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An Analysis of Construction Cost and Schedule Performance

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AN ANALYSIS OF CONSTRUCTION COST AND SCHEDULE

PERFORMANCE

THESIS

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AFIT/GEM/ENV/08-M02

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Abstract

Cost and schedule performance are widely accepted in the literature and in industry as effective measures of the success of the project management effort. Earned Value Analysis (EVA) is one method to objectively measure project cost and schedule. This research evaluates the cost and schedule performance of 1,322 completed United States Air Force (AF) Military Construction (MILCON) projects, executed from 1990 to 2005. The impact of Major Command (MAJCOM), Construction Agent (CA), facility type (CATCODE), individually and in combination, on the EVA metrics of Cost Performance Index (CPI), Time Performance Index (TPI), and CPI*TPI were evaluated. The results indicate that AF MILCON projects are typically executed either on or below their respective budgets, but typically take more time than expected for construction. This outcome implies that AF MILCON projects trade time performance in an effort to control costs. When cost and performance are given equal weight, the sacrifice made in time performance is greater than the benefit gained in cost performance.

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I – Introduction

The management of project cost, schedule, and quality has a long history in the construction industry. These three project parameters are frequently at odds with one another; project managers must actively manage tradeoffs among them until the project is complete. Air Force Instruction (AFI) 32-1021 defines MILCON as "any construction, development, conversion, or extension of any kind carried out with respect to a military installation. MILCON includes construction projects for all types of buildings, roads, airfield pavements, and utility systems costing $750,000 or more," (Department of the Air Force, 2003; p.21) though prior to 2003, projects costing more than $500,000 were considered as MILCON projects. Funds for MILCON projects are approved bi-annually by Congress through the Military Construction Appropriations Act, and approved MILCON projects have five years to be completed before the appropriation expires (Department of the Air Force, 2003). Given this, the total time needed for a MILCON project to go from planning to a completed facility usually ranges from three to five years (Department of the Air Force, 2000). The MILCON cycle consists of four elements: planning, programming, design, and construction.

Planning and Programming

The planning and programming phases of the MILCON project lifecycle take place at the base or wing level. The planning and programming processes identify estimated costs and scope of the project, typically including the mission impact of the new facility, the proposed project location, required utility runs, and any information regarding environmental impacts associated with the new facility. Installations "identify, develop, and validate MILCON projects." Major commands (MAJCOMs) "compile, validate, and submit" their AF MILCON programs to headquarters (HQ) AF (AFI 32-1021, 21). The output of the MILCON planning and programming process is the Department of Defense form 1391 (DD 1391) Military Construction Project Data. "The DD 1391, by itself, shall explain and justify the project to all levels of the AF, Office of the Secretary of Defense, Office of Management and Budget, and Congress." (Department of the Air Force, 2003: 21) Once the program is approved by the AF corporate structure, it is submitted to congress, and then signed into law in the president's budget; the programmed amounts (PAs) in the law become the projects' budgets (Department of the Air Force, 2003: 24).

Design and Construction

Projects that have been approved by congress and the president are able to move into the design and construction phases. While installations have a large role to play in the planning and programming of AF MILCON projects, the MAJCOMs retain budget and scope control in the design and construction phases. For the period included in this study, execution of approved AF MILCON projects has been delegated to the MAJCOM level. During the design phase, the basic requirements identified by the planning and programming process are developed into an actual facility design suitable for construction contractors to bid on. The design process is when the primary stakeholders in the project are identified and their requirements are documented in the project's drawings and specifications. Typically, the stakeholders include the MAJCOM project manager, the Construction Agent (CA) project manager, and representatives from the using organization and local civil engineer unit, as a minimum.

The construction phase of the AF MILCON process is when the actual facility gets built. The construction phase begins when the bidding documents are advertised and ends when all construction work is complete and has been accepted by the government. It is common for the government to accept beneficial occupancy when the facility is substantially complete. The contractor will typically have a punch list of small items remaining to be corrected before the contract is considered complete, but the facility is complete enough for the using agency to occupy and operate the facility.

MILCON Execution Agencies.

The MAJCOMs each have their own branches responsible for the design and construction of their AF MILCON projects. The MAJCOM MILCON management offices can choose between three agencies to execute their programs: the US Army Corps of Engineers (USACE), the US Naval Facilities Engineering Command (NAVFAC), and the Air Force Center for Engineering and the Environment (AFCEE). USACE, NAVFAC, and AFCEE are referred to as design and construction agents (CA) (AFI 32-1023, Ch 5-6). The size of the program that can be executed by AFCEE is limited by the AF MILCON Program Management Plan to five percent of the amount executed by USACE.

Motivation

Today's AF budget resources are being stretched ever thinner in support of the global war on terrorism and fleet modernization requirements (Moseley, 2006). Increasing construction budgets and aging infrastructure means that the AF must apply its limited capital investment dollars in the most effective manner possible to ensure adequate support of the mission (*America's aging infrastructure,* 2007). Table 1, DoD MILCON Budget and its Percentage of the Total Budget for FYs 2004-2007, shows how the MILCON budget as a percentage of the total defense budget has been increasing over the last four years (Department of Defense, 2007). To ensure optimum mission support, the efficacy of the AF MILCON program needs to be optimized to the maximum extent possible.

Table 1 – DoD MILCON and Total Budget and its Percentage FYs 2004-2007

FY	MILCON	Total	MILCON percentage
2004	$6,137	$490,621	1.25 %
2005	$7,260	$505,796	1.44 %
2006	$8,938	$491,815	1.8 %
2007	$12,614	$463,205	2.7 %

Note. Housing MILCON not included

All dollar amounts in millions

Problem Statement

The AF needs to allocate scarce MILCON resources for maximum positive impact on the mission. This research intends to determine if there is statistically significant variation in the cost and schedule performance of projects based on MAJCOM, CA, facility type, or any combination of these three factors. This research investigated if any MAJCOM or MAJCOMs achieve higher levels of cost and schedule performance than any other MAJCOMs, as well as if there are certain MAJCOM and CA combinations that achieve higher levels of cost and schedule performance than other combinations. In addition, this research investigated if there are variations in MAJCOM or CA performance with respect to the constructed facility type. These differences, should they exist, will be used to inform AF leaders about the cost and schedule performance of the agencies associated with AF MILCON project delivery. This information can then be shared with all AF MILCON project managers to ensure the program delivers the maximum possible benefit to the AF.

Research Questions

1. Is there a statistically significant difference in the ability of MAJCOMs to successfully accomplish projects with respect to cost and schedule performance measures as compared to the other MAJCOMs?
2. Is there a statistically significant difference in the ability of CAs to successfully accomplish projects for each MAJCOM with respect to cost and schedule performance measures as compared to other MAJCOM and CA combinations?

3. Is there a statistically significant difference in the ability of construction agents to successfully accomplish projects for each MAJCOM with respect to cost and schedule performance measures for different types of facilities as compared to other types of facilities?
4. Can the differences in success between construction agents as determined through research questions one, two and three, if any, be attributed to pre-project planning processes?

Data and Analysis Methodology

Analysis will be performed on projects with the following selection criteria:

1. All project locations across the AF.
2. Minimum project value at the MILCON spending level. This level was $500,000 for FY95 to FY02 and $750,000 for FY03 to FY06.
3. All projects will be more than 95% complete between FY90 and FY05.
4. Due to differences in funding and contracting policies, no military family housing projects or Non-Appropriated Funds (NAF) will be included in this study.

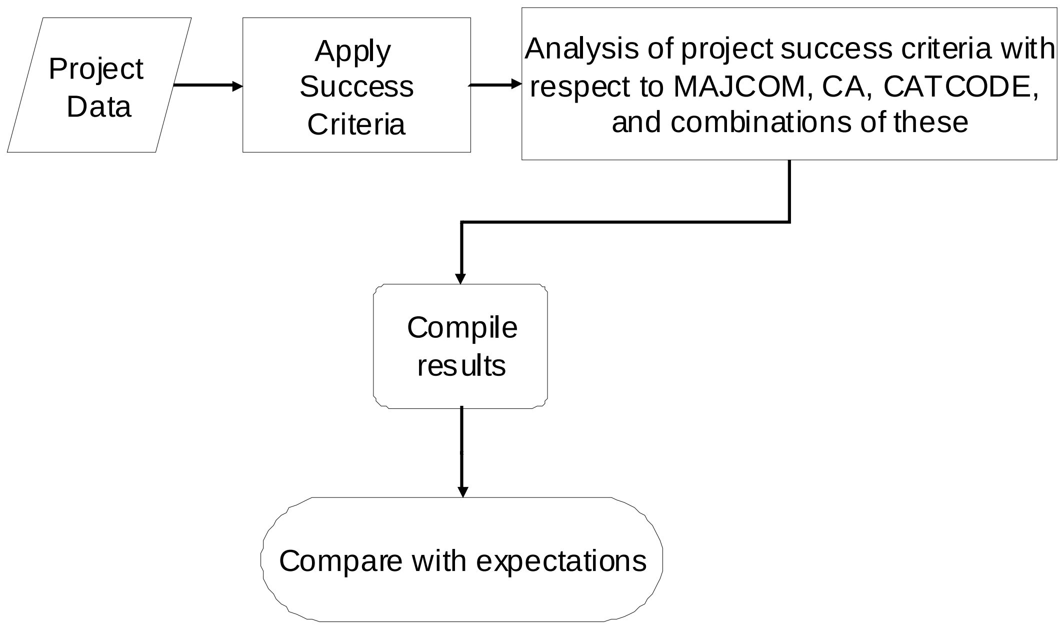

Figure 1 Research Flow Chart

The methodology flow chart in Figure 1 was used to conduct the research process. The data for this effort was collected from the AF Automated Civil Engineer System – Project Management (ACES-PM) information system. ACES-PM is the system of record for all Air Force construction projects. The report from ACES-PM contains data from 1,659 AF MILCON projects from 1990 to 2005 that are at least 95 percent complete. The ACES-PM data was analyzed using Analysis of Variance (ANOVA) techniques to objectively measure the differences between each CA's ability to complete projects that address the cost and schedule performance measures.

Thesis Overview

The remainder of this thesis is organized into four chapters. Chapter Two will present a review of the previous research conducted in the areas of project success factors, project success criteria, and the impact of pre-project planning on project success. Chapter Three will present the data analysis and exploratory research methodology. Chapter Four presents the results of the data analysis, and Chapter Five presents the conclusions limitations and contributions of the research, and areas for future research.

II. Literature Review

The project management literature has developed critical success factors (CSFs) and criteria for measuring project success. However, the literature shows limited consensus regarding a comprehensive list of CSFs. Although, there is also a lack of consensus regarding an all-encompassing suite of success criteria that delivers consistent results for all project stakeholders, there is a growing consensus regarding particular CSFs and success criteria that are applicable to all facility construction projects. Therefore, this chapter covers the development of the project management field and the techniques used by academics and practitioners in this field to complete projects successfully. The emerging CSFs and success criteria with the most concurrence in the literature will be used in this research in Chapters 3 and 4 to analyze Air Force Military Construction (AF MILCON) program project data.

