha. A p-value of less than alpha will indicated the predictor had a significant effect on the outcome variable. A regression model was examined to determine if any predictive attributes exist between the variable pair.

To address Q4, to what extent, if any, is the relationship between RGR and a CPI correlated, the RGR was compared to the CPI values. A correlation test within SPSS was exercised to determine Spearman's rank order correlation as well as the magnitude and type of correlation (Black, 1999). A two-tailed test was used to validate the correlation. The confidence level was established at $\alpha = .05$ and the degrees of freedom is N-2. Linear regression analysis was used to analyze the variance and data normality. The RGR predictor coefficient was examined for significance to the CPI outcome variable using the p-value compared to alpha. A p-value of less than alpha will indicated the predictor had a significant effect on the outcome variable. A regression model was examined to determine if any predictive attributes exist between the variable pair.

To address Q5, to what extent, if any, is the relationship between DMDT and a SPI, the DMDT was compared to the SPI values. A correlation test within SPSS was exercised to determine Spearman's rank order correlation as well as the magnitude and type of correlation (Black, 1999). A two-tailed test was used to validate the correlation. The confidence level was established at $\alpha = .05$ and the degrees of freedom is N-2. Linear regression analysis was used to analyze the variance and data normality. The DMDT predictor coefficient was examined for significance to the SPI outcome variable using the p-value compared to alpha. A p-value of less than alpha will indicated the predictor had a significant effect on the outcome variable. A regression model was examined to determine if any predictive attributes exist between the variable pair.

To address Q6, to what extent, if any, is the relationship between DMDT and a CPI correlated, the DMDT was compared to the CPI values. A correlation test within SPSS was exercised to determine Spearman's rank order correlation as well as the magnitude and type of correlation (Black, 1999). A two-tailed test was used to validate the correlation. The confidence level was established at $\alpha = .05$ and the degrees of freedom is N-2. Linear regression analysis was used to analyze the variance and data normality. The DMDT predictor coefficient was examined for significance to the CPI outcome variable using the p-value compared to alpha. A p-value of less than alpha will indicated the predictor had a significant effect on the outcome variable. A regression model was examined to determine if any predictive attributes exist between the variable pair.

To address Q7, do the performance-based logistics metrics of ORR, RGR, and DMDT have an effect on earned value metrics of SPI and CPI, the ORR, RGR, and DMDT covariates was compared to the SPI and CPI values. Correlation and regression testing was used to test the predictor variables of ORR, RGR, and DMDT to determine significant effects to the outcome variables of SPI and CPI. The predictor variables for ORR, RGR, and DMDT formulated a two-factor, three-level unbalanced design. The design is unbalanced because there will be an unequal number of ORR, RGR, and DMDT predictors observations. Each column from the data collection instrument in Appendix C represented the factors for ORR, RGR, and DMDT. Each row was used to identify the month of each observation. The confidence level was established at $\alpha = .05$. Minitab 15 was used to analyze the data's normalcy, independence and equality of variance. The predictor variables were examined for significance to the SPI and CPI outcome variables using the *p*-value compared to alpha. Any factor with a *p*-value of less than alpha will indicate the predictor has a significant effect on the outcome variables. The null hypothesis was rejected if any of the predictor factors indicated a significant effect to the outcome variables.

To address Q8, is there an interaction effect between the earned value metrics of SPI and CPI? Correlation and Mann-Whitney testing was used to test the predictor variables of ORR, RGR, and DMDT to determine significant interactions between to the outcome variables of SPI and CPI. Correlation and Mann-Whitney testing tests within Minitab was exercised. The predictor variables for ORR, RGR, and DMDT formulated a two-factor, three-level balanced design. The design was unbalanced because there will be an equal number of ORR, RGR, and DMDT predictor observations. Each column from the data collection instrument in Appendix C represented the factors for ORR, RGR, and DMDT. Each row was used to identify the month of each observation. The confidence level was established at $\alpha = .05$. Minitab 15 was used to analyze the data's normalcy, independence and equality of variance. The interaction between outcome variables of SPI and CPI will use the *p*-value compared to alpha. Any factor with a *p*-value of less than alpha will indicate the predictor has a significant effect on the outcome variables. The null hypothesis was rejected if any of the predictor factors indicate a significant interaction between the outcome variables

Methodological Assumptions, Limitations, and Delimitations

The predictor variable data was evaluated quarterly by managers from two qualified organizations, the contractor and the government, and therefore, was assumed to be reliable. Owings (2010) suggested the performance-based logistics metric data quality was assumed high, based on employment of consistent methods of fee-based performance measurements from 2004 to 2010. The experience level that managers have with performance-based logistics metric collection techniques was assumed sufficiently high for this program without problems associated with inexperience.

The outcome variable data was assumed to be reliable and accurate because the calculations and processes used were compliant with the government data item description, DI-MGT-81466A as well as compliant with the organizational earned-value management system description. The experience level that managers had with earned value management metric development techniques was assumed sufficiently high for this program without problems associated with inexperience.

Limitations. The data for the research consisted of census data for the Shadow 200 performance-based logistics program from 2004 to 2011. The study was not intended to be applied to variable pair relationships for other programs or populations. The research assumptions associated with this data were not extended to other performance-based logistics programs or other defense programs.

Potential threats to validity internal for this research included variation of management personnel, variation with individual projects contributing to the performance-based logistics program, decision-making, and number of aircraft systems supported throughout the duration of data collection. There may be variation between each fiscal contract year for the predictor variable criteria. There may be outliers within the data population, which may have skewed the correlation factors.

Delimitations. The data collected were delimited to the 2004 to 2011 fiscal contract year's metric data from the Shadow 200 performance-based logistics program. The outcome variable data used for the study was used in a wide variety of defense industry programs, and the predictor variable data may not adequately reflect metric measurements for other defense programs.

Ethical Assurances

Informed consent was not required because there are no human research participants in this study. Lawyers from AAI's legal as well as administrators from the United States Army Aviation and Missile Command Unmanned Aircraft System Project Office have provided written authorization to use the data for this research. The approval documentation was provided in Appendix B. The authorized use of data is limited to the averaged monthly values for the earned value indices of SPI and CPI and the ORR, RGR, and DMDT performance-based logistics metrics. Because no industry or government sponsorship supports this research, there was no influence for specific data sampling selections. The statistical testing was conducted on a laptop computer, causing no harm to any person or property. Institutional Review Board approval was obtained prior to any data collection.

Summary

Earned value management within the context of performance-based logistics data assessed the amount of covariance and predictive attributes. Variable interdependency was explored to provide predictive capabilities and early warning signs to enhance the predictive nature of earned value management employed in a performance-based logistics environment. This chapter consisted of methods for conducting a quantitative correlational study to investigate the relationships between earned value management metrics with performance-based logistics metrics.

Chapter 4: Findings

The purpose of the quantitative correlational study was to explore the relationships between the outcome variables of cost (CPI) and schedule performance indices (SPI) with the predictor variables of Operational Readiness Rate (ORR), Reliability Growth Rate (RGR), and Depot Mean Downtime (DMDT). The interval-level predictor-outcome variable pairs were tested for association using Spearman's rank correlation and modeled using linear regression. A three-predictor multiple linear regression model using ORR, RGR, and DMDT was used to examine the relationships among the three predictors, analyzed concurrently with the outcome variables (Nowicki, 2008). Because two factors of the outcome variables, SPI and CPI were not normally distributed, Mann-Whitney testing was used to examine the effect of the predictor variables of ORR, RGR, and DMDT to the outcome variables (Black, 1999).

The chapter is structured into three sections for the presentation of results. The first section presents descriptive results for each variable. The second section organizes the results of hypothesis testing for each of the eight question and hypotheses. The third section evaluates the findings and provides an inferential analysis from which implications and conclusions may be drawn.

Results

The quantitative focus of the study was to examine the relationships of earned value management metrics with performance-based logistic metrics. Measures of central tendency for SPI, CPI, ORR, RGR, and DMDT were analyzed as shown in Table 2. The predictor and outcome variables were collected as archived data from the Shadow 200 performance-based logistics program. Variations in observations existed for the number of observations for ORR, RGR, and DMDT as monthly data were recorded to comply with contractual requirements.

Table 2

Descriptive Analysis for Predictor and Outcome Variables

Variable	*n*	*M*	*Median*	*SD*	Anderson-Darling *p*-Value
SPI	88	1.005	1.008	0.086	< 0.005
CPI	88	1.126	1.094	0.168	< 0.005
ORR	88	95.303	96.650	3.941	< 0.005
RGR	70	55.904	51.898	29.829	< 0.005
DMDT	50	68.903	71.000	11.385	0.013

Observations for SPI, CPI, and ORR comprised of the census data from the beginning of the Shadow 200 performance-based logistics program when earned value management metrics were recorded. The RGR metric was not recorded as a metric until a Shadow 200 performance-based logistics program requirement was created in May 2006 to track the operational performance of the system. There were 50 monthly observations for DMDT from January 2008 through February 2012. The DMDT metric was not recorded as a metric until a Shadow 200 performance-based logistics program requirement was created in January 2008 to track the return and refurbishment of repairable spare parts for the system. There were no missing observations.