Development of the Project Management Discipline

Network Techniques were first applied to project management in the 1950s and 1960s. Network techniques are characterized by separating a project into a series of inter-connected subtasks known as the work breakdown structure (WBS). The tasks within the WBS have cost and time allocated to their accomplishment. Two models are widely used to analyze and monitor the accomplishment of tasks within the WBS: the program evaluation and review technique (PERT) and critical path method (CPM). The PERT was developed by the United States (US) Navy in cooperation with Booz-Allen Hamilton and the Lockheed Corporation to manage the Polaris submarine and missile program in 1958. Dupont developed the CPM during the same period. The PERT has wide application in research and development projects, while the CPM has garnered acceptance in the construction industry. The two methods are quite similar; the academic community frequently combines them for educational presentation. While the PERT was strictly focused on managing project timelines using probabilistic techniques, the CPM used deterministic time estimates. CPM was designed to help manage time and cost trade-offs. Network techniques like the PERT and CPM allow managers to discern a critical path whose activities cannot be delayed without adversely affecting the project's timeline. The PERT and the CPM also identify activities that can be delayed for a certain amount of time without delaying the project as a whole; these items are said to have slack or float (Meredith and Mantel, 2000, 307). By monitoring the critical path throughout the project, managers can apply resources where they will provide the greatest benefit to the overall project.

The application of PERT and CPM reinforced the importance of schedule and cost performance in project management; managers were trained to focus on how to improve project cost, schedule, and quality performance (Dvir & Lechler, 2003:1). Additionally, the use of earned value analysis or management (EVA or EVM, respectively) supports project manager's ability to control project cost and schedule. EVA facilitates cost and schedule control because its performance indices are calculated from cost and schedule variances; these are used to forecast project cost and schedule performance at completion. Because EVA gives indications early in the project's life-cycle about the cost and schedule performance of the project at completion, managers can take corrective actions to ensure timely, on-budget delivery (Anbari, 2003,12). Cost, -

schedule, and quality performance have come to be known as the "iron triangle" of project management (Jha and Iyer, 2007)

Facility Project Critical Success Factor Development

In 1982, Rockart introduced the concept of critical success factors (CSFs) and defined them as "those few key areas of activity in which favorable results are absolutely necessary for a particular manager to reach his or her goals." Although Rockart's CSFs were originally introduced in the context of information systems, they have since been applied to projects in other disciplines.

Ashley, Lurie, and Jaselskis (1987) found that projects benefited from emphasis in "planning effort (construction and design), project manager goal commitment, project team motivation, project manager technical capabilities, scope and work definition, and control systems." Their study focused on the difference between average and outstanding projects; it generated an initial list of approximately 2,000 factors. The list was derived from literature review and construction project personnel interviews. Similar factors were then combined, resulting in 46 factors that were subjectively grouped into five major categories: 1) management, organization and communication, 2) scope and planning, 3) controls, 4) environmental, economic, political, and social, and 5) technical. Input from several construction project personnel representing both owners and contractors was obtained; 11 of the 46 factors from the list of 2,000 were selected for further analysis. A survey and structured interview of construction personnel from eight companies was then conducted. The purpose of the second survey and construction interview was to determine if the factors derived from the first set of interviews could be statistically correlated to project success.

The results of the objective and subjective data from the study were statistically analyzed using several different techniques. Two-sample hypothesis tests were accomplished to determine whether the differences in average percentages found were statistically significant. Correlation analysis was then done to determine if the factors had a causal effect on construction project success. The analysis found 6 of the 11 factors, planning effort (construction and design), project manager goal commitment, project team motivation, Project Manager (PM) technical capabilities, scope and work definition, and control systems achieved statistically significant differences between the mean values of the average and outstanding projects (Ashley, Lurie, and Jaselskis, 1987:72).

Sanvido, Grobler, Parfitt, Guvenis, and Coyle (1992) were the first to apply Rockart's (1982) CSFs specifically to construction. Even though their investigation uncovered many definitions of success, common success criteria began to emerge. Designers, owners, and contractors all recognized the financial needs of the other parties; owners need projects completed on time and on budget while designers and contractors need profits. Additionally, all three parties agree that projects free from litigation are more likely to be considered successful (Sanvido et al., 1992:96-97). After analysis of 16 projects, Sanvido et al (1992) recommended four CSFs for construction projects in order of priority: the facility team; contracts, changes, and obligations; facility experience; and optimization information. Interestingly, poor quality design documents were found in both successful and unsuccessful projects, but projects with functional facility teams were able to work around this deficiency (Sanvido et al., 1992: 110).

According to Gibson and Hamilton (1994:10) pre-project planning for a capital facility is defined "as the process of developing sufficient strategic information for owners to address risk and decide to commit resources to maximize the chance for a successful project". Since Rockart's (1982) CSFs were applied to project management many researchers have found CSFs that are related to the pre-project planning stages.

Gibson and Hamilton (1994) divided pre-project planning into four subprocesses: organize for pre-project planning; select alternatives; develop project definition package; and make decision. Gibson and Hamilton (1994) found a "positive, quantifiable, relationship" (p. x) between effort expended during the pre-project planning phase and the ultimate success of the project. The effort expended during pre-planning "directly affects the cost and schedule predictability of the project" (p. x). Survey and interview instruments were used extensively by Gibson and Hamilton (1994) to determine the impact of pre-project planning on project success.

In 1999, Chua, Kog, and Loh's article "Critical Success Factors for Different Project Objectives" investigated whether the CSFs related to achieving cost, schedule, or quality performance objectives were independent; for example, are the CSFs related to cost performance the same as the CSFs for schedule performance? The study found that each project objective produced a different set of CSFs; however, adequacy of plans and specifications and constructability emerged as the two most CSFs for all three project objectives. PM competency and PM commitment and involvement were also common to all three objectives at differing levels of significance (Chua, Kog, and Loh, 1999: 147).

Evolution of Facility Project Success Criteria

Concurrent with the development of CSFs through the 1980s, researchers were also investigating project success criteria. Researchers began to recognize that construction projects have many stakeholders with different objectives depending on the phase of the project (de Wit, 1986: 13).

Even as project management was emerging as a formal discipline in the 1950s managers recognized that project success primarily involves meeting cost, schedule, and budget goals (Dvir and Lechler, 2003:1, Freeman and Beale, 1988:68). Gaddis (1954) discussed the importance of the project manager's skill to balance emphasis between performance, budget, and time requirements and the constant conflict between them. Baker, Murphy, and Fisher (1980) conducted a study of 650 completed National Aeronautics and Space Administration projects and found that cost and schedule performance were correlated with project success, but were not found to be linearly related to perceived success or failure. Additionally, cost and schedule performance were not part of 29 perceived management characteristics significantly related to perceived project success or failure. The latter result was attributed to the fact that the projects studied were already completed, and that the importance of cost and schedule performance can diminish as time passes and managers forget how critical the budget and timeline were during a project's execution phase. By the mid-1980s, researchers began to differentiate between the success of the project itself and the success of the project management effort. Success criteria that focus solely on cost, schedule, and quality primarily measure the efficacy of the project management effort (de Wit, 1986: 13).

Pinto and Slevin (1988) found that the concept of project success was ambiguously understood by project managers and loosely defined in the literature. Additionally, some projects can initially be perceived as failures but then be viewed as major successes as time passes, or vice versa (Pinto and Slevin, 1988: 67). One study found that the most frequently used success criteria in the literature were budget performance, schedule performance, client satisfaction, and project manager/team satisfaction (Ashley, Lurie, and Jaselskis, 1988: 69). Pinto and Slevin (1988) introduced the project implementation success criteria of technical validity, organizational validity, and organizational effectiveness. A project is technically valid if it works as intended. A project is organizationally valid if it is “right” for the client and contributes to improved organizational effectiveness. Lastly, organizational effectiveness “is concerned with determining whether…it is contributing to an improved level of organizational effectiveness in the client’s organization” (Pinto and Slevin, 1988: 68-69). Pinto and Slevin (1988) hypothesized that cost and schedule performance were important success criteria, but not the only success criteria.

A seemingly straightforward way to measure the success of a project is to compare the results of the project to the objectives laid out for the project before it was undertaken. However, problems arise when some objectives are in conflict with others; this becomes readily apparent when the objectives of different stakeholders are considered. Objectives can change with each major phase of the project over its life-cycle; this further complicates the measurement of project success. Lastly, there is a hierarchical dimension to project success as each level of management of an organization can have different, sometimes conflicting, objectives (de Wit, 1986: 13).

In 1992 Freeman and Beale introduced a technique to objectively measure the criteria of scope, quality, cost, and duration using discounted cash flow methods like Net Present Value (NPV). DCF-based project success criteria utilize concepts from engineering economics to determine if a project was a success. Freeman and Beale (1992) hypothesized that from the viewpoint of any stakeholder, if the PV of the revenues is greater than the PV of the costs, then the project can be considered successful. This study analyzed the DCFs associated with a commercial high-rise building in Sydney, Australia. The DCFs were analyzed from several points of view to determine if there are success criteria common to both points of view. The conclusion was that "scope, quality, cost, and duration" (p 16) could be utilized in a DCF paradigm to develop project success measures.

Griffith, Gibson, Hamilton, Tortora, and Wilson (1999 categorized projects by their cost, schedule, and quality performance. Objective values for project quality were calculated by comparing the project's design capacity with its actual output. The project success index is calculated from a formula that assigns values to budget achievement, schedule performance, percent capacity attained six months after completion, and plant utilization attained six months after completion. A limitation of the Griffith et al. (1999) study is that the project must produce measurable outputs; therefore, it is limited to facilities with quantifiable outputs, such as factories, refineries, power plants, and communications facilities. Projects whose outputs are not directly quantifiable are not well suited to the project success index. For instance, the increase in an organization's effectiveness after the construction of a new corporate headquarters would be very difficult to objectively measure.

Chan, Scott, and Lam (2002) analyzed 20 studies published from 1990 through 2000 and found that 13 different success criteria were advocated by these studies. However, 18 of the 20 studies used time, cost, and quality as components of success. Furthermore, three studies published in the late 1990s used the iron triangle as the sole means of measuring success (Chan, Scott, Lam, 2002:122).

By the year 2000, researchers were beginning to include subjective measurements of project success criteria in addition to the well-established objective criteria. Items such as project management team teamwork in addition to the traditional iron triangle criteria were evaluated using survey and interview techniques to capture the viewpoints of different project stakeholders (Hughes, Tippett, and Thomas, 2004).

Anbari (2003) introduced simplified and extended EVA metrics to facilitate implementing EVA on real-world projects. EVA supports the simultaneous management of "project scope, time, and cost" (Anbari, 2003:12). EVA uses four key parameters to evaluate performance: Planned Value (PV); Budget at Completion (BAC); Actual Cost (AC); and Earned Value (EV). The Cost Performance Index (CPI) is calculated as the ratio of the budgeted of work performed over the actual cost of work performed. The Schedule Performance Index is calculated as the ratio of actual costs of work performed over the budgeted cost of the work scheduled. The Time Performance Index (TPI) is analogous to the CPI; it is calculated using fields from the earned value parameter. However, the TPI is calculated with units of time instead of currency; it is the ratio of budgeted amount of time for work performed over the actual amount of time used for work performed (Meredith and Mantel, 2000). EVA metrics are widely understood and EVM is used throughout the project management industry for all types of projects. The US Federal Government has used EVA and EVM on large acquisition programs for decades (Anbari, 2003).