Data distribution. The Anderson-Darling test for normality of distribution for DMDT (p=0.013) and SPI, CPI, ORR, and RGR (p<0.05) concluded the data distribution was not normal. A subsequent distribution goodness-of-fit test was performed in Minitab confirmed the data presented a non-normal distribution; therefore, non-parametric testing was necessary to examine the effect of the predictor variables of ORR, RGR, and DMDT to the SPI and CPI outcome variables.

Correlation analysis. Using Spearman's rank order correlation coefficient (r_s) (p<.05) correlation analysis was performed to determine the variable pair intercorrelations (see Table 3). Spearman's rank order correlation was used as variables were not normally distributed and a monotonic relationship existed between variable pairs (Black, 1999). A correlation value from 0.01 to 0.30 was considered as weak correlation; 0.31 to 0.60 medium; and 0.61 to 1.0 as high correlation between the variable pairs (Black, 1999).

Table 3

Spearman intercorrelations for study predictor and outcome variables

Variable	*1*	*1*	*2*	*3*	*4*	*5*
1. ORR		-	-0.280*	-0.229	-0.212*	0.000
2. RGR			-	0.192	-0.017	0.062
3. DMDT				-	-0.051	0.497*
4. SPI					-	-0.015
5. CPI						-

Note. n=87 (ORR, SPI, and CPI), n=70 (RGR), n=50 (DMDT); *p< 0.05.

Hypotheses 1-6. Three significant correlations were identified from the correlation analysis. A significant correlation was found between ORR and SPI (r_s=-0.212; p=0.048), ORR and RGR (r_s=-0.280; p=0.019), and DMDT and CPI (r_s= 0.497; p<.05).

Hypotheses 7-8. Regression analysis followed the results of correlation to re-examine all predictor-outcome relationship pairs. Regression analysis was used to determine if modeling performance-based logistics metrics with cost and schedule performance metrics in a nonschedule-based program, such as the Shadow 200 program provided enhanced forecasting capabilities rather than earned value metrics of the SPI and CPI (Alvarado, Silverman, & Wilson, 2004). The information used for the regression models in the study comprised of census data from November 2004 through April 2012; therefore, the data set was representative of the population to infer an interpolated prediction from within the dataset. Tables 4 through 11 depict the regression analysis for each research question and corresponding hypothesis.

The coefficient of determination, r^2 was used to determine the proportion of variance that the predictor variable affected the outcome variable (Black, 1999). The r^2 also described how well the regression model represented the data by describing how much of the variation was explained by the model. For the purpose of this study, a r^2 value from 0.001 to 0.240 was considered to have a weak-strength regression model fit and explained between 0% to 24% of the variation between the predictor outcome variable pair. A value from 0.241 to 0.800 was considered to have a medium-strength model fit with 24.1% to 80% of the variation between the variable pair explained. Values from 0.801 to 1.0 were considered to have a strong-strength model fit and explained between 80.1% and 100% of the variable pair variation.

Research Question Q1 and Hypothesis.

Q1. To what extent, if any, is the relationship between Operational Readiness Rate and a Schedule Performance Index correlated?

$H1_0$. There is no significant correlation between Operational Readiness Rate and a Schedule Performance Index.

$H1_1$. A significant correlation exists between Operational Readiness Rate and a Schedule Performance Index.

Table 4

Regression Analyses for ORR and SPI

	SPI		
Variable	*B*	*SE B*	*B*
ORR	1.748	0.210	-0.008*
R^2	.127		
F	12.560		

Note. *n*=87; **p*<.05.

The results from the regression analysis were depicted in Table 4. The regression analysis was performed to test if ORR significantly predicted SPI. ORR was found to significantly predict the outcome of SPI (p=0.001). ORR did not explain a significant proportion of variance in SPI with a weak-strength regression model fit and 12.7% of the variation explained by the ORR and SPI variables. The regression model was created from Minitab to indicate the characteristics of how changing the predictor variable affects the outcome variable. The predictor equation was SPI = 1.750 – (0.008 x ORR). Based on this result the null hypothesis ($H1_0$) was rejected and support existed for the alternative hypothesis. There was a significant inverse relationship between Operational Readiness Rate and a Schedule Performance Index.

Research Question Q2.

Q2. To what extent, if any, is the relationship between Operational Readiness Rate and a Cost Performance Index correlated?

H2$_0$. There is no significant correlation between Operational Readiness Rate and a Cost Performance Index.

H2$_1$. A significant correlation exists between Operational Readiness Rate and a Cost Performance Index.

Table 5

Regression Analysis for ORR and CPI

	CPI		
Variable	*B*	*SE B*	*B*
ORR	1.692	0.434	-0.006
R^2	.019		
F	1.700		

Note. n=87; *p<.05.

The results of regression analysis were depicted in Table 5. Regression analysis was performed to test if ORR significantly predicted CPI. ORR did not significantly predict the outcome for CPI. ORR did not explain a significant proportion of variance in CPI with a weak-strength regression model fit. The coefficient of determination indicated 1.9% of the variation between the ORR and CPI variables was predicted by the model. Based on this result the null hypothesis (H2$_0$) was not rejected, and no support existed for the alternative hypothesis. There was no significant correlation between Operational Readiness Rate and a Cost Performance Index.

Research Question Q3.

Q3. To what extent, if any, is the relationship between Reliability Growth Rate and a Schedule Performance Index correlated?

H3$_0$. There is no significant correlation between Reliability Growth Rate and a Schedule Performance Index.

H3$_1$. A significant correlation exists between Reliability Growth Rate and a Schedule Performance Index.

Table 6

Regression Analysis for RGR and SPI

	SPI		
Variable	*B*	*SE B*	*β*
RGR	1.021	0.018	-0.001
R^2	.045		
F	3.190		

Note. *n*=70; **p*<.05.

The results from the regression analysis were depicted in Table 6. Regression analysis was performed to test if RGR significantly predicted SPI. RGR did not significantly predict the outcome for SPI (p=0.078). RGR did not explain a significant proportion of variance in SPI. The coefficient of determination indicated 4.5% of the variation between the RGR and SPI variables was predicted by the model. The r^2 indicated a weak model fit in the regression equation. Based on these results the null hypothesis (H3$_0$) was not rejected, and no support existed for the alternative hypothesis. There was no significant correlation between Reliability Growth Rate and a Schedule Performance Index.

Research Question Q4.

Q4. To what extent, if any, is the relationship between Reliability Growth Rate and a Cost Performance Index correlated?

H4$_0$. There is no significant correlation between Reliability Growth Rate and a Cost Performance Index.

H4$_1$. A significant correlation exists between Reliability Growth Rate and a Cost Performance Index.

Table 7

Regression Analysis for RGR and CPI

	CPI		
Variable	*B*	*SE B*	*B*
RGR	1.071	0.031	0.001*
R^2	.059		
F	4.300		

Note. n=70; *p<.05.

The results from the regression analysis were depicted in Table 7. Regression analysis was performed to test if RGR significantly predicted CPI. RGR was not found to significantly predict the outcome of SPI (p=0.890). RGR did not explain a significant proportion of variance in CPI. The r^2 indicated a weak-strength model fit with 5.9% of the variation between the RGR and CPI variables. A regression model was created from Minitab to indicate the characteristics of how changing the predictor variable affects the outcome variable. The predictor equation was CPI = 1.070 + (0.001 x RGR). Based on this result the null hypothesis (H4$_0$) was not rejected, and no support existed for the alternative hypothesis. There was no significant correlation between Reliability Growth Rate and a Cost Performance Index.

Research Question Q5.

Q5. To what extent, if any, is the relationship between Depot Mean Downtime and a Schedule Performance Index correlated?

H5$_0$. There is no significant correlation between Depot Mean Downtime and a Schedule Performance Index.

H5$_1$. A significant correlation exists between Depot Mean Downtime and a Schedule Performance Index.

Table 8

Regression Analysis for DMDT and SPI

	SPI		
Variable	*B*	*SE B*	*B*
DMDT	0.975	0.061	0.000
R^2	.002		
F	0.090		

Note. n=50; **p*<.05.

The results from the regression analysis were depicted in Table 8. Regression analysis was performed to test if RGR significantly predicted SPI. DMDT did not significantly predict the outcome for SPI (p=0.770). DMDT did not explain a significant proportion of variance in SPI with a weak-strength regression model fit. The coefficient of determination indicated 0.2% of the variation between the ORR and CPI variables was predicted by the model. Based on this result the null hypothesis (H5$_0$) was not rejected, and no support existed for the alternative hypothesis. There was no significant correlation between Depot Mean Downtime and a Schedule Performance Index.

Research Question Q6.

Q6. To what extent, if any, is the relationship between Depot Mean Downtime and a Cost Performance Index correlated?

$H6_0$. There is no significant correlation between Depot Mean Downtime and a Cost Performance Index.

$H6_1$. A significant correlation exists between Depot Mean Downtime and a Cost Performance Index.

Table 9

Regression Analysis for DMDT and CPI

	CPI		
Variable	*B*	*SE B*	*B*
DMDT	0.802	0.072	0.004*
R^2	.249		
F	15.920		

Note. n=50; *p<.05.

The results from the regression analysis were depicted in Table 9. Regression analysis was performed to test if DMDT significantly predicted CPI. DMDT was found to significantly predict the outcome of CPI (p<.05). The r^2 was used to indicate 24.9% of the variance between the DMDT and CPI was explained by the regression model and considered to have a medium-strength predictive capability. The regression model was created from Minitab to indicate the characteristics of how changing the predictor variable affects the outcome variable. The predictor equation was CPI = 0.802 + (0.004

x DMDT). Based on this result the null hypothesis ($H6_0$) was rejected and support existed for the alternative hypothesis. A significant correlation existed between Depot Mean Downtime and a Cost Performance Index.

Research Question Q7.

Q7. Do the performance-based logistics metrics of Operational Readiness Rate, Reliability Growth Rate, and Depot Mean Downtime have an effect on earned value metrics of Cost and Schedule Performance Indices?

$H7_0$. The Operational Readiness Rate, Reliability Growth Rate, and Depot Mean Downtime have no significant multivariate main effects for Cost and Schedule Performance Indices.

$H7_1$. The Operational Readiness Rate, Reliability Growth Rate, and Depot Mean Downtime have significant multivariate main effects for Cost and Schedule Performance Indices.

Table 10

Regression Analysis for Performance-based Logistics and SPI

	SPI		
Variable	*B*	*SE B*	β
ORR	1.596	0.657	-0.006
RGR		0.000	-0.001*
DMDT		0.001	0.000
R^2	.109		
F	1.870		

Note. n=50; *p<.05.

The results from the SPI multiple regression analysis was depicted in Table 10. Multiple linear regression analysis was used to test whether ORR, RGR, and DMDT predicted SPI. The results of the regression indicated ORR (β_1), RGR (β_2), and DMDT (β_3) had a weak-strength coefficient of determination to explain 10.9% of the variance, and ORR, RGR, and DMDT combined did not predict SPI (p=0.150). A regression formula was determined as SPI = 1.60 – (0.00604 x ORR) – (0.000909 x RGR) + (0.000421 x DMDT). The ORR (p=0.370) and DMDT (p=0.630) were not significant in the regression model. Therefore, RGR alone was found to be significant in the regression model (p=0.026); yet, no other significant values were found. The results indicated 89.1% of the model was not explained by the three predictor variables combined (R^2 =10.9%).

Table 11

Regression Analysis for Performance-based Logistics and CPI

	SPI		
Variable	*B*	*SE B*	*β*
ORR	1.687	0.008	-0.009
RGR		0.000	-0.001
DMDT		0.002	0.004*
R^2	.288		
F	6.210		

Note. n=50; *p<.05.

The results from the CPI multiple regression analysis was depicted in Table 11. For the CPI outcome variable, the results of the regression indicated ORR (β_1), RGR

(β_2), and DMDT (β_3) explained 28.8% of the. It was found that ORR, RGR, and DMDT combined did significantly predict CPI (p=0.001). A regression model was created from Minitab to indicate the characteristics of how changing the predictor variable affects the outcome variable. The predictor model was determined as SPI = 1.69 – (0.009 x ORR) – (0.001 x RGR) + (0.004 x DMDT).

The DMDT predictor variable was the only significant coefficient in the multiple regression model (p<.05). Results indicated 71.2% of the model was not explained by the three predictor variables combined (R^2=28.8%). The ORR, RGR, and DMDT had no significant multivariate main effects for SPI and CPI indices; therefore, the null hypothesis ($H7_0$) was not rejected, and no support existed for the alternative hypothesis. Therefore, the Operational Readiness Rate, Reliability Growth Rate, and Depot Mean Downtime had no significant multivariate main effects for the Cost and Schedule Performance Indices.

Research Question Q8.

Q8. Is there an interaction effect between the earned value metrics of Cost and Schedule Performance Indices?

$H8_0$. There is no significant interaction effect between the earned value metrics of Cost and Schedule Performance Indices.

$H8_1$. There is a significant interaction effect between the earned value metrics of Cost and Schedule Performance Indices.

Intercorrelations were not found between SPI and CPI was $r_s(88) = -0.015$ (p=0.890). The correlation results indicated no significant relationship between the predictor outcome variable pair; therefore, the null hypothesis ($H8_0$) was not rejected, and no support existed for the alternative hypothesis.

Mann-Whitney analysis. Parametric testing was not considered in this study because the data was not normally distributed and Spearman's coefficient was used for correlation testing. Mann-Whitney analysis was used in Minitab to test the equality of the two population means between SPI and CPI (Black, 1999). The test met the assumption for independent samples from the two populations; however, the data violated the assumption for a normally distributed set of data for ANOVA testing to be used as the SPI and CPI medians were 1.008 and 1.094 respectively. The 95% confidence interval for the difference between population means was [-0.123 to -0.070] and the test statistic W = 5439.000 was significant ($p < .05$). There was sufficient information to reject the null hypothesis ($H8_0$), as a significant intercorrelation effect existed between SPI and a CPI, and a significant difference was found between the population means of SPI and CPI within the Shadow 200 performance-based logistics program. There was a significant interaction effect between the earned value metrics of Cost and Schedule Performance Indices.

Hypotheses by Research Question

A summarization of the hypotheses selected by research question is provided. For Research Question 1, the null hypothesis ($H1_0$) was rejected; there was a significant inverse relationship between Operational Readiness Rate and a Schedule Performance Index. For Research Question 2, the null hypothesis ($H2_0$) was not rejected; there was no significant correlation between Operational Readiness Rate and a Cost Performance Index. For Research Question 3, the null hypothesis ($H3_0$) was not rejected; there was no significant correlation between Reliability Growth Rate and a Schedule Performance Index. For Research Question 4, the null hypothesis ($H4_0$) was not rejected; there was no significant correlation between Reliability Growth Rate and a Cost Performance Index. For Research Question 5, the null hypothesis ($H6_0$) was rejected; a significant correlation existed between Depot Mean Downtime and a Cost Performance Index. For Research Question 6, the null hypothesis ($H6_0$) was rejected; a significant correlation existed between Depot Mean Downtime and a Cost Performance Index. For Research Question 7, the null hypothesis ($H7_0$) was not rejected; the Operational Readiness Rate, Reliability Growth Rate, and Depot Mean Downtime had no significant multivariate main effects for the Cost and Schedule Performance Indices. For Research Question 8, the null hypothesis ($H8_0$) was rejected; there was a significant interaction effect between the earned value metrics of Cost and Schedule Performance Indices.

Evaluation of Findings

The study used Spearman's rank order correlation to assess correlations between the predictor variables of ORR (X_1), RGR (X_2), and DMDT (X_3) and outcome variables of SPI (Y_1) and CPI (Y_2). The study examined predictive modeling using regression analysis for each predictor-outcome variable pair independently. Combining the predictor variables to each outcome variable was also examined using multiple regression to determine if a significant model existed to indicate the characteristics of how changing the predictor variable affects each outcome variable. Non-parametric testing of the differences between outcome variable means was also performed using Mann-Whitney testing to determine if an interaction effect existed between variables. Quantitative analysis was appropriate for this study as continuous measurements for the predictor and outcome variables may allow for inferences from the correlation and regression analysis (Black, 1999).

Research Questions 1 and 2, ORR and earned value management metrics.

The ORR was shown to be inversely moderately correlated with SPI and no correlation was found with CPI. This finding supported an increase in the ORR rate, which was an indicator for product performance for the Shadow 200 system, resulted in a decrease in SPI for the project's schedule performance for the Shadow 200 performance-based logistics program during the months examined. These findings compare with Kim's (2008) research, which reported a periodic analysis of the performance trends can be used to identify problems early in the program's execution stages and provide program managers with indicators of success to the outcome of the program. Kim's research was relevant to this study as the earned value metrics were also early warning indicators to project performance for the Shadow 200 performance-based logistics program.

The ORR findings suggested performance-based logistics programs may have been influenced by the organizational value chain for ongoing improvement of the product performance project schedule performance (Barber, 2008). In a performance-based logistics context, critical capabilities management and reactive critical capabilities solutions were essential to preventing or improving poor program performance through the application of corrective measures. Technology improvements may require effective implementation to change performance-based logistics metrics interactions with schedule performance metrics of the project (Plumer, 2010).

Research Questions 3 and 4, RGR and earned value management metrics.

The RGR was shown to have no correlation with SPI or CPI, and RGR was shown to have an inverse weak correlation with the ORR rate. These findings supported no effect with the RGR rate, which was an indicator for product reliability for the Shadow 200 system, and project performance indicated by SPI or CPI. The RGR findings suggested the Shadow 200 performance-based logistics program adequately planned a systems engineering approach compares to Nowicki's (2008) research which suggested to increase product reliability through analysis such as Failure Mode Effects and Criticality Analysis, and Fault Tree Analysis within earned value management cost and schedule performance measurement thresholds. The findings also compared with Monius (2011), who suggested the Shadow 200 performance-based logistics program used greater than 80% level-of-effort for earned value management measurement techniques, limiting the benefits of schedule performance indicators in an earned value management context. Earned value methods, such as level of effort, were used to manage tasks based upon the ambiguity and flexibility required to meet performance-based logistics metrics. The level of effort earned value management based tasks did not measure differences in schedule variance and the SPI (Stratton, 2007). The extensive use of level-of effort earned value management techniques may be appropriate for lifecycle sustainment projects such as the Shadow 200 performance-based logistics program, however it was ineffective for use in this study to examine the relationships with RGR and SPI.