III. Methodology

Introduction

This research seeks to uncover if there are differences in the cost and schedule performance of the Military Construction (MILCON) projects with respect to different Major Commands (MAJCOMs), construction agents (CAs), facility category code (CATCODE), or some combination of these three characteristics. The Earned Value Analysis (EVA) metrics of Cost Performance Index (CPI), Time Performance Index (TPI), and the product of these two, CPI*TPI, were used as indicators of a MILCON project's cost and schedule performance. These metrics were then analyzed using analysis of variance statistical techniques.

Source Data

The data for this study were taken from the Automated Civil Engineer System—Project Management (ACES-PM) module. ACES-PM is the system of record the Air Force (AF) uses to track construction project data from the planning phase through to the completion of construction. The system tracks a number of descriptors and metrics related to the construction process; of interest for this research effort are the milestone schedule dates and cost data. Specific fields from ACES-PM used in this research are summarized and described in Table 2.

Table 2

Description of Data Fields Utilized in this Research

Field	Definition	Description
		Cost Fields
CMAT	Contract Modification Amount Total	The total change to the original contract price
OCA	Original Contract Amount	The contracted price for the project; it is the quantity of the winning contractor's bid.
PA	Programmed Amount	The approved budget for the project
SIOH	Supervision, Inspection, Over Head	Management fee charged by CAs to the Air Force (AF) to manage project execution
		Schedule Fields
BOD	Beneficial Occupancy Date	The date that the contractor has completed enough of the work for the using agency to move in and begin operating.
ECD	Estimated Completion Date	The completion date specified in the original contract.
NTP	Notice to Proceed	The notice to proceed is issued by the government after contract award; it notifies the contractor that work can begin on the site.

Analysis Metrics

The ACES-PM data was evaluated using the principles of earned value analysis (EVA) as discussed in Chapter 2. EVA uses ratios of budgeted (planned) versus actual performance as metrics. While there are numerous EVA metrics available, this research focuses on the CPI, TPI, and the product of these two metrics, CPI*TPI. Table 3 provides the EVA variables and metrics along with the equations needed to calculate them (Meredith and Mantel 2000: 430-431).

Table 3

Explanation of EVA Variables and Metrics

Acronym	Description	ACES-PM Fields Utilized
	Variables	
BCWP	Budgeted Cost of Work Performed	PA
ACWP	Actual Cost of Work Performed	OCA + CMAT + SIOH
STWP	Scheduled Time of Work Performed	ECD - NTP
ATWP	Actual Time of Work Performed	BOD - NTP
	Metrics	
CPI	Cost Performance Index	BCWP / ACWP
TPI	Time Performance Index	STWP / ATWP

The dynamics of the EVA metrics are best explained using an example. Figure 3 shows the CPI, TPI, and CPI*TPI data for three notional projects. The performance categories, shown as colored rectangles in Figure 3, are taken from Anbari's (2003) article on EVA methods and extensions. Project A depicts CPI and TPI scores of 0.85 and a CPI*TPI score of 0.7225. The CPI and TPI metrics alone only indicate that the project completed late and over budget. By analyzing the CPI*TPI metric it becomes clear that this project performed very poorly overall. Project B represents a project that exceeded its budget, but was completed earlier than anticipated; the CPI, TPI, and CPI*TPI values are 0.9, 1.1, and 0.99 respectively. For project B, analyzing CPI and TPI metrics alone would indicate contradictory results. The CPI*TPI metric in this case shows that the project can be considered borderline successful because the additional cost was offset by a sufficiently early completion. Lastly, project C shows how a project with good performance in CPI and TPI can achieve excellent overall performance when both metrics are considered together. These notional projects demonstrate how the CPI*TPI metric allows us to systematically identify projects that achieved truly exceptional cost and schedule performance and projects that have had cost exchanged for time, or vice versa.

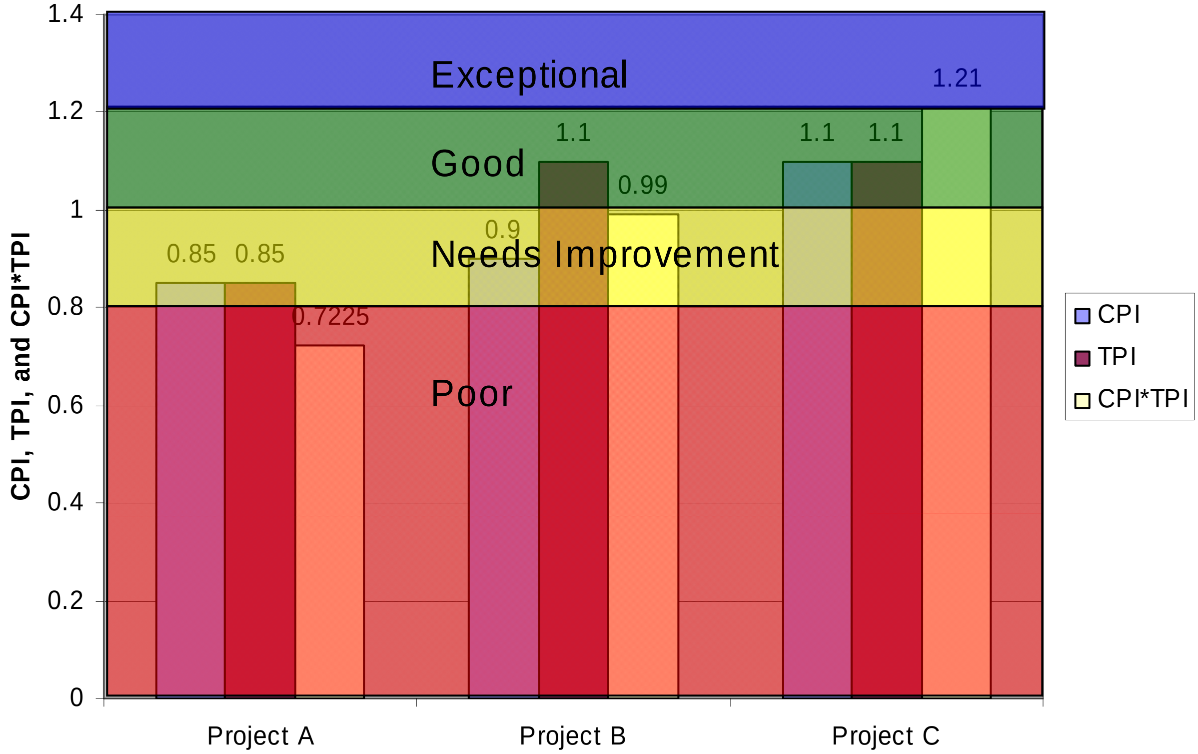

Figure 2 EVA Metric Notional Data

Hypotheses, and Analysis of Variance (ANOVA) tests

The independent variables (IVs) used in this research MAJCOM, MAJCOM-CA, MAJCOM-CA-CATCODE, CA, CA-CATCODE, CATCODE, and MAJCOM-CATCODE-CA. The dependent variables in this research are Construction Performance Index (CPI), Time Performance Index (TPI), and CPI*TPI. Recall from the research questions in Chapter 1 that the first research question seeks to uncover if there are differences in the cost and schedule performance of the IVs.

The hypotheses in this research involve the cost and schedule performance associated with each MILCON project in the dataset, categorized by MAJCOM, CA, and CATCODE. The first hypothesis is that the cost performance of the projects conducted by each IV cannot be statistically differentiated from each other. To test this hypothesis, the dataset is analyzed by IV. Table 4 presents the null and alternate hypothesis of the one-way ANOVA used to test this hypothesis.

If a statistically significant result is returned by the ANOVA, exhaustive ANOVA testing was conducted to determine which IVs exhibit statistically significant variation; this procedure is accomplished for all of the DVs.

Table 4

ANOVA Hypothesis Tests for Performance Metrics

Hypotheses	Description Hypotheses
	Null Hypothesis
H_0: $\mu_1 = \mu_2 = \mu_3 \ldots \mu_n = 0$	Null hypothesis that there is no difference in the metric performance between each MAJCOM, where n is the number of MAJCOMs evaluated.
	Alternative Hypothesis
H_a : at least one μ is not equal to the others	Alternative hypothesis that at least one metric's results is different that the other MAJCOMs.

McClave, Benson, and Sincich (2005:567)

Additional hypotheses tests were conducted to answer research questions two and three from Chapter 1. Specifically, the hypothesis above was tested for CA, CATCODE, MAJCOM-CA, MAJCOM-CATCODE, CA-CATCODE and MAJCOM-CA-CATCODE. The dataset for each IV is organized by identifying which specific IV values are associated with each project. Every project in the dataset is associated with a MAJCOM, CA, and CATCODE. Grouping projects by like IVs enables the comparison of the variation of the IVs using ANOVA tests. For example, if in Air Combat Command (ACC) tasks the Omaha district of the Corps of Engineers (NWO) to build a new runway (CATCODE 11), the project will have a MAJCOM value of ACC, a CA value of NWO, and a CATCODE of 11. In the MAJCOM analysis it will be grouped with other ACC projects, in the CA analysis, it will be grouped with other NWO projects, and in the CATCODE analysis it will be grouped with other airfield pavements projects. The project will also have an IV of ACC-NWO for the MAJCOM-CA analysis, an IV of ACC-NWO-11 for the MAJCOM-CA-CATCODE analysis, and so on until all of the IVs are exhausted.

The IVs are separated into groups that cannot be statistically distinguished from each other through exhaustive ANOVA tests where IVs are exhaustively removed from the dataset until the ANOVA fails to reject the null hypothesis. The IVs that were removed in the previous step are then subject to additional ANOVA testing to determine if there is significant variation between the groups identified in the first round of tests. The process continues until all of the significant variation for each IV is identified.

Interpretation of Results

The ANOVA tests separate the IVs into groups that have performance metric values that cannot be statistically differentiated from each other. By using the mean values associated with each IV, the results are categorized into three groups: Statistically Significant Low (SSL), Statistically Significant Medium (SSM), and Statistically Significant High (SSH) metric categories.

The SSH category will consist of IVs that have the highest metric mean values for that particular test. The SSL metric category will consist of IVs that have the lowest mean metric values. Lastly, the SSM metric category consists of IVs that have mean metric values that are between the high and low metric categories.

IV. Analysis and Results

Distribution of Analysis Metrics

The Cost Performance Index (CPI), Time Performance Index (TPI), and CPI*TPI metric distributions for the Major Commands (MAJCOMs), Construction Agents (CAs), category code (CATCODE), MAJCOM-CA, and MAJCOM-CA- CATCODE were evaluated. A minimum sample size of 30 projects was established for the MAJCOMs, CAs, MAJCOM-CAs and CATCODEs to minimize the effect of small sample size on the results. The minimum sample for the MAJCOM-CA-CATCODE analysis was reduced to 10 because there were no MAJCOM-CA-CATODE combinations that could be associated with 30 projects. Table 5 shows the categories and quantities of Independent Variables (IVs) analyzed in this research.