RGR was inversely correlated to ORR. The RGR-ORR relationship suggested the Shadow 200 performance-based logistics program effectively focused on reliability improvements as a critical element of integrated logistics support toward a consolidated approach to increasing a weapon system's operational readiness (Devries, 2005). The RGR-ORR relationship may be influenced by incentivizing for performance. Further research to examine the influence of monetary incentives in a performance-based logistics context may be required to further understand these relationships. An examination for quantitative incentive criteria to exceed performance-based logistics ORR metric performance thresholds may be important to better understand the influence of a performance-based logistics program, such as the Shadow 200 program, to focus on reliability improvement as a method to achieve the incentive.

Research Questions 5 and 6, DMDT and earned value management metrics.

DMDT was shown to have no correlation with SPI; however, DMDT was shown to have a significant positive moderate correlation to CPI. This finding supported an indicator for the product repair turnaround time for the Shadow 200 system, was a method to reduce project cost. Further research may provide researchers with an understanding for other methods.

The DMDT positive correlation and regression model to CPI suggested as the DMDT increased, the project cost performance indicator would increase for the Shadow 200 performance-based logistics program. Effective product repair turnaround time may have been implemented from optimized stockage levels to sustain the availability, maintainability, and supportability of replacement parts (Nowicki, 2008). The research compares to Graves (1999), who suggested the benefits of the item-based inventory model using a weighted average of repair demand accommodated for a random failure rate and measurements for deterministic lead-times. A finding in the current study suggested DMDT, which measures turnaround and lead-time, may lead to optimal product repair turnaround and lead-time to minimize program cost performance.

The systems approach concept used by the Shadow 200 performance-based logistics program used a three-tier system, and this three-tier system may support the positive correlation between DMDT and CPI. Tier one organizational and their two intermediate-level maintenance actions were performed at the operational location with organic sparing and repairing capabilities. Tier three depot-level maintenance actions included major repairs and were performed at either AAI's manufacturing or dedicated subcomponent vendor facilities. These findings compare to Nowicki (2008), whose research suggested using a systems approach concept with next higher echelon tiers may provide logistical support for sparing and repairs to the subordinate echelons. Tier two peer echelons had supported as the next higher echelon should the tier three echelon not have availability of parts or repair capability (Nowicki, 2008).

Research Questions 7 and 8, performance-based logistics and earned value management metrics. The findings suggested performance-based logistics metrics for the Shadow 200 program had no significant multivariate main effects with earned value management metrics, however there was a significant interaction effect between the earned value metrics of Cost and Schedule Performance. This finding complements Marshall's (2007) research, which suggested the effectiveness of earned value management metrics was a positive and significant predictor to the effectiveness of project success. Marshall's findings are relevant to this study because a defined set of performance metrics established the defined scope, schedule, and cost, such as ORR, RGR, and

DMDT in this study, may be used to understand earned value outcome variables indicating project performance. This research also compares with Plumber's (2010) research, which correlated the effectiveness of project performance with earned value management using established customer satisfaction metrics for Information Technology projects. Plumber's research was relevant because established metrics were used to determine effective performance in the context of earned value management. Performance-based logistics metrics were used in this research as measures of technical satisfaction to determine effective project performance from performance metrics within an earned value management context. These studies parallel this study from the context of using established and relevant performance metrics to examine the relationships between effectiveness of earned value management correlated to project performance metrics (Marshall, 2007; Plumber, 2010; Kim, 2008).

Summary

The purpose of the quantitative correlation study was to examine relationships between interval-level performance-based logistics metrics of ORR, RGR, and DMDT with the earned value management metrics of SPI and CPI. The study used archival census data from the Shadow 200 performance-based logistics program, which implemented earned value management as a lifecycle support program from November 2004 through February 2012. Spearman's rank correlation was performed to determine the relationship between predictor-outcome variable pairs and used to indicate the type and strength of the relationship (Black, 1999). Three significant correlations were identified from the correlation analysis: (a) ORR and SPI, (b) ORR and RGR, and DMDT and CPI. Regression was used to determine the predictive modeling relationships for the study (Black, 1999), and multiple regression combined a three-predictor model to earned value metrics to identify statistically significant variable effects or interactions. The ORR, RGR, and DMDT had no significant multivariate main effects for SPI and CPI indices. Mann-Whitney testing indicated there was a significant intercorrelation between SPI and CPI within the Shadow 200 performance-based logistics program.

The performance-based logistics and earned value management fields of study may be affected this research because the relationships of performance-based logistics predictor variables were examined within the context of earned value management outcome variables. The research described the interrelationships within the context of the Shadow 200 performance-based logistics program. The results of this research were consistent with other research within the performance-based logistics and earned value management fields of study independently.

Chapter 5: Implications, Recommendations, and Conclusions

The purpose of the quantitative correlational study was to explore the relationships between the outcome variables of cost and schedule performance indices with the predictor variables of ORR, RGR, and DMDT. The study addressed the problem that it is not known to what extent interdependency exists between earned value management and performance-based logistics service contracts (Nowicki, 2008). Quantitative methods were used to test hypothesis, which comprised of intercorrelation and multiple linear regression to compare data from earned value management and performance-based logistics service contract metrics (Black, 1999). Six interval-level predictor-outcome variable pairs were tested for association using correlation and modeled using linear regression (Black, 1999). A three-predictor multiple linear regression model using ORR, RGR, and DMDT was used to examine the relationships with all three predictors as analyzed concurrently with the outcome variables (Nowicki, 2008).

The research assumptions associated with the archival data were limited to the census data for the Shadow 200 performance-based logistics program from 2004 to 2011. The research was not intended to be applied to variable pair relationships for other programs or populations. Variations of management personnel, decision-making, and number of aircraft systems supported throughout the duration of data collection, which may have affected generalizability to other programs or settings.

The chapter is structured into three sections. The first section presents implications to describe conclusions for each research question and limitations effecting the results. Recommendations are provided to suggest recommendations for practical applications, use of results, and future research. The chapter concludes with a summary of key points to this research.

Implications

The problem is that it is not known to what extent interdependency exists between earned value management and performance-based logistics service contracts (Nowicki, 2008). Officials at the United States Office of Management and Budget acknowledged this problem and issued mandates for cost, schedule, and technical integration required in federal programs by 2006 (Visitacion, 2007). Department of Defense analysts also acknowledged issues with implementing earned value for nonschedule-based service contracts (DoD, 2006). The purpose of this quantitative correlational study was to explore the relationships between the performance-based logistics metrics of ORR, RGR, and DMDT with the outcome variables of SPI and CPI as earned value management metrics.

Measurements for outcome variables of SPI and CPI were critical for forecasting project performance. Questions relevant to the predictor and outcome variables were used to collect data to examine the interactions and interdependencies (Vogt, 2007). Each research question with its associated null and alternate hypothesis are identified to address the problem statement for the study.

Research Question Q1. Following is Research Question Q1 restated with the associated null and alternative hypotheses.

Q1. To what extent, if any, is the relationship between Operational Readiness Rate and a Schedule Performance Index correlated?

$H1_0$. There is no significant correlation between Operational Readiness Rate and a Schedule Performance Index.

$H1_1$. A significant correlation exists between Operational Readiness Rate and a Schedule Performance Index.

There was a significant intercorrelation between ORR and SPI (r_s=-0.212; p=0.048) within the Shadow 200 performance-based logistics program. Because of the significance, dependence between the ORR performance-based logistics metric and the SPI earned value management metric existed. The negative polarity of the intercorrelation indicated the direction of the dependence. The negative correlation implies that higher metric values for ORR tend to go with lower values for SPI and lower values for ORR go with higher values for SPI. ORR may not cause SPI to be inversely changed as the ORR changes; however, there may be shared commonalities such as process maturity, contract years, managers, or consistency in decision-making; however, the causation for this predictor-outcome variable dependency cannot be suggested from the results of this study. Further research using quantitative and qualitative methods may help researchers to understand the causation. Managers can use the dependence as an early warning indicator for future project performance (Marshall, 2007).

Performance-based logistics integrated into the initial acquisition processes with total life cycle system management concepts may achieve higher system readiness levels (Devries, 2005). Early integration of the Shadow 200 performance-based logistics program may be a contribution factor to the Shadow 200 system's mean ORR of 95.3% from November 2004 through April 2012. Managers can use the dependence as an early warning indicator for future project performance. Doerr, Lewis, and Eaton (2005) suggested monetary incentives to suppliers using performance-based logistics programs to exceed performance threshold requirements may also be a factor for the significant relationships.

Research Question Q2. Following is Research Question Q2 restated with the associated null and alternative hypotheses.

Q2. To what extent, if any, is the relationship between Operational Readiness Rate and a Cost Performance Index correlated?

$H2_0$. There is no significant correlation between Operational Readiness Rate and a Cost Performance Index.

$H2_1$. A significant correlation exists between Operational Readiness Rate and a Cost Performance Index.

No significant relationship was found between ORR and CPI (r_s=0.000; p=0.997) for the Shadow 200 performance-based logistics program from November 2004 through April 2012, although other performance-based logistics programs may have similar results. This finding did not support the purpose of this research. The results for Research Question Q2 showed that ORR had no significant correlation to imply that tendencies to the ORR metric was related to any changes in the CPI metric. No conclusions could be made for the ORR-CPI variable pair and their correlations, except there is not enough evidence to suggest that a statistically significant relationship exists.

Research Question Q3. Following is Research Question Q3 restated with the associated null and alternative hypotheses.

Q3. To what extent, if any, is the relationship between Reliability Growth Rate and a Schedule Performance Index correlated?

H3$_0$. There is no significant correlation between Reliability Growth Rate and a Schedule Performance Index.

H3$_1$. A significant correlation exists between Reliability Growth Rate and a Schedule Performance Index.

No significant relationship was found between RGR and SPI (r_s=-0.017; p=0.890) in the study. The observations collected for RGR and SPI did not support the purpose of this research. The results for Research Question Q3 showed that RGR had no significant correlation to imply that tendencies to the RGR metric were related to any changes in the SPI metric. No conclusions could be made for the RGR-SPI variable pair and their correlations, except there is not enough evidence to suggest that a statistically significant relationship exists.

Research Question Q4. Following is Research Question Q4 restated with the associated null and alternative hypotheses.

Q4. To what extent, if any, is the relationship between Reliability Growth Rate and a Cost Performance Index correlated?

H4$_0$. There is no significant correlation between Reliability Growth Rate and a Cost Performance Index.

H4$_1$. A significant correlation exists between Reliability Growth Rate and a Cost Performance Index.

No significant relationship was found between RGR and CPI (r_s=-0.062; p=0.608) in the study. The observations collected for RGR and SPI did not support the purpose of this research. The results for Research Question Q4 showed that RGR had no significant correlation to imply that tendencies to the RGR metric were related to any changes in the CPI metric. No conclusions could be made for the RGR-CPI variable pair and their correlations, except there is not enough evidence to suggest that a statistically significant relationship exists.

Research Question Q5. Following is Research Question Q5 restated with the associated null and alternative hypotheses.

Q5. To what extent, if any, is the relationship between Depot Mean Downtime and a Schedule Performance Index correlated?

H5$_0$. There is no significant correlation between Depot Mean Downtime and a Schedule Performance Index.

H5$_1$. A significant correlation exists between Depot Mean Downtime and a Schedule Performance Index.

No significant relationship was found between DMDT and SPI (r_s=-0.051; p=0.727) in the study. The observations collected for DMDT and SPI did not support the purpose of this research. The results for Research Question Q5 showed that DMDT had no significant correlation to imply that tendencies to the DMDT metric were related to any changes in the SPI metric. No conclusions could be made for the DMDT-SPI variable pair and their correlations, except there is not enough evidence to suggest that a statistically significant relationship exists.

Research Question Q6. Following is Research Question Q6 restated with the associated null and alternative hypotheses.

Q6. To what extent, if any, is the relationship between Depot Mean Downtime and a Cost Performance Index correlated?

H6$_0$. There is no significant correlation between Depot Mean Downtime and a Cost Performance Index.

H6$_1$. A significant correlation exists between Depot Mean Downtime and a Cost Performance Index.

DMDT significantly correlated to CPI (r_s=-0.497; p<.05). There was a dependence between the DMDT performance-based logistics metric and the CPI earned value management metric. The positive polarity of the intercorrelation indicated the direction of the dependence. The positive correlation implies that higher metric values for DMDT tend to go with higher values for CPI and lower values for DMDT go with lower values for CPI.

Causation for the correlation cannot be determined from this research, however Villanueve (2009) suggested modeling the optimal quantity of spare parts using a DMDT metric to meet the cost performance objectives enhanced the managers' ability to make provisioning decisions to sustain the desired performance level using multi-objective problem solving to optimize performance levels. Nowicki (2008) reported supply chain integration methods included optimization for modeling, asset visibility, and availability minimized shorter lead-time required less capital investment for quantities of spares to maintain the minimum safety stockage levels necessary for system readiness. The use of an on-line database to model and track spares inventory quantities on the Shadow 200 performance-based logistics program may attribute to the positive moderately correlated predictor-outcome variable pair of DMDT and CPI.

Further research using quantitative and qualitative methods may help researchers to understand the causation.

Research Question Q7. Following is Research Question Q7 restated with the associated null and alternative hypotheses.

Q7. Do the performance-based logistics metrics of Operational Readiness Rate, Reliability Growth Rate, and Depot Mean Downtime have an effect on earned value metrics of Cost and Schedule Performance Indices?

$H7_0$. The Operational Readiness Rate, Reliability Growth Rate, and Depot Mean Downtime have no significant multivariate main effects for Cost and Schedule Performance Indices.

$H7_1$. The Operational Readiness Rate, Reliability Growth Rate, and Depot Mean Downtime have significant multivariate main effects for Cost and Schedule Performance Indices.

The results from the SPI multiple regression analysis, ORR, RGR, and DMDT combined did not significantly predict SPI and did significantly predict CPI for the Shadow 200 performance-based logistics program from November 2004 through April 2012. Because not all three predictor variables were found significant in the regression model for either the SPI or CPI, the research partially supported the purpose of this research by indicating to managers using earned value management that a combined performance-based logistics model is as likely to effect the SPI earned value metric as any other factor. A predictive model can be used to determine a combined performance-based logistics model with the CPI earned value management metric. Managers can use a combined performance-based logistics predictive model as an early warning indicator for future project cost performance.

Research Question Q8. Following is Research Question Q8 restated with the associated null and alternative hypotheses.

Q8. Is there an interaction effect between the earned value metrics of Cost and Schedule Performance Indices?

$H8_0$. There is no significant interaction effect between the earned value metrics of Cost and Schedule Performance Indices.

$H8_1$. There is a significant interaction effect between the earned value metrics of Cost and Schedule Performance Indices?

A Mann-Whitney testing was used to determine a significant interaction effect existed between SPI and a CPI. Although the results indicated the relationship between the predictor outcome variable pair was not significant, an inverse relationship existed. Within the context of the Shadow 200 performance-based logistics program, as the schedule performance increased the cost performance decreased.

The study reinforces MacDonnell and Clegg (2007) suggestion that cost integration for maintenance, repair, and overhaul services, which were fundamental to performance-based logistics, required integration within the accounting system as a business model to provide early warnings of cost or schedule problems. The research supports the problem identified in this research within the context of the Shadow 200's performance-based logistics metrics of ORR, RGR, and DMDT have significant relationships and predictive modeling to the earned value metrics of SPI and CPI. These relationships may demonstrate benefits of the business model integration.

Bower and Finegan (2009) hypothesized, the use of metrics in earned value management narrowly measured program performance with respect to cost and schedule elements and failed to measure the effect on other factors such as environmental, quality, or societal needs, limiting the use of earned value management for some industries. The low R^2 values discovered during regression analysis in this study suggest the similar factors may prevent further explanation of the variance contribution to each regression model.

Current literature suggests some attributes of earned value management, such as the SPI could not determine the schedule health of the program because the SPI did not differentiate schedule performance against critical or noncritical path schedule activities (Lukas, 2008). Stratton (2007) also maintained the SPI metric became unreliable for predicting project completion performance as a project nears completion. Lukas (2008) reported earned schedule was used to indicate performance based upon the schedule for work completed rather than the value of work completed. Therefore, SPI may not be an adequate earned value metric for the Shadow 200 performance-based logistics program with approximately 80% level of effort scope.

Recommendations

Recommendations for practice. With a large portion of scope in the Shadow 200 performance-based logistics program measured as level of effort, project performance using earned schedule measured against the planned duration for the project may provide earned value managers increased accuracy in the anticipated project completion date in time instead of dollars (Stratton, 2007). Vandevoorde and Vanhoucke (2006) suggest using critical path methods to increase the validity of predicting project schedule performance. Performance-based logistics managers using a critical path or earned schedule methods of schedule management may also focus on the factors contributing to the variance in the regression models. Further practice is necessary to evaluate the benefits of using the critical path or earned schedule methods on high-proportion level of effort programs. Further practice may also provide a better understanding for managers examining the effectiveness of the earned schedule or critical path scheduling methods in a performance-based logistics program as comparative studies between performance-based logistics and traditional lifecycle support logistics programs.

Recommendations for future research. Additional research to investigate the limitations of this research with weak-strength regression model fitting may help managers understand other factors effecting the variable interaction such as the influence of performance-based logistics monetary incentives may help researchers understand how these incentives effect performance metrics. Additional quantitative studies from archived data may lead researchers to understand how system technological improvements, reliability improvements, and inventory modeling affect CPI and SPI. Cipicchio (2008) and Fowler (2008) asserted performance-based logistics transferred transaction costs in lieu of spares replacement as an investment in improving reliability and life cycle cost reduction. Maintaining a system's readiness level through reliability improvement instead of levels of spare parts may attribute to efficient cost levels.

Further quantitative research using historical data is also recommended to determine the effects and relationships between performance-based logistics and earned value management metrics for programs other than the Shadow 200 program. Other organizational variables that may have contributed to the results including organizational experience with performance-based logistics, the organizational level of maturity of the earned value management system, industry, management decision-making, or other organizational-specific characteristics (Stratton, 2006). Each of the predictor and outcome variables may have affected the results of the study. More observational studies within the context of performance-based logistics within earned value management programs are needed to explain other variable interactions for the predictor-outcome variables used in this study.