Table 5

Categories, Minimum Sample, and Number of Items in each Category

IV Category	Quantity of IVs
MAJCOM (N ≥ 30 projects)	8
CA (N ≥ 30 projects)	14
CATCODE (N ≥ 30projects)	11
MAJCOM-CATCODE (N ≥ 30 projects)	8
CA-CATCODE (N ≥ 10 projects)	29
MAJCOM-CA (N ≥ 30 projects)	11
MAJCOM-CA-CATCODE (N ≥ 10 projects)	10

As discussed in Chapter 3, the CPI, TPI, and CPI*TPI metrics for each MAJCOM, MAJCOM-CA, CA, CA-CATCODE, and MAJCOM-CA-CATCODE were compiled; one-way ANOVAs were then used to test the hypotheses identified in Table 4. The upcoming sections in this chapter identify the hypothesis tests associated with each research question put forth in Chapter 1. The data for each hypothesis test is presented in tabular form.

The distribution of all projects included in the dataset is shown in Figure 3; there are 1,322 projects represented in this histogram. Figure 3 shows that the data are approximately normal: mound shaped and approximately symmetrical about the mean.

Histograms of the distributions of each MAJCOMs' CPI, TPI, and CPI*TPI results can be found in Appendix A. The key assumptions for ANOVAs are that the distribution is approximately normal, that the sample is randomly selected, and that the population variances are equal.

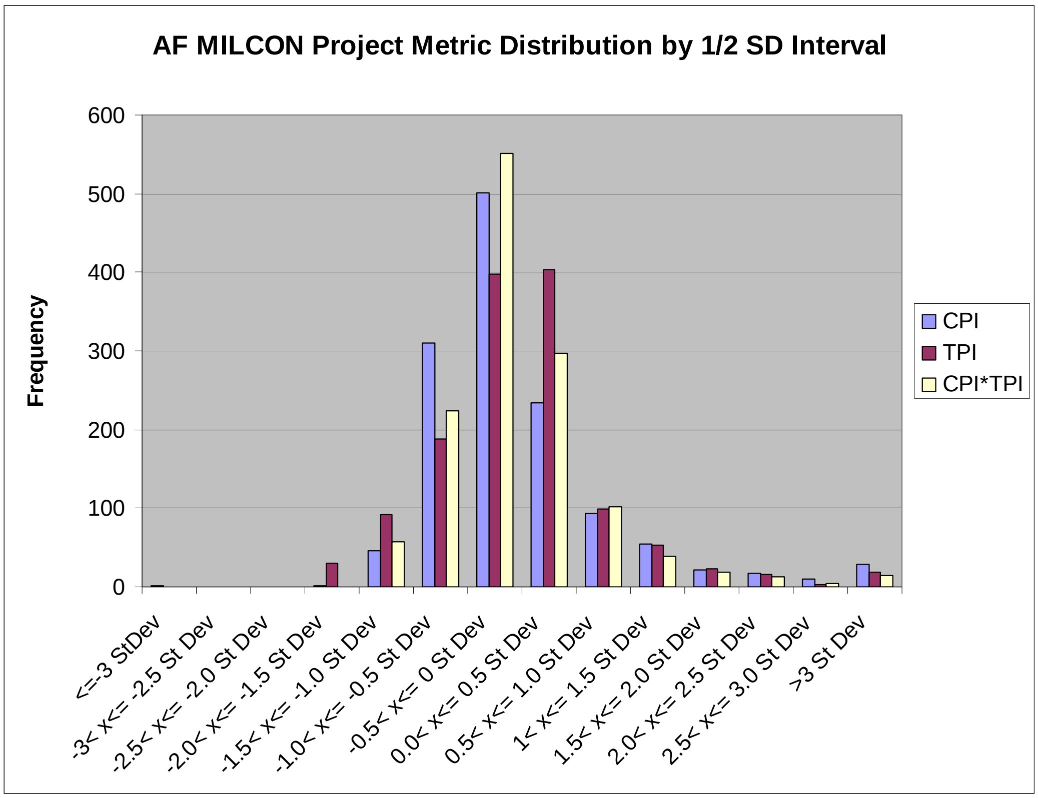

Figure 3 AF CPI, TPI, and CPI*TPI Distribution, N=1322

Research Question 1

Is there a statistically significant difference in the ability of MAJCOMs to successfully accomplish projects with respect to cost and schedule performance measures as compared to all other AF MILCON projects?

MAJCOM CPI Performance

The CPI descriptive statistics for the MAJCOMs are shown in Table 6. Recall from Table 3 that the CPI is calculated as the ratio of the project's budgeted costs over its actual cost, and CPI values greater than one indicate a project that has been completed for less than the amount budgeted for it, projects with a CPI equal to one have been delivered exactly on their budget, and projects with a CPI less than one have exceeded their budget. Table 6 includes: the abbreviation used for the MAJCOM; the MAJCOM's full name; the column labeled "count" indicates how many projects in the dataset were executed by that MAJCOM; the "sum" column is the sum of the metrics for the respective MAJCOM; the "average" column represents the arithmetic mean of the metric; and the "variance" column is self-explanatory. Note that the average CPI value for each MAJCOM is greater than one; this indicates that, on average, all of the MAJCOMs are able to accomplish their projects for less than their respective budgets. USAFE and PAF have achieved the greatest average CPI metrics in this dataset; although the higher variance for PAF indicates that they are not as consistent as USAFE in CPI performance.

Table 6

MAJCOM Names and CPI Descriptive Statistics N = 1266

MAJCOM	*Full Name*	*Count*	*Sum*	*Average*	*Variance*
ACC	Air Combat Command	233	245.28204	1.0527126	0.0403624
AETC	Air Education and Training Command	160	168.21663	1.0513539	0.0449447
AFMC	Air Force Materiél Command	156	171.30893	1.0981342	0.0791698
AFRC	Air Force Reserve Command	119	129.64733	1.0894734	0.0479776
AFSOC	Air Force Special Operations Command	44	48.458225	1.1013233	0.0690533
AFSPC	Air Force Space Command	84	90.951134	1.0827516	0.053906
AMC	Air Mobility Command	167	178.80492	1.0706882	0.0659235
PAF	***Pacific Air Forces***	***174***	***199.85886***	***1.1486141***	***0.110321***
USAFE	***United States Air Forces in Europe***	***129***	***155.34605***	***1.2042329***	***0.0820641***

Note. ***Bold and Italics*** indicate SSH peformance; **Bold** indicates SSL performance

Table 7 is the standard ANOVA results table used in this research. The "SS" column represents the "Sum of Squares" terms, the "df" column represents the degrees of freedom, and the "MS" column represents the "Mean Square" terms, used to calculate the test statistic for the ANOVA test. The "F" column is the test statistic calculated from the aforementioned values. The "p-value" is the probability that the null hypothesis is true, and the "Fcrit" column is the critical value of the F-test statistic at the 0.05 level of significance.

The one-way ANOVA results in Table 7 show that there is significant variation in the CPI metrics for the MAJCOMs. MAJCOMs were then systematically removed from the dataset and ANOVAs were accomplished on those remaining. Systematically removing MAJCOMs from the dataset until the p-value exceeds 0.05 illuminates which MAJCOMs are the source of the variation that drives the p-value to the level that the null hypothesis can be rejected. In this case, removing USAFE and PAF from the analysis resulted in a p-value large enough to fail to reject the null hypothesis. Further analysis of USAFE and PAF did not reveal differences significant enough to reject the null hypothesis; therefore, USAFE and PAF average CPI performance cannot be distinguished from each other. Table 7 summarizes the results of the ANOVA tests. PAF and USAFE have achieved Statistically Significant High (SSH) CPI performance with mean metric values of 1.15 and 1.20 respectively. The remaining MAJCOMs all exhibit Statistically Significant Medium (SSM) CPI performance with mean values from 1.05 to 1.10. The data does not support the conclusion that any MAJCOM has statistically significant low (SSL) CPI performance.

Table 7

MAJCOM CPI One-Way ANOVA Results

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
			All MAJCOMs			
Between Groups	2.8770	8	0.3596	5.4848	7.9424E-07	1.9458
Within Groups	82.4195	1257	0.0656			
Total	85.2965	1265				
			All MAJCOMs except USAFE and PAF			
Between Groups	0.3455	6	0.0576	1.0419	0.3964	2.1080
Within Groups	52.8298	956	0.0553			
Total	53.1752	962				
			USAFE and PAF Only			
Between Groups	0.22916	1	0.2292	2	0.1279	3.8725
Within Groups	29.58974	301	0.0983			
Total	29.8189	302				

MAJCOM TPI Performance

The MAJCOM TPI descriptive statistics are shown in Table 8. Recall from Chapter 3 that the TPI is calculated as the ratio of the estimated scheduled time of work performed over the actual time of work performed. Therefore, projects with TPI values that are greater than one were completed ahead of schedule, those with a TPI equal to one were on schedule, and projects with a TPI less than one were behind schedule. In contrast with the CPI performance in the previous section, only two MAJCOMs managed to achieve average TPI values that were greater than one: ACC and PAF. Systematically removing MAJCOMs from the dataset as discussed in the previous section about CPI performance produced the results shown in Table 9.

Table 8

MAJCOM TPI Descriptive Statistics N=1266

Groups	*Count*	*Sum*	*Average*	*Variance*
ACC	***233***	***245.7191***	***1.0546***	***0.1106***
AETC	160	155.6502	0.9728	0.1651
AFMC	156	149.1658	0.9562	0.1446
AFRC	119	110.1880	0.9259	0.3858
AFSOC	44	34.8823	0.7928	0.0998
AFSPC	84	81.3369	0.9683	0.1141
AMC	167	152.1073	0.9108	0.1344
PAF	174	177.4403	1.0198	0.3315
USAFE	129	113.8751	0.8828	0.2035

Note. ***Bold and Italics*** indicate SSH peformance; **Bold** indicates SSL performance

The one-way ANOVA results shown in Table 9 show that there is variation between the MAJCOMs' average TPI performance and that the null hypothesis is rejected. Removing ACC from the dataset eliminates enough variation to fail to reject the null hypothesis at the 0.05 level of significance. Other MAJCOMs were removed from the dataset to determine if alternative MAJCOM removal schemes would have a similar affect on the p-value without success. ACC is the only MAJCOM in the SSH TPI category with an average value of 1.05. The remaining MAJCOMs are all in the SSM TPI performance category with average TPI values that range from 0.79 to 1.01. The data does not support the conclusion that any MAJCOM demonstrates SSL TPI performance.

Table 9

MAJCOM TPI One-way ANOVA Results

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
			All MAJCOMs			
Between Groups	5.2628	8	0.6578	3.4554	0.0006	1.9458
Within Groups	239.3134	1257	0.1904			
Total	244.5762	1265				
			All MAJCOMs except ACC			
Between Groups	2.91703	7	0.4167	1.9991	0.0524	2.0185
Within Groups	213.6597	1025	0.2084			
Total	216.5767	1032				

MAJCOM CPI*TPI Performance

Recall from Figure 3, Chapter 3 that the CPI*TPI metric allows projects to be compared to each other based on cost and schedule performance, with equal weight given to each. Table 10 summarizes the descriptive statistics for the CPI*TPI metric for this dataset. Two of the average values for the CPI*TPI metric are less than one, indicating that most of the MAJCOMs are capable of achieving good cost and schedule performance on average. Only AMC and AFSOC failed to achieve an average CPI*TPI score that was greater than or equal to one.