Conclusions

These findings support information to the primary purpose of this research. There is sufficient evidence to suggest the CPI earned value management metric was significantly correlated with RGR and DMDT independently and correlated with ORR, RGR, and DMDT performance-based logistics metrics combined. A significant predictive model existed between CPI with ORR, RGR, and DMDT metrics. There also was sufficient evidence to suggest the SPI was significantly correlated with CPI.

During this study, three significant correlations were identified from the correlation analysis. A significant inverse correlation was found between ORR and SPI. There was an inverse relationship between ORR and the RGR. A moderate positive correlation between DMDT and the CPI was also significant. The significant interaction effects between schedule and cost performance indices indicated a significant difference between the population means of the schedule and cost performance indices within the Shadow 200 performance-based logistics program. The interaction effect may benefit managers of earned value management programs to examine the interaction within other programs to understand the effectiveness of schedule and cost integration.

It was found that ORR, RGR, and DMDT significantly predicted CPI. A regression model indicated characteristics of how changing the predictor variable affects the outcome variable. The predictor model may be used to integrate performance-based logistics within organizational accounting systems (MacDonnell & Clegg, 2007) with earned value cost metrics for maintenance, repair, and overhaul services to provide early warnings of cost problems. Additionally, the model predictions discovered in this research may be used to address life cycle sustainment weaknesses within the acquisition process as an additional management tool to forecast program performance and identify early warning indications of problems within the context of earned value management (Russell, 2009).

References

Alvarado, C. M., Silverman, R. P., & Wilson, D. S. (2004). Assessing the performance of construction projects: Implementing earned value management at the general services administration. *Journal of Facilities Management, 3*(1), 92-92-105.

Azizian, N. (2011). A framework for evaluating technology readiness, system quality, and program performance of U.S. DoD acquisitions. Engineering Mgt and Systems Engineering. *ProQuest Dissertations and Theses.* doi:10.1002/sys.20186

Barber, E. (2008). How to measure the "value" in value chains. *International Journal of Physical Distribution & Logistics Management, 38*(9), 685-685-698. doi:10.1108/09600030810925971

Black, T. R. (1999). *Doing quantitative research in the social sciences.* London: Sage.

Bower, D. C., and Finegan, A. D. (2009). New approaches in project performance evaluation techniques. *International Journal of Managing Projects in Business; 2*(3), 435-444. doi:10.1108/17538370910971072

Buchanan, N., & Klingner, D. E. (2007). Performance-based contracting: Are we following the mandate?1. *Journal of Public Procurement, 7*(3), 301-301-332.

Cicmil, S., & Hodgson, D. (2006). New possibilities for project management theory: A critical engagement. *Project Management Journal, 37*(3), 111-111-122.

Defense Update (2006, October 16). Shadow 200 tactical UAV system. *Defense Update.* Retrieved from http://defense-update.com/products/s/shadow.htm

De Lorenzo, R.,A., Freid, R. L., & Villarin, A. R. (1999). Army aeromedical crash rates. *Military Medicine, 164*(2), 116-116-8.

Devries, H. J. (2005). Performance-based logistics – barriers and enablers to effective implementation. *Defense AR Journal, 11*(3), 242-253.

DoD (2006). *Performance based logistics: A program manager's product support guide.* Defense Acquisition University Press. Ft Belvoir, VA.

Doerr, K., Lewis, I., & Eaton, D. R. (2005). Measurement issues in performance-based logistics. *Journal of Public Procurement, 5*(2), 164-164-186.

Drzymalski, J. (2008). *A synchronized supply chain for a multi-echelon, multi-stage system.* Available from ProQuest Dissertations and Theses database. (UMI No. 3314489)

Faul, F., Erdfelder, E., Buchner, A., & Lang, A. G. (2009). Statistical power analyses using G*Power 3.1: Tests for correlation and regression analyses. *Behavior Research Methods, 41*, 1149-1160.

Federal Register, volume 73 2008, online: Defense Federal Acquisition Regulation Supplement; Earned Value Management Systems (DFARS Case 2005-D006). <http://www.thefederalregister.com/d.p/2008-04-23-E8-8706>

Fleming, E. D., and Koppelman, J. M. (2006). *Earned value project management*, (3rd ed.) Project Management Institute, Inc., Newtown Square, PA.

Fowler, R. (December, 2007). *Performance based life cycle support – The new PBL.* Presented at the North American Defense Logistics Conference, Crystal City, VA.

Geary, S. (2006). Ready for combat. *DC Velocity, 4*(7), 75-80.

Gowan, J. A., Mathieu, R. G., & Hey, M. B. (2006). Earned value management in a data warehouse project. *Information Management & Computer Security, 14*(1), 37-37-50.

Hendersen, G. R. (2007). *Quality Improvement with Minitab.* Hoboken, NJ: John Wiley & Sons, Inc. doi:10.1002/9781119975328

Infanti, M. (2010, June). *Things are changing*. Paper presented at the 26th Annual International Conference and Training EVM World Conference. Naples, FL.

Johnson, C. (2006). Implementing an ANSI/EIA-748-compliant earned value management system. *Contract Management, 46*(4), 36-43.

Jones, S. R., & Zsidisin, G. A. (2008). Performance implications of product life cycle extension: The case of the A-10 aircraft. *Journal of Business Logistics, 29*(2), 189-215

Kautz, K. (2009). The impact of pricing and opportunistic behavior on information systems development. *JITTA : Journal of Information Technology Theory and Application, 10*(3), 24-24-40.

Kim, B. C. (2007). *Forecasting project progress and early warning of project overruns with probabilistic methods.* Available from ProQuest Dissertations and Theses database. (UMI No. 3296425)

Kim, S. (2008). *Performance-Based Logistics: Incentive contracting in the aftermarket.* Available from ProQuest Dissertations and Theses database. (UMI No. 3328601)

Kobren, B. (2009). What performance based logistics is and what it is not – and what it can do and cannot do. *Defense Acquisition University*. 254-267. Retrieved from http://dau.mil

King, R. J. (2007). *A decision-making framework for total ownership cost management of complex systems: a Delphi study*. Available from ProQuest Dissertations and Theses database. (UMI No. 3302636)

Kratz, L. (March, 2007). *Achieving actionable logistics*. Presented at the 23rd Annual National Logistics Conference and Exhibition, Miami, FL.

Kuehn, U. (2007). Earned value management - why am I being forced to do it? *AACE International Transactions,* (15287106), EV51-EV51-EV53,EV55-EV59,EV510-EV511.

LeBlanc, L., Hill, J., Harder, J., & Greenwell, G.. (2009). Modeling uncertain forecast accuracy in supply chains with postponement. *Journal of Business Logistics, 30*(1), 19-52.

Lu, Y. & Song, J-S. (2005). Order-Based Cost Optimization in Assemble-to-Order Systems. *Operations Research, 53*(1), 151-169.

Lukas, J. A. (2006). Bad estimates just don't happen. *AACE International Transactions,* (15287106), ES31-ES31-ES36.

Lukas, J. A.,P.E.C.C.E. (2008). Earned value analysis - why it doesn't work. *AACE International Transactions,* (15287106), EV11-EV11-EV19,EV110.

MacDonnell M., Clegg, B. (2007). Designing a support system for aerospace maintenance support systems. *Journal of Management Technology, 8*(2), 139-152.

Marshall, R. A. (2007). The contribution of earned value management to project success on contracted efforts. *Journal of Contract Management, 1*(2), 288-294. doi:10.1108/17538370810866386

Melese, F., Franck, R., Angelis, D., & Dillard, J. (2007). Applying insights from transaction cost economics to improve cost estimates for public sector purchases: The case of U.S. military acquisition. *International Public Management Journal, 10*(4), 357-357-385.

Miller, R. (2006). *Technical data: An output from systems engineering in the context of the LCMC*. 9th Annual System Engineering Conference. San Diego, CA. Retrieved from http://www.dtic.mil/ndia/2006systems/Wednesday/miller7.pdf

Monius, C. (May, 2011). *The road to validation: A contractor's self assessment & DCMS EVM Center's readiness assessment.* Poster session presented at the EVMS World 2011 27th Annual International Conference, Tampa, FL.

Murphy, R. K., & Beach, S. D. (2010). Using strategic planning in support of defense acquisitions. *Information & Security, 25*, 57-57-77.

National Defense Industrial Association (2005). *National Defense Industrial Association (NDIA) Program Management Systems Committee (PMSC) ANSI/EIA-748-A Standard for Earned Value Management Systems Intent Guide.* (1st ed.). Arlington, VA: NDIA.

Nowicki, D. R. (2008). Optimization models in support of performance based logistics (PBL) contracts. Available from ProQuest Dissertations and Theses database. (UMI No. 3314297)

Nowicki, D., Kumar, U. D., Studel, H.J., and Verma, D. (2008). Spares provisioning under a performance-based logistics contract: profit-centric approach. *Journal of Operational Research Society, 59*, 342-354.

Owen, J. (2008). Implementing EVM in an R&D environment: From infancy to adolescence. *Cost Engineering, 50*(10), 12-17.