Table 10

MAJCOM CPI*TPI ANOVA Descriptive Statistics

Groups	*Count*	*Sum*	*Average*	*Variance*
ACC	233	258.9516	1.1114	0.1682
AETC	160	165.6678	1.0354	0.2793
AFMC	156	165.3614	1.0600	0.3312
AFRC	119	126.0657	1.0594	1.6142
AFSOC	44	38.6932	0.8794	0.1737
AFSPC	84	88.0035	1.0477	0.1835
AMC	167	165.1664	0.9890	0.3142
PAF	174	202.3238	1.1628	0.5070
USAFE	129	133.1804	1.0324	0.2509

Even though two MAJCOMs had average CPI*TPI values lower than one, the ANOVA results shown in Table 11 reveal that the differences in MAJCOM CPI*TPI performance is not statistically significant. No further ANOVAs were conducted for this metric because this test indicates that the means of the CPI*TPI metric are not statistically distinguishable from each other.

Table 11

MAJCOM CPI*TPI One-Way ANOVA Results

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	4.9359	8	0.6170	1.4917	0.1555	1.9458
Within Groups	519.8980	1257	0.4136			
Total	524.8339	1265				

Research Question 2 –

Is there a statistically significant difference in the ability of construction agents to successfully accomplish projects for each MAJCOM with respect to cost and schedule performance measures as compared to all other AF MILCON projects?

MAJCOM-CA CPI Performance

The IV used to investigate the ability of construction agents to successfully accomplish projects for each MAJCOM with respect to cost and schedule performance was MAJCOM-CA. As discussed earlier in this paper, the MAJCOMs are responsible for all phases of the MILCON program, but they must choose a CA to execute the design and construction phases of the MILCON process on their behalf. The IVs used to investigate the performance of the MAJCOMs and their CAs are given by the MAJCOM responsible for the project, then the CA that executed the design and construction phases. For example, the MAJCOM-CA of PAF-POA represents the pairing of Pacific Air Forces with the Alaska district of the US Army Corps of Engineers (USACE). The data to answer research question two was analyzed in the same way as in the previous section. Recall from Table 5 that there are 11 MAJCOM-CAs with a sample size of 30 or more. Similar to the tables in the previous section, Table 12 shows each MAJCOM-CA's abbreviation, full name, number of projects executed, sum of project metrics, arithmetic mean, and variance respectively. The ANOVA table follows the same format as the previous section.

Table 12 shows that the MAJCOM-CAs on average are able to execute their projects for less than their budgets. AETC-SWF is the only exception. Table 13 shows the ANOVA results for the all the MAJCOM-CAs. MAJCOM-CAs were then systematically removed to determine the source of the variation that prevents acceptance of the null hypothesis.

Table 12

MAJCOM-CA Names and CPI Descriptive Statistics N = 514

MAJCOM-CA	*Full Name*	*Count*	*Sum*	*Mean*	*Variance*
ACC-SPL	Air Combat Command - Los Angeles District	32	32.450812	1.0140879	0.0247639
AETC-SAM	Air Education and Training Command - Mobile District	34	36.621854	1.0771133	0.0295169
AETC-SWF	**Air Education and Training Command - Fort Worth District**	**50**	**49.984017**	**0.9996803**	**0.0417906**
AFMC-SPK	Air Force Materiaél Command - Sacramento District	36	43.621322	1.2117034	0.2605415
AFRC-LRL	Air Force Reserve Command - Louisville District	46	50.480784	1.0974083	0.0317695
AFSOC-SAM	Air Force Special Operations Command - Mobile District	33	35.660816	1.0806308	0.053858
AFSPC-NWO	Air Force Space Command - Omaha District	45	47.112964	1.0469548	0.041297
AMC-NWS	Air Mobility Command - Seattle District	37	42.438489	1.1469862	0.1604724
PAF-POA	Pacific Air Forces - Alaska District	99	111.07402	1.1219598	0.0992014
USAFE-AF	US Air Forces in Europe - Air Force	38	44.680523	1.1758032	0.0630678
USAFE-NAU	US Air Forces in Europe - European District	64	75.093357	1.1733337	0.0604494

Note. ***Bold and Italics*** indicate SSH peformance; **Bold** indicates SSL performance

Table 13 shows the results of the ANOVA when AETC-SWF is removed from the dataset; it indicates a failure to reject the null hypothesis. Other MAJCOM-CAs were investigated; none produced a similar change in p-value. The ANOVA results indicate that AETC-SWF has SSL CPI performance. The data does not support any conclusions about MAJCOM-CAs achieving SSH CPI performance. However, given the fact that the MAJCOM-CAs are achieving average CPI performance that is greater than one, a lack of SSH performers does not necessarily imply mediocre CPI performance for the AF MILCON program when considered in its entirety.

Table 13

MAJCOM-CA CPI One-Way ANOVA Results

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
			All MAJCOM-CAs			
Between Groups	2.0093	10	0.2009	2.5574	5.0818E-03	1.8495
Within Groups	39.5191	503	0.0786			
Total	41.5284	513				
			All MAJCOM-CAs except AETC-SWF			
Between Groups	1.3662	9	0.1518	1.8392	0.0593	1.9005
Within Groups	37.4714	454	0.0825			
Total	38.8376	463				

MAJCOM-CA TPI Performance

The time performance descriptive statistics of the MAJCOM-CAs are shown in Table 14. In contrast with the CPI results from the previous section, there are only four MAJCOM-CAs with average TPI values that are greater than one. This indicates that the majority of the MAJCOM-CAs have trouble delivering their projects within the time allotted for their completion. AFSOC-SAM has the lowest average TPI score of 0.7568.

Table 14

MAJCOM-CA TPI Descriptive Statistics N = 514

Groups	*Count*	*Sum*	*Average*	*Variance*
ACC-SPL	32	34.7136	1.0848	0.0260
AETC-SAM	34	35.7718	1.0521	0.1749
AETC-SWF	**50**	**47.4638**	**0.9493**	**0.2074**
AFMC-SPK	36	36.6202	1.0172	0.1411
AFRC-LRL	**46**	**35.7569**	**0.7773**	**0.0634**
AFSOC-SAM	**33**	**24.9738**	**0.7568**	**0.0734**
AFSPC-NWO	45	42.1831	0.9374	0.0727
AMC-NWS	37	34.4408	0.9308	0.1209
PAF-POA	***99***	***112.8121***	***1.1395***	***0.4532***
USAFE-AF	**38**	**31.8694**	**0.8387**	**0.0897**
USAFE-NAU	**64**	**54.4726**	**0.8511**	**0.1801**

Note. ***Bold and Italics*** indicate SSH peformance; **Bold** indicates SSL performance

Table 15 summarizes the results of the ANOVA tests that were accomplished for TPI results of the MAJCOM CAs. The p-value from the ANOVA that included all of the MAJCOM-CAs causes the rejection of the null hypothesis. MAJCOM-CAs were then systematically removed from the dataset and ANOVA tests re-accomplished until the p-value exceeded the significance level of 0.05. Unlike the ANOVAs conducted up to this point in the research, five IVs had to be removed from the analysis before the null hypothesis could be accepted. A third ANOVA was accomplished on the five IVs that were separated from the original sample to determine if there was variation between these

IVs. Table 15 shows that the null hypothesis for the five MAJCOM-CAs was rejected. MAJCOM-CAs were then removed from the dataset to find the source of the variation between these groups; PAF-POA proved to be the source of the variation. The previously described sequence of ANOVA tests revealed that PAF-POA is the only MAJCOM-CA that demonstrates SSH TPI performance.

Table 15

MAJCOM-CA TPI One-way ANOVA Results

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
All MAJCOM-CAs						
Between Groups	8.3603	10	0.8360	4.4973	4.1929E-06	1.8495
Within Groups	93.5057	503	0.1859			
Total	101.8660	513				
PAF-POA, AFSOC-SAM, AFRC-LRL, USAFE-NAU, and USAFE-AF Removed						
Between Groups	0.68608	4	0.1715	1.6102	0.1736	2.4221
Within Groups	19.0673	179	0.1065			
Total	19.75336	183				
PAF-POA, AFSOC-SAM, AFRC-LRL, USAFE-NAU and USAFE-AF only						
Between Groups	7.1412	5	1.4282	6.2165	1.6025E-05	2.2419
Within Groups	74.4384	324	0.2297			
Total	81.5796	329				
AFSOC-SAM, AFRC-LRL, USAFE-NAU and USAFE only						
Between Groups	1.013231	4	0.2533077	1.906602	0.1102378	2.4115902
Within Groups	30.02595	226	0.1328582			
Total	31.03918	230				

MAJCOM-CA CPI*TPI Performance

Table 16 shows the descriptive statistics for the MAJCOM-CA CPI*TPI metric in a manner identical to the previous presentation of this material. For CPI*TPI there are five IVs with average performance that is greater than one, and six with average performance that is less than one. This result is expected because so many MAJCOM-CAs had average CPI performance that was greater than one and average TPI performance that was less than one. Once again, ANOVAs were conducted to discern the source of variation in the dataset.

Table 16

MAJCOM-CA CPI*TPI ANOVA Descriptive Statistics N = 514

Groups	*Count*	*Sum*	*Average*	*Variance*
ACC-SPL	32	35.0591	1.0956	0.0427
AETC-SAM	34	38.5710	1.1344	0.2359
USAFE-NAU	64	61.8469	0.9664	0.2215
USAFE-AF	38	37.9228	0.9980	0.2125
PAF-POA	***99***	***125.0828***	***1.2635***	***0.6502***
AMC-NWS	37	39.1640	1.0585	0.2461
AFSPC-NWO	45	44.0293	0.9784	0.1084
AFSOC-SAM	**33**	**27.3693**	**0.8294**	**0.1449**
AFRC-LRL	**46**	**39.1811**	**0.8518**	**0.1056**
AFMC-SPK	36	45.8659	1.2741	0.7902
AETC-SWF	50	48.9458	0.9789	0.4200

Note. ***Bold and Italics*** indicate SSH peformance; **Bold** indicates SSL performance

The results of the ANOVAs are shown in Table 17; they indicate the null hypothesis when all MAJCOM-CA combinations are included must be rejected. Systematically removing MAJCOM-CAs from the analysis revealed that PAF-POA, AFSOC-SAM, and AFRC-LRL were the source of the variation. Performing an ANOVA on the previously mentioned MAJCOM-CAs reveals that among these groups there is still significant variation; IVs were removed from this dataset until the null hypothesis could be accepted at the 0.05 significance level. Removing PAF-POA fails to reject the null. The analysis shows that PAF-POA has achieved SSH CPI*TPI performance, while AFSOC-SAM and AFRC-LRL have achieved SSL CPI*TPI performance.