Owings, T. (2010). Unmanned Aircraft Systems (UAS) project office (PO) finds powerful cost efficiency advantages through proper performance-based logistics (PBL). *Army AL&T Magazine* (January-March 2010).

Plumer, D., R. (2010). *The relationship between earned value management metrics and customer satisfaction.* Available from ProQuest Dissertations and Theses database. (UMI No. 3470460)

Project Management Institute (2009) Cost control: Tools and techniques. *Project Management Body of Knowledge* (4th ed.). Newtown Square, PA: PMI.

Randall, W. S., Pohlen, T. L., & Hanna, J.B. (2010). Evolving a theory of performance-based logistics using insights form service dominant logic. *Journal of Business Logistics, 31*(2). 35-61.

Regan, S. T. (2006). EVMS internal and DCAA audit recommendations. *AACE International Transactions,* (15287106), EV31-EV31-EV37.

Rodriguez-Candela, A. S. (2007). *N-dimensional effectiveness metric-compensating reward scheme in performance-based logistics contracts.* Available from ProQuest Dissertations and Theses database. (UMI No. 3317890)

Russell, S. H. (2011). Earned value management uses and misuses. *Air Force Journal of Logistics, 32*(2), 87-91.

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

Silva, C. and Disano, M. (November, 2007). *Beyond PBL – Outcome focused performance.* Poster session presented at the 2007 DoD Maintenance Symposium, Fort Worth, TX. Retrieved from http://www.sae.org/events/dod/presentations/2007pblsilva.pdf

Sols, A., Nowicki, D., Verma, D. (2008). Defining the fundamental framework of an effective performance-based logistics (PBL) contract. *Engineering Management Journal, 19*(2), 40-50.

Spring, B. (2010). Performance-based logistics: Making the military more efficient. *Backgrounder. The Heritage Foundation* (2411).

Spring, M., & Araujo, L. (2009). Service, services and products: Rethinking operations strategy. *International Journal of Operations & Production Management, 29*(5), 444-467.

Storms, K.. (2010). Earned value management implementation in a public agency capital improvement project. *Cost Engineering, 52*(3), 6-9.

Stratton, R. (2006). *The Earned Value Management Maturity Model.* (1st ed.). Vienna, VA: Management Concepts.

Stratton, R. W., E.V.P. (2007). Applying earned schedule analysis to EVM data for estimating completion date. *AACE International Transactions,* (15287106), EV41-EV41-EV44.

Templin, C. R., and Christensen, D. S. (2003). *Acquisition reform in the Department of Defense: Has DoD broken through the reform barrier?* Business Management Facility Research Seminar. BYU Marriott School. Retrieved from http://marriottschool.byu.edu/emp/BMS/Website%20Archive/Documents/Acquisition%20Reform%20Final.doc

Torocomian, T. (2008). Trucking meets performance-based logistics. *Transport Topics, 37*(94), 9-10.

Tremaine, R., and Seligman, D. (2010). It's time to take the chill out of cost containment and re-energize a key acquisition practice. *Defense AR Journal, 17*(2), 242-267.

US Army (2009). Department of Defense Performance-Based Logistics awards program for excellence in performance based logistics. Unmanned Aircraft Systems

Project Manager's Office. Redstone Arsenal, AL. Retrieved from http://thecenter.utk.edu/images/Users/30/pblawards/Subsystem2009/ShadowPBLAward.pdf

Villanueva Jaquez, D. (2009). *Multiple objective optimization of performance based logistics*. (Doctoral Dissertation) Retrieved from http://digitalcommons.utep.edu/dissertations/AAI1473900/

Vandevoorde, S., and Vanhoucke, S. (2006) A comparison of different project duration forecasting methods using earned value metrics. *International Journal of Project Management, 24*(4), 289-302.

Vanhoucke, S., and Vandevoorde, S. (2007). A simulation and evaluation of earned value metrics to forecast the project duration. *The Journal of the Operational Research Society, 58*(10), 1361-1374.

Visitacion, M. S. (2007, Debunking commonly held EVM myths. *Contract Management, 47*(9), 51-51-52.

Vitasek, K., and Geary, S. (2008). *A rose by another name: The tenants of PBL.* Bellevue, WA: Supply Chain Visions.

Vitasek, K., & Geary, S. (2008).Performance-based logistics redefines department of defense procurement. *World Trade, WT 100, 21*(6), 62-65.

Vogt, W. P. (2007). *Quantitative Research Methods for Professionals.* Boston, MA: Allyn and Bacon.

White, M. (2005). ERP systems: Do they work as project controls solutions? *Cost Engineering, 47*(6), 7-7-8.

Zimmerman, L. V. (2006). Don't create variances during planning. *AACE International Transactions,* (15287106), EV91-EV91-EV94.

Appendixes

Appendix A:

ANSI/EIA-748 Standards Description

EVMS Category Guidelines	Guideline Description
Organization	
Guideline 1	Define the authorized work elements for the program. A work breakdown structure (WBS), tailored for effective internal management control, is commonly used in this process.
Guideline 2	Identify the program organizational structure including the major subcontractors responsible for accomplishing the authorized work, and define the organizational elements in which work will be planned and controlled.
Guideline 3	Provide for the integration of the company's planning, scheduling, budgeting, work authorization and cost accumulation processes with each other, and as appropriate, the program work breakdown structure and the program organizational structure.
Guideline 4	Identify the company organization or function responsible for controlling overhead (indirect costs).
Guideline 5	Provide for integration of the program work breakdown structure and the program organizational structure in a manner that permits cost and schedule performance measurement by elements of either or both structures as needed.
Planning, Scheduling and Budgeting	
Guideline 6	Schedule the authorized work in a manner which describes the sequence of work and identifies significant task interdependencies required to meet the requirements of the program.
Guideline 7	Identify physical products, milestones, technical performance goals, or other indicators that will be used to measure progress.
Guideline 8	Establish and maintain a time-phased budget baseline, at

the control account level, against which program performance can be measured. Initial budgets established for performance measurement will be based on either internal management goals or the external customer negotiated target cost including estimates for authorized but undefinitized work. Budget for far-term efforts may be held in higher level accounts until an appropriate time for allocation at the control account level. On government contracts, if an over-target baseline is used for performance measurement reporting purposes, prior notification must be provided to the customer.

Guideline 9	Establish budgets for authorized work with identification of significant cost elements (labor, material, etc.) as needed for internal management and for control of subcontractors.
Guideline 10	To the extent it is practicable to identify the authorized work in discrete work packages, establish budgets for this work in terms of dollars, hours, or other measurable units. Where the entire control account is not subdivided into work packages, identify the far term effort in larger planning packages for budget and scheduling purposes.
Guideline 11	Provide that the sum of all work package budgets plus planning package budgets within a control account equals the control account budget.
Guideline 12	Identify and control level of effort activity by time-phased budgets established for this purpose. Only that effort which is unmeasurable or for which measurement is impracticable may be classified as level of effort.
Guideline 13	Establish overhead budgets for each significant organizational component of the company for expenses which will become indirect costs. Reflect in the program budgets, at the appropriate level, the amounts in overhead pools that are planned to be allocated to the program as indirect costs.
Guideline 14	Identify management reserves and undistributed budget.
Guideline 15	Provide that the program target cost goal is reconciled with the sum of all internal program budgets and management reserves.

Accounting Considerations

Guideline 16	Record direct costs in a manner consistent with the budgets in a formal system controlled by the general books of account.
Guideline 17	When a work breakdown structure is used, summarize direct costs from control accounts into the work breakdown structure without allocation of a single control account to two or more work breakdown structure elements.
Guideline 18	Summarize direct costs from the control accounts into the contractor's organizational elements without allocation of a single control account to two or more organizational elements.
Guideline 19	Record all indirect costs which will be allocated to the contract.
Guideline 20	Identify unit costs, equivalent unit costs, or lot costs when needed.
Guideline 21	For EVMS, the material accounting system will provide for: Accurate cost accumulation and assignment of costs to control accounts in a manner consistent with the budgets using recognized, acceptable, costing techniques. Cost performance measurement at the point in time most suitable for the category of material involved, but no earlier than the time of progress payments or actual receipt of material. Full accountability of all material purchased for the program including the residual inventory.

Analysis and Management Reports

Guideline 22	At least on a monthly basis, generate the following information at the control account and other levels as necessary for management control using actual cost data from, or reconcilable with, the accounting system: Comparison of the amount of planned budget and the amount of budget earned for work accomplished. This comparison provides the schedule variance. Comparison of the amount of the budget earned and the actual (applied where appropriate) direct costs for the same work. This comparison provides the cost variance.

Guideline 23	Identify, at least monthly, the significant differences between both planned and actual schedule performance and planned and actual cost performance, and provide the reasons for the variances in the detail needed by program management.
Guideline 24	Identify budgeted and applied (or actual) indirect costs at the level and frequency needed by management for effective control, along with the reasons for any significant variances.
Guideline 25	Summarize the data elements and associated variances through the program organization and/or work breakdown structure to support management needs and any customer reporting specified in the contract.
Guideline 26	Implement managerial actions taken as the result of earned value information.
Guideline 27	Develop revised estimates of cost at completion based on performance to date, commitment values for material, and estimates of future conditions. Compare this information with the performance measurement baseline to identify variances at completion important to company management and any applicable customer reporting requirements including statements of funding requirements.