Table 17

MAJCOM CPI*TPI One-Way ANOVA Results

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
		All MAJCOM-CAs				
Between Groups	11.0559	10	1.1056	3.3520	0.0003	1.8495
Within Groups	165.9071	503	0.3298			
Total	176.9630	513				
		PAF-POA, AFSOC-SAM, AFRC-LRL removed				
Between Groups	3.1468	7	0.4495	1.5889	0.1377	2.0375
Within Groups	92.7968	328	0.2829			
Total	95.9436	335				
		PAF-POA, AFSOC-SAM, AFRC-LRL only				
Between Groups	7.7992	2	3.8996	9.3342	0.0001	3.0476
Within Groups	73.1103	175	0.4178			
Total	80.9095	177				
		AFSOC-SAM and AFRC-LRL only				
Between Groups	0.0096	1	0.0096	0.0790	0.7794	3.9651
Within Groups	9.3889	77	0.1219			
Total	9.3985	78				

The MAJCOM-CA CPI*TPI analysis reveals that TPI performance is outweighing CPI performance in this dataset. Recall from the CPI portion of the MAJCOM-CA analysis that the data did not support the conclusion that anyone was achieving SSH CPI performance and that AETC-SWF was the only MAJCOM-CA achieving SSL CPI performance. The TPI portion of the MAJCOM-CA analysis showed that PAF-POA was the only MAJCOM-CA combination to achieve SSH TPI performance while AETC-SWF, AFRC-LRL, AFSOC-SAM, USAFE-NAU, and USAFE-AF achieved SSL performance. Even though PAF-POA did not achieve SSH CPI performance, it still achieved SSH CPI*TPI performance. Similarly, AFSOC-SAM and AFRC-LRL were not identified as SSL CPI performers, but were identified as SSL performers by the CPI*TPI analysis. Another interesting point is that AETC-SWF was listed as a SSL CPI and TPI performer, but was not found to be SSL in the CPI*TPI analysis.

Combining the CAs with the MAJCOMs has produced unexpected results because the MAJCOMs with statistically significant variation in their performance identified in the analysis for research question one do not appear in the results of research question two. Recall from research question one that PAF and USAFE displayed SSH CPI performance, and that ACC displayed SSH TPI performance; these were the only statistically significant findings for the MAJCOMs. In the results just discussed for research question two, there is no relationship between superior performance by a MAJCOM in one category and superior performance by the corresponding MAJCOM-CA in the same category. For example, ACC had superior TPI performance among the MAJCOMs, but PAF-POA was the only MAJCOM-CA with SSH TPI performance.

The CAs were analyzed on their own to investigate if there was a relationship between how CAs scored on their own versus when they are paired with a MAJCOM.

The same techniques used to analyze the MAJCOMs and MAJCOM-CAs were used analyze the CAs.

CA CPI Performance

The CAs' abbreviations, district names, and CPI descriptive statistics are shown in Table 18, and the CPI ANOVA results are shown in Table 19. Similar to the MAJCOMs, all of the CAs are able to achieve average CPI values that exceed one; this indicates that on average their projects are delivered below their budgets.

Table 18

CA Names and CPI Descriptive Statistics N = 1,004

MAJCOM-CA	*Full Name*	*Count*	*Sum*	*Mean*	*Variance*
AF	***Air Force***	***49***	***56.8404***	***1.1600***	***0.0562***
LRL	Louisville District	74	80.6759	1.0902	0.0340
NAU	***European District***	***65***	***76.2732***	***1.1734***	***0.0595***
NWK	Kansas City District	31	33.0594	1.0664	0.0460
NWO	Omaha District	95	98.9493	1.0416	0.0267
NWS	Seattle District	84	94.5195	1.1252	0.0973
POA	Alaska District	105	117.8510	1.1224	0.0950
SAM	Mobile District	130	139.8474	1.0757	0.0477
SAS	Savannah District	66	69.1314	1.0474	0.0286
SOU	South Division (Navy)	66	68.7287	1.0413	0.0211
SPK	Sacramento District	69	78.7467	1.1413	0.1724
SPL	Los Angeles District	46	47.9292	1.0419	0.0479
SWF	**Fort Worth District**	**74**	**74.4721**	**1.0064**	**0.0335**
SWT	Tulsa District	50	54.8453	1.0969	0.0581

Note. ***Bold and Italics*** indicate SSH peformance; **Bold** indicates SSL performance

The removal of SWF, NAU, and AF allows the null hypothesis to not be rejected at the 0.05 level of significance as shown in Table 19. SWF, NAU, and AF were then analyzed on their own to determine the amount of variation between these groups. The analysis reveals that NAU and AF have achieved SSH CPI performance while SWF has achieved SSL CPI performance.

Table 19

CA CPI One-Way ANOVA Results

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
			All CAs			
Between Groups	2.2504	13	0.1731	2.8858	4.1045E-04	1.7300
Within Groups	59.3868	990	0.0600			
Total	61.63724	1003				
			SWF, NAU, and AF removed			
Between Groups	1.0140	10	0.1014	1.6185	0.0967	1.8424
Within Groups	50.4324	805	0.0626			
Total	51.44633	815				
			SWF, NAU, and AF only			
Between Groups	1.1723	2	0.5861	12	0.0000	3.0448
Within Groups	8.9544	185	0.0484			
Total	10.1267	187				
			NAU and AF only			
Between Groups	0.0050	1	0.0050	0.0867	0.7690	3.9258
Within Groups	6.5068	112	0.0581			
Total	6.511844	113				

CA TPI Performance

Table 20 shows the descriptive statistics associated with the CAs TPI performance; the CAs demonstrate a mix of average TPI values that indicate a mixed record of delivering projects either before or on their estimated completion dates. Table 21 shows the results of the ANOVA tests that were run on the CA TPI data.

Table 20

CA TPI Descriptive Statistics

Groups	*Count*	*Sum*	*Average*	*Variance*
AF	**49**	**41.5288**	**0.8475**	**0.0847**
LRL	**74**	**61.3440**	**0.8290**	**0.0842**
NAU	**65**	**55.6047**	**0.8555**	**0.1785**
NWK	31	39.7782	1.2832	1.1712
NWO	95	96.8137	1.0191	0.0820
NWS	84	81.8564	0.9745	0.1435
POA	105	118.4521	1.1281	0.4341
SAM	**130**	**118.4070**	**0.9108**	**0.1231**
SAS	66	65.4323	0.9914	0.0809
SOU	66	73.3881	1.1119	0.1818
SPK	69	71.9423	1.0426	0.1694
SPL	46	48.7709	1.0602	0.0548
SWF	74	73.6757	0.9956	0.1899
SWT	50	41.7309	0.8346	0.0925

Note. ***Bold and Italics*** indicate SSH peformance; **Bold** indicates SSL performance

The ANOVA results reveal that the null hypothesis cannot be accepted with all of the CAs included. CAs were systematically removed from the dataset until the p-value was large enough to fail to reject the null hypothesis; in this case AF, LRL, NAU, SAM, and SWT had to be removed. Another ANOVA test was accomplished on the previously mentioned five CAs; this test revealed that there is not enough variation in these CAs to reject the null. AF, LRL, SAM, and SWT all have SSL TPI metrics; therefore they exhibit SSL TPI performance when compared to the rest of the sample.

Table 21

CA TPI One-way ANOVA Results

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
All CAs						
Between Groups	12.2549	13	0.9427	4.9940	0.0000	1.7300
Within Groups	186.8759	990	0.1888			
Total	199.1308	1003				
AF, LRL, NAU, SAM, and SWT removed						
Between Groups	3.5948	8	0.4494	1.9454	0.0510	1.9532
Within Groups	144.8260	627	0.2310			
Total	148.4208	635				
AF, LRL, NAU, SAM, and SWT only						
Between Groups	0.43581	4	0.1090	0.9405	0.4405	2.3965
Within Groups	42.0500	363	0.1158			
Total	42.48578	367				

CA CPI*TPI Performance

Table 22 shows the descriptive statistics for the CPI*TPI metric. There are fewer CAs with average CPI*TPI performance that is less than one than TPI alone; this is expected since all of the CAs had CPI performance that was greater than one. The ANOVA test results are shown in Table 23.

Table 22

CA CPI*TPI ANOVA Descriptive Statistics

Groups	*Count*	*Sum*	*Average*	*Variance*
AF	49	48.8292	0.9965	0.1996
LRL	**74**	**66.8969**	**0.9040**	**0.1294**
NAU	**65**	**63.1826**	**0.9720**	**0.2202**
NWK	31	48.3588	1.5600	5.6515
NWO	**95**	**100.7350**	**1.0604**	**0.1203**
NWS	84	91.8299	1.0932	0.2396
POA	***105***	***131.5419***	***1.2528***	***0.6233***
SAM	**130**	**127.9492**	**0.9842**	**0.1954**
SAS	**66**	**68.6446**	**1.0401**	**0.1131**
SOU	66	76.73823	1.1627005	0.236797
SPK	69	83.83953	1.2150657	0.556913
SPL	46	50.43073	1.0963202	0.086258
SWF	74	75.55522	1.0210164	0.333554
SWT	**50**	**45.74324**	**0.9148649**	**0.152918**

Note. ***Bold and Italics*** indicate SSH peformance; **Bold** indicates SSL performance

The initial ANOVA test indicates that the null must be rejected. CAs were systematically removed until the p-value was large enough to fail to reject the null hypothesis; this resulted in the removal of LRL, NAU, NWO, POA, SAM, and SAS from the data. A new ANOVA test was run on the seven previously mentioned CAs; this test revealed that the removal of POA allowed the null hypothesis to be accepted for the set of seven CAs. The analysis indicates that POA has SSH CPI*TPI performance while LRL, NAU, NWO, SAM, and SAS have SSL CPI*TPI performance.

Table 23

CA CPI*TPI One-Way ANOVA Results

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
			All CAs			
Between Groups	18.3428	13	1.4110	3.3242	0.0001	1.7300
Within Groups	420.2166	990	0.4245			
Total	438.5595	1003				
			SAS, NAU, POA, SWT, SAM, LRL, and NWO removed			
Between Groups	3.1468	7	0.4495	1.5889	0.1377	2.0375
Within Groups	92.7968	328	0.2829			
Total	95.9436	335				
			SAS, NAU, POA, SWT, SAM, LRL, and NWO only			
Between Groups	7.6258	6	1.2710	5.2581	0.0000	2.1142
Within Groups	139.7127	578	0.2417			
Total	147.3385	584				
			SAS, NAU, SWT, SAM, LRL, and NWO only			
Between Groups	1.4818	5	0.2964	1.8758	0.0971	2.2330
Within Groups	74.8917	474	0.1580			
Total	76.37358	479				

After analyzing the CAs' CPI, TPI, and CPI*TPI performance a trend begins to emerge. As previously discussed, the CPI, TPI, and CPI*TPI performance of the MAJCOMs does not appear related to MAJCOM-CA performance. No MAJCOM identified as SSH or SSL in any metric is in the same category for the same metric in the MAJCOM-CA analysis; the same is not true for the CAs. In this research, if a CA appears in a particular performance category for a specific metric for CAs alone, it is much more likely to appear in the same category for the MAJCOM-CA results. Table 4U summarizes these results. The bulk of the commonality between CA and MAJCOM-CA performance appears in the poor TPI category. There is only one such relationship in the CPI category, and two in the CPI*TPI category. This seems to indicate that the CAs have a consistently more dominant affect on the projects' TPI performance compared to the MAJCOMs.

One explanation of the comparatively large impact of CA on cost and schedule performance might be in the way that the metrics are calculated. The focus of this research is on the cost and schedule performance of construction projects; the metrics are all calculated with data from the construction phase of the project. The CAs have the greatest control over the activities that are ongoing during the construction phase; therefore, it appears logical that the presence of a CA in one category would be an indicator that the MAJCOM-CA with the same CA would appear in another category. Another explanation might be that the dynamics of the working relationship between particular MAJCOMs and a CA can have a negative impact on the TPI metric.

Research Question 3

Is there a statistically significant difference in the ability of MAJCOM-CAs to successfully accomplish projects with respect to cost and schedule performance measures for different types of facilities as compared to each other?

The ability of MAJCOM-CAs to accomplish projects with respect to cost and schedule performance was analyzed by integrating the category code (CATCODE) into the calculations. The CATCODE in ACES-PM is a five digit number; however, for this research it was truncated to two digits so that facility family group was analyzed, instead of specific facility. Analysis by facility family group allows for similar facilities to be aggregated into larger samples for analysis without comparing dissimilar facility types. For example, the difference between an aircraft parking apron and a taxiway is not important to this research; the difference between an airfield pavement and a dormitory is. Even with using the two-digit category code, the minimum sample size of 30 had to be relaxed to 10; there were no CAs or MAJCOM-CAs that had built 30 of any particular facility family group. Table 24 provides the CATCODEs and the corresponding description of the facility type.

The research into the effect of facility type on cost and schedule performance led to analysis of the CATCODE, MAJCOM-CATCODE, CA-CATCODE, and MAJCOM-CA-CATCODE data. The effect of CATCODE on cost and schedule performance was analyzed on its own to determine if facility type on its own would be a predictor of cost and schedule performance independent of the other IVs.

CATCODE CPI Performance

Table 24 shows the descriptive statistics associated with each CATCODEs' CPI results; the CATCODEs all have average CPI values that are greater than one. This result is consistent with other portions of this research. Similar to the previous sections of this research, the minimum sample size for the CATCODE analysis is 30 projects to minimize the effect of small sample size on the cost and schedule performance metrics.

Table 24

CATCODE with Names and CPI Descriptive Statistics N = 1,095

CATCODE	*Description*	*Count*	*Sum*	*Mean*	*Variance*
11	***Airfield Pavements***	***79***	***93.774247***	***1.1870158***	***0.0753587***
13	Communication, Navigational Aids, and Airfield Lighting	37	42.444825	1.1471574	0.0690635
14	Local Area Network Operations Facilities	148	155.73568	1.0522681	0.0256009
17	Training Facilities	120	129.62211	1.0801843	0.0490122
21	Maintenance Facilities	222	240.49266	1.0833003	0.0700785
31	Research, Development, Test and Evaluation Laboratories	34	38.009649	1.1179309	0.0450128
44	Storage Facilities	39	42.983771	1.102148	0.0338089
61	Administration Facilities	68	75.895855	1.1161155	0.1454916
72	Dorms, Officers Quarters, and Dining Halls	191	199.43613	1.0441682	0.0266105
73	**Personnel Support Facilities**	**78**	**80.254912**	**1.0289091**	**0.032106**
74	**Indoor Morale, Welfare, and Recreation Facilities**	**79**	**81.465355**	**1.031207**	**0.0332661**

Note. ***Bold and Italics*** indicate SSH peformance; **Bold** indicates SSL performance

Table 25 shows the results of the ANOVA tests that were run on the CATCODE CPI data. The p-value for the first ANOVA indicates that there is significant variation present between the analysis groups; enough variation to reject the null hypothesis. CATCODEs were then systematically removed until the p-value raised enough to fail to reject the null; CATCODEs 11, 73, and 74 were removed. A third ANOVA was conducted on the CATCODEs that were removed which indicated that there was significant variation between the three remaining groups. The last ANOVA test was conducted on CATCODEs 73 and 74; this ANOVA indicates that CATCODE 11 has SSH performance while CATCODEs 73 and 74 have SSL performance.

Table 25

CATCODE CPI One-Way ANOVA Results

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
			All CATCODEs			
Between Groups	1.9759	10	0.1976	3.8187	4.3354E-05	1.8394
Within Groups	56.0884	1084	0.0517			
Total	58.0643	1094				
			All CATCODEs except 11, 73, and 74			
Between Groups	0.6739	7	0.0963	1.8148	0.0812	2.0203
Within Groups	45.1435	851	0.0530			
Total	45.8174	858				
			11, 73, and 74 only			
Between Groups	1.2948	2	0.6474	13.7824	0.0000	3.0346
Within Groups	10.9449	233	0.0470			
Total	12.2397	235				
			11 removed			
Between Groups	0.0002	1	0.0002	0.0063	0.9366	3.9022
Within Groups	5.0669	155	0.0327			
Total	5.0671	156				

CATCODE TPI Performance

Table 26 shows the descriptive statistics for each CATCODE's TPI performance. Consistent with previous TPI analyses in this research, there is only one CATCODE with an average TPI value that exceeds one; this indicates that all facilities except airfields are usually delivered after their estimated completion date.

Table 26

CATCODE TPI Descriptive Statistics N = 1,095

Groups	*Count*	*Sum*	*Average*	*Variance*
11	79	81.3435	1.0297	0.5520
13	37	35.7788	0.9670	0.2312
14	148	141.3239	0.9549	0.1168
17	120	114.0974	0.9508	0.3627
21	222	217.7522	0.9809	0.1582
31	34	32.5501	0.9574	0.2114
44	39	38.5882	0.9894	0.1373
61	68	67.0879	0.9866	0.1147
72	191	185.9028	0.9733	0.1469
73	78	69.6850	0.8934	0.2056
74	79	70.9345	0.8979	0.0892

Note. ***Bold and Italics*** indicate SSH peformance; **Bold** indicates SSL performance

Table 27 shows the results of the ANOVA tests that were run on the CATCODE TPI data. The p-value for the first ANOVA indicates that there is not significant enough variation present between the analysis groups to reject the null hypothesis; therefore the CATCODEs' TPI performance cannot be distinguished from each other in a statistically significant way.

Table 27

CATCODE TPI One-way ANOVA Results

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
			All CATCODEs			
Between Groups	1.2489	10	0.1249	0.6232	0.7950	1.8394
Within Groups	217.2553	1084	0.2004			
Total	218.5042	1094				

CATCODE CPI*TPI Performance

Table 28 summarized the descriptive statistics for the CATCODE CPI*TPI performance. All but two of the CATCODEs have average values that are greater than one; this indicates that the AF MILCON program is able to effectively exchange budget resources for time resources on most types of facilities and achieve average CPI*TPI values that are greater than one. The only exceptions are CATCODEs 73 and 74; recall that these two CATCODEs were identified as having SSL CPI performance in Table 24. It is not surprising that CATCODE 73 and would have the lowest average CPI*TPI scores.

Table 28

CATCODE CPI*TPI ANOVA Descriptive Statistics N = 514

Groups	*Count*	*Sum*	*Average*	*Variance*
11	79	95.3957	1.2075	0.5539
13	37	40.4378	1.0929	0.3098
14	148	148.9917	1.0067	0.1717
17	120	130.5913	1.0883	1.6092
21	222	236.6996	1.0662	0.2513
31	34	36.6650	1.0784	0.3076
44	39	42.2462	1.0832	0.2018
61	68	77.2700	1.1363	0.6002
72	191	192.3254	1.0069	0.1651
73	78	71.0222	0.9105	0.2230
74	79	72.5661	0.9186	0.0921

Note. ***Bold and Italics*** indicate SSH peformance; **Bold** indicates SSL performance

The results of the ANOVA test are shown in Table 29; the p-value is not small enough to reject the null. Therefore, the average CPI*TPI scores do not exhibit statistically significant variance. Even though CATCODE 11 achieved the highest averages for CPI, TPI, and CPI*TPI performance, the metrics were not large enough to be statistically significant in TPI or CPI*TPI.

Table 29

CATCODE CPI*TPI One-Way ANOVA Results

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
		All CATCODEs				
Between Groups	6.3255	10	0.6326	1.5571	0.1143	1.8394
Within Groups	440.3726	1084	0.4062			
Total	446.6981	1094				

MAJCOM-CATCODE CPI Performance

Table 30 summarizes the MAJCOM-CATCODE CPI descriptive statistics. Consistent with other parts of this research, the average CPI value for each MAJCOM-CATCODE is greater than one; this indicates that the MAJCOM-CATCODE combinations with $N \geq 30$ deliver projects for less than their respective budgets on average.

Table 30

MAJCOM-CATCODE CPI Descriptive Statistics N = 290

Groups	*Count*	*Sum*	*Average*	*Variance*
ACC-14	36	37.4904	1.0414	0.0226
ACC-21	54	55.9925	1.0369	0.0575
AETC-17	31	34.5214	1.1136	0.0493
AETC-72	36	38.2469	1.0624	0.0281
AFRC-21	38	40.6629	1.0701	0.0333
AMC-14	32	35.8893	1.1215	0.0196
AMC-21	32	34.6317	1.0822	0.1508
PAF-72	31	32.3932	1.0449	0.0181

Note. Bold and Italics indicate SSH peformance; Bold indicates SSL performance

Table 31 shows the results of the ANOVA test conducted on the data summarized in Table 30. The p-value is not small enough to reject the null hypothesis; therefore, these MAJCOM-CATCODEs have CPI performance that cannot be statistically distinguished from each other.

Table 31

MAJCOM-CATCODE CPI One-Way ANOVA Results

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
All MAJCOM-CATCODEs						
Between Groups	0.2581	7	0.0369	0.7783	0.6060	2.0421
Within Groups	13.3598	282	0.0474			
Total	13.6179	289				

MAJCOM-CATCODE TPI Performance

The average TPI performance of the MAJCOM-CATCODEs is shown in Table 32. The average TPI values are evenly mixed between values that are greater or less than one. This indicates that half of the MAJCOM-CATCODEs finish early, and half finish after their estimated completion dates.

Table 32

MAJCOM-CATCODE TPI Descriptive Statistics N = 290

Groups	*Count*	*Sum*	*Average*	*Variance*
ACC-14	36	40.1119	1.1142	0.1435
ACC-21	54	55.9925	1.0369	0.0575
AETC-17	31	31.1620	1.0052	0.0852
AETC-72	36	34.8968	0.9694	0.1969
AFRC-21	38	35.3026	0.9290	0.1563
AMC-14	32	29.5389	0.9231	0.1336
AMC-21	**32**	**26.5052**	**0.8283**	**0.0807**
PAF-72	31	33.0999	1.0677	0.2259

Note. Bold and Italics indicate SSH peformance; Bold indicates SSL performance

Table 33 shows the results of the ANOVA tests on the MAJCOM-CATCODE data. The ANOVA test on all of the MAJCOM-CATCODEs in Table 32 shows that the null hypothesis is rejected. MAJCOM-CATCODEs were then systematically removed from the data to until the p-value was large enough to fail to reject the null hypothesis. Removing the AMC-21 data from the ANOVA resulted in a failure to reject the null hypothesis that the average TPI performances of the remaining MAJCOM-CATCODEs were not statistically significantly different from each other. The ANOVA test revealed that AMC-21 displayed SSL TPI performance.