Revisions and Data Maintenance

Guideline 28	Incorporate authorized changes in a timely manner, recording the effects of such changes in budgets and schedules. In the directed effort prior to negotiation of a change, base such revisions on the amount estimated and budgeted to the program organizations.
Guideline 29	Reconcile current budgets to prior budgets in terms of changes to the authorized work and internal replanning in the detail needed by management for effective control.
Guideline 30	Control retroactive changes to records pertaining to work performed that would change previously reported amounts for actual costs, earned value, or budgets. Adjustments should be made only for correction of errors, routine accounting adjustments, effects of customer or management directed changes, or to improve the baseline

	integrity and accuracy of performance measurement data.
Guideline 31	Prevent revisions to the program budget except for authorized changes.
Guideline 32	Document changes to the performance measurement baseline.

Note. Adapted from "National Defense Industrial Association (NDIA) Program Management Systems Committee (PMSC) ANSI/EIA-748-A Standard for Earned Value Management Systems Intent Guide," *National Defense Industrial Association*, 2005, pp. 1-39.

Appendix B:

Request for Data Usage/ Information Release Request

INFORMATION RELEASE REQUEST

DATE: 6APR10

INSTRUCTIONS TO ORIGINATORS:

1. PRINT WITH BALLPOINT PEN OR TYPE.
2. SUBMIT AT LEAST FIFTY DAYS IN ADVANCE OF REQUESTED RELEASE DATE.
3. PROVIDE 10 COPIES OF THE MANUSCRIPT/MATERIAL TO CONTRACT MANAGEMENT.

EMPLOYEE (S) NAME AND TITLE	ORGANIZATION NAME	ORG. CODE	EXT.	REQUESTED RELEASE DATE:
[illegible]	[illegible] CORPORATION		5657	NLT 20MAY10

TITLE OF MATERIAL	NAME OF PUBLICATION OR OTHER MEDIUM OF RELEASE
[illegible]	DOCTORAL DISSERTATION
	IF PRESENTATION, GIVE LOCATION AND DATE OF MEETINGS

DESCRIPTION AND PURPOSE OF MATERIAL

DOCTORAL LEVEL RESEARCH TO [illegible] COST AND SCHEDULE [illegible] WITH PBL METRICS

CONTRACT NUMBER AND PROGRAM NAME

[illegible] AND [illegible]

ANSWER ALL THE FOLLOWING QUESTIONS BY CHECKING EITHER A YES OR NO BLOCK

	YES	NO
1. IS THIS MATERIAL IN CONNECTION WITH WORK PERFORMED UNDER:		
A. CONTRACTUAL PROGRAMS?	☒	☐
B. INDEPENDENT RESEARCH & DEVELOPMENT?	☐	☒
C. CORPORATE SPONSORED RESEARCH?	☐	☒
D. BID AND PROPOSAL?	☐	☒
2. DOES MATERIAL CONTAIN GOVERNMENT CLASSIFIED INFORMATION?	☐	☒
3. IS THE MATERIAL TO BE RELEASED OR TRANSFERRED TO FOREIGN NATIONALS? (OTHER THAN PUBLICLY ACCESSIBLE JOURNALS)	☐	☒

EMPLOYEE (S) SIGNATURE AND DATE: [signature] 6APR10

Director, Business Development Defense Programs or PRODUCT TEAM LEADER (Read and sign statement)

I certify that this material is unclassified, technically accurate, does not violate the contractor's proprietary rights, does not violate export restrictions, and is suitable for release.

[signature] SIGNATURE 26 May '10 DATE

APPROVED BY:	SIGNATURE:	DATE
EXPORT CONTROL (IF REQUIRED)	[signature]	5/28/10
LEGAL-INTELLECTUAL PROPERTY *	[signature]	5/25/10
CONTRACT MANAGEMENT: *	[signature]	5/25/10

Subject to May 14 2010 e-mail [illegible]

Appendix C:

Data Collection Instrument

Month	ORR	RGR	DMDT	CPI	SPI
Nov-04	85.9			2.249	1.494
Dec-04	86.4			1.001	1.005
Jan-05	88.0			1.117	1.130
Feb-05	82.8			1.030	1.082
Mar-05	87.7			1.090	1.072
Apr-05	87.0			1.042	1.047
May-05	95.0			1.033	1.035
Jun-05	86.0			1.033	1.033
Jul-05	85.0			1.022	1.023
Aug-05	90.9			0.997	1.013
Sep-05	80.4			0.985	1.005
Oct-05	94.4			0.974	0.996
Nov-05	97.0			1.025	1.018
Dec-05	93.0			1.093	1.020
Jan-06	98.0			1.143	1.016
Feb-06	96.7			1.160	1.000
Mar-06	88.8			1.085	1.003
Apr-06	94.8			1.052	1.002
May-06	99.0	48.5		1.273	0.763
Jun-06	97.0	196.0		1.390	0.367
Jul-05	93.0	97.8		1.434	0.933
Aug-05	93.2	118.7		1.352	1.013
Sep-06	92.8	49.6		1.412	1.032
Oct-06	95.8	58.0		1.425	1.063
Nov-06	90.9	68.5		1.323	1.071
Dec-06	96.7	58.9		1.093	1.070
Jan-07	98.2	84.8		1.143	1.078
Feb-07	98.8	33.0		1.129	1.037
Mar-07	97.2	68.0		1.147	1.057
Apr-07	96.3	81.8		1.131	1.031
May-07	97.9	51.3		1.199	1.025
Jun-07	98.5	46.3		1.212	1.013
Jul-07	95.5	27.3		1.165	0.995
Aug-07	96.2	41.1		1.133	0.371
Sep-07	97.4	68.2		1.294	1.000
Oct-07	98.7	32.8		1.132	0.938
Nov-07	97.0	34.5		0.991	0.336
Dec-07	97.5	30.5		1.297	0.969
Jan-08	96.8	89.5	75.0	1.379	0.671
Feb-08	96.7	53.7	75.0	1.147	0.962
Mar-09	96.3	19.4	75.0	1.291	0.970
Apr-08	96.5	43.4	74.0	1.185	1.004
May-08	92.4	37.8	74.0	1.167	0.964
Jun-08	96.8	33.0	74.0	1.245	0.987

Month	ORR	RGR	DMDT	CPI	SPI
Jul-08	93.3	32.5	75.0	1.181	0.985
Aug-08	93.0	38.3	75.0	1.186	0.958
Sep-08	93.6	88.7	75.0	1.195	0.956
Oct-08	93.3	49.1	39.4	1.163	0.972
Nov-08	98.6	33.1	39.4	1.025	0.756
Dec-08	97.1	91.5	39.4	0.905	0.653
Jan-09	95.1	91.4	37.0	0.927	0.910
Feb-09	97.6	34.9	37.0	1.026	1.028
Mar-09	96.4	62.7	37.0	1.042	1.016
Apr-09	93.4	36.7	49.4	0.999	0.990
May-09	95.9	36.3	49.4	1.034	0.993
Jun-09	96.0	24.9	49.4	1.053	0.994
Jul-09	97.6	12.7	35.0	1.010	1.025
Aug-09	97.7	49.2	35.0	1.009	1.003
Sep-09	97.7	47.1	35.0	0.979	1.009
Oct-09	98.2	20.1	36.7	1.009	0.934
Nov-09	98.3	23.6	36.7	1.047	0.934
Dec-09	98.2	42.1	35.7	0.879	1.000
Jan-10	97.7	53.5	39.5	0.975	1.011
Feb-10	99.1	63.0	39.5	1.065	1.021
Mar-10	95.3	43.1	39.5	1.123	1.022
Apr-10	95.3	36.4	65.7	1.052	1.044
May-10	94.5	44.6	55.7	1.110	1.049
Jun-10	94.4	49.93	65.7	1.104	1.052
Jul-10	95.6	61.43	70.3	1.063	1.040
Aug-10	95.8	78.9	70.3	1.092	1.044
Sep-10	97.3	60.68	70.3	1.082	1.038
Oct-10	92.1	32.95	72.7	1.030	1.036
Nov-10	97.5	14.30	72.7	1.062	0.998
Dec-10	97.3	19.04	72.7	1.216	0.999
Jan-11	95.6	33.31	75.5	1.146	1.037
Feb-11	97.4	0.0	75.5	1.144	1.022
Mar-11	95.3	40.7	76.5	1.135	1.040
Apr-11	99.6	32.4	71.0	1.055	1.059
May-11	99	36.9	71.0	1.092	1.053
Jun-11	95.1	110.0	71.0	1.082	1.043
Jul-11	93.8	99.1	80.2	1.077	1.019
Aug-11	94	97.5	80.2	1.000	0.997
Sep-11	99.3	68.3	80.2	1.004	0.991
Oct-11	97.4	46.1	82.8	0.989	1.030
Nov-11	97.4	38.52	82.8	0.920	0.958
Dec-11	97.3	33.01	93	1.215	0.999
Jan-12	97.9	56.579	93	1.146	1.007
Feb-12	98.7	51.389	91.4	1.144	1.022