Table 33

MAJCOM-CATCODE TPI One-way ANOVA Results

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
All MAJCOM-CATCODEs						
Between Groups	2.0047	7	0.2864	2.1994	0.0345	2.0421
Within Groups	36.7205	282	0.1302			
Total	38.7252	289				
AMC-21 removed						
Between Groups	1.0837	6	0.1806	1.3248	0.2464	2.1348
Within Groups	34.2185	251	0.1363			
Total	35.30214	257				

MAJCOM-CATCODE CPI*TPI Performance

Table 34 summarizes the descriptive statistics for the MAJCOM-CATCODE CPI*TPI data. Six of the eight MAJCOM-CATCODEs have average CPI*TPI performance that is greater than one; indicating that these combinations deliver projects with good cost and schedule performance.

Table 34

MAJCOM-CATCODE CPI*TPI ANOVA Descriptive Statistics N = 290

Groups	*Count*	*Sum*	*Average*	*Variance*
ACC-14	36	42.1468	1.1707	0.2208
ACC-21	54	59.7201	1.1059	0.1531
AETC-17	31	35.2058	1.1357	0.2108
AETC-72	36	36.8827	1.0245	0.2054
AFRC-21	38	37.6438	0.9906	0.1818
AMC-14	32	33.4092	1.0440	0.2327
AMC-21	32	28.8278	0.9009	0.1834
PAF-72	31	34.2763	1.1057	0.2374

Note. Bold and Italics indicate SSH peformance; Bold indicates SSL performance

The results of the ANOVA test on the MAJCOM-CATCODE CPI*TPI data are shown in Table 35. The data does not have enough variation to reject the null hypothesis; therefore we cannot draw any conclusions about the average CPI*TPI performance of the MAJCOM-CATCODEs shown in Table 34.

Table 35

MAJCOM-CATCODE CPI*TPI One-Way ANOVA Results

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
All MAJCOM-CATCODEs						
Between Groups	1.8426	7	0.2632	1.3232	0.2390	2.0421
Within Groups	56.0995	282	0.1989			
Total	57.9420	289				

CA-CATCODE CPI Performance

The analysis up to this point has focused on IVs that have at least 30 projects in the sample. The data does not contain any CAs that have executed at least 30 projects of any particular CATCODE. A sample size of 10 was selected for this portion of the research to enable analysis of the CAs with respect to CATCODE. Table 36 shows the descriptive statistics for each CA-CATCODE combination tested in this research. There are 25 CA-CATCODEs with an average CPI value that is greater than one; there are four with average values that are less than one. These average CPI values indicate that the CA-CATCODEs usually deliver projects under or very close to, their allotted budgets.

Table 36

CA-CATCODE and CPI Descriptive Statistics N = 408

CA-CATCODE	*Count*	*Sum*	*Mean*	*Variance*
LRL-17	11	12.3458	1.1223	0.0582
LRL-21	14	14.8403	1.0600	0.0192
NAU-14	12	12.9959	1.0830	0.0939
NAU-72	12	14.0469	1.1706	0.0557
NWO-17	11	11.5341	1.0486	0.0144
NWO-61	13	13.2541	1.0195	0.0105
NWO-72	11	10.6175	0.9652	0.0132
NWO-74	11	10.8824	0.9893	0.0034
NWS-14	17	20.0172	1.1775	0.0395
NWS-17	11	11.4774	1.0434	0.0220
NWS-21	22	24.8598	1.1300	0.2189
POA-21	19	20.3367	1.0704	0.0238
POA-72	17	17.6473	1.0381	0.0102
POF-72	13	13.6741	1.0519	0.0311
SAM-14	13	13.1717	1.0132	0.0198
SAM-17	17	18.5114	1.0889	0.0368
SAM-21	21	23.6319	1.1253	0.1308
SAM-72	20	21.4662	1.0733	0.0227
SAS-21	15	16.1044	1.0736	0.0383
SOU-21	12	12.0964	1.0080	0.0106
SOU-72	14	13.6753	0.9768	0.0085
SPK-21	18	18.5561	1.0309	0.0631
SPL-21	10	9.8098	0.9810	0.0231
SWF-17	11	11.3019	1.0274	0.0228
SWF-61	11	11.1367	1.0124	0.0200
SWF-72	17	17.2905	1.0171	0.0187
SWT-21	13	13.2319	1.0178	0.0108
SWT-72	12	12.8515	1.0710	0.0405
TAC-11	10	11.2412	1.1241	0.0472

Note. ***Bold and Italics*** indicate SSH peformance;
Bold indicates SSL performance

Table 37 shows the results of the ANOVA test conducted on the CA-CATCODE combinations in Table 36; the data does not support any statistically significant differences between the CPI performances of these IVs.

Table 37

CA-CATCODE CPI One-Way ANOVA Results

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
			All CA-CATCODEs			
Between Groups	1.2079	28	0.0431	0.9633	0.5215	1.5061
Within Groups	16.9716	379	0.0448			
Total	18.1795	407				

CA-CATCODE TPI Performance

Table 38 summarizes the descriptive statistics for the TPI performance of the CA-CATCODE data analyzed in this research. Consistent with other TPI results in this research, the average TPI values are both above and below one; this indicates that consistent delivery of projects by their estimated completion date is not achieved for most CAs, regardless of facility type.

Table 38

CA-CATCODE TPI Descriptive Statistics N = 408

CA-CATCODE	*Count*	*Sum*	*Mean*	*Variance*
LRL-17	11	9.1721563	0.8338324	0.0357366
LRL-21	14	11.229731	0.8021236	0.1513553
NAU-14	12	9.5417978	0.7951498	0.0683521
NAU-72	12	10.253203	0.8544336	0.1004858
NWO-17	11	11.508694	1.0462449	0.0787665
NWO-61	13	10.657267	0.8197898	0.0357178
NWO-72	11	12.589695	1.1445177	0.1062976
NWO-74	11	10.953972	0.9958156	0.0298678
NWS-14	17	17.000216	1.0000127	0.1007893
NWS-17	11	9.5607656	0.8691605	0.0244947
NWS-21	22	20.92494	0.9511336	0.1078519
POA-21	19	22.115834	1.1639913	0.8412744
POA-72	***17***	***21.14214***	***1.243655***	***0.2734643***
POF-72	13	10.714656	0.8242043	0.0857793
SAM-14	13	11.902372	0.9155671	0.0888704
SAM-17	17	15.374546	0.9043851	0.1019795
SAM-21	21	21.678879	1.0323276	0.1462136
SAM-72	20	17.423576	0.8711788	0.0465052
SAS-21	15	15.933981	1.0622654	0.1150167
SOU-21	12	12.41942	1.0349516	0.0767756
SOU-72	14	16.698239	1.1927314	0.1896116
SPK-21	18	15.841074	0.8800597	0.0533654
SPL-21	10	9.951388	0.9951388	0.0075044
SWF-17	11	10.690572	0.9718702	0.1406937
SWF-61	11	11.778176	1.0707432	0.175839
SWF-72	17	16.09434	0.9467259	0.0411854
SWT-21	13	11.337493	0.8721149	0.09158
SWT-72	**12**	**7.5547867**	**0.6295656**	**0.0318622**
TAC-11	10	15.604222	1.5604222	3.3020974

Note. ***Bold and Italics*** indicate SSH peformance; **Bold** indicates SSL performance

Table 39 shows the results of the ANOVA tests carried out on the data represented in Table 38. The TPI data has enough variation to reject the null hypothesis. CA-CATCODEs were systematically removed until the p-value from the ANOVA was large enough to reject the null hypothesis. Another ANOVA test was accomplished on the POA-72 and SWT-72 data to determine if they were statistically different from each other; the low p-value from that test shows that their average TPI values are statistically different from each other. POA-72 exhibits SSH performance, while SWT-72 exhibits SSL performance.

Table 39

CA-CATCODE TPI One-way ANOVA Results

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
			All CA-CATCODEs			
Between Groups	10.7515	28	0.3840	1.8463	6.3115E-03	1.5061
Within Groups	78.8234	379	0.2080			
Total	89.5749	407				
			POA-72 and SWT-72 removed			
Between Groups	8.09182	26	0.3112	1.4785	0.0645	1.5272
Within Groups	74.0975	352	0.2105			
Total	82.18929913	378				
			POA-72 and SWT-72 only			
Between Groups	2.6527	1	2.6527	15.1556	5.8695E-04	4.2100
Within Groups	4.7259	27	0.1750			
Total	7.3787	28				

CA-CATCODE CPI*TPI Performance

Table 40 shows the descriptive statistics for the CA-CATCODE CPI*TPI data. In line with other portions of this research, average CPI*TPI values are above and below one.

Table 40

CA-CATCODE CPI*TPI Descriptive Statistics N = 408

CA-CATCODE	*Count*	*Sum*	*Mean*	*Variance*
LRL-17	11	10.35034	0.94094	0.1013316
LRL-21	14	11.889502	0.84925	0.1779696
NAU-14	12	9.772671	0.814389	0.0309677
NAU-72	12	11.831048	0.985921	0.1440794
NWO-17	11	12.083476	1.098498	0.106674
NWO-61	13	10.868902	0.836069	0.0467042
NWO-72	11	12.223973	1.11127	0.1470922
NWO-74	11	10.868594	0.988054	0.0362225
NWS-14	17	20.205607	1.188565	0.2238923
NWS-17	11	9.8868977	0.898809	0.0273352
NWS-21	22	23.962156	1.089189	0.2996769
POA-21	19	24.293208	1.27859	1.1608866
POA-72	17	21.858986	1.285823	0.2854931
POF-72	13	11.105994	0.854307	0.094108
SAM-14	13	11.821553	0.90935	0.0808122
SAM-17	17	17.143558	1.008445	0.2441361
SAM-21	21	24.191229	1.151963	0.2722585
SAM-72	20	18.587383	0.929369	0.0579553
SAS-21	15	16.704824	1.113655	0.0880451
SOU-21	12	12.55407	1.046173	0.0931774
SOU-72	14	16.457406	1.175529	0.213454
SPK-21	18	16.493172	0.916287	0.1185521
SPL-21	10	9.7425356	0.974254	0.0262087
SWF-17	11	11.089336	1.008121	0.1668794
SWF-61	11	11.640218	1.058202	0.1198952
SWF-72	17	16.216503	0.953912	0.0430626
SWT-21	13	11.486474	0.883575	0.0906278
SWT-72	**12**	**8.2377939**	**0.686483**	**0.0675508**
TAC-11	10	15.894977	1.589498	2.4260906

Note. ***Bold and Italics*** indicate SSH peformance; **Bold** indicates SSL performance

Table 41 shows the results of the ANOVA tests conducted on the CA-CATCODE CPI*TPI data. The first ANOVA test on all of the IVs in Table 38 reveals that there is statistically significant variation in the data. CA-CATCODEs were then systematically removed until the null hypothesis for the ANOVA test failed to be rejected. Although several candidate CA-CATCODEs were removed, SWT-72 was the only one that resulted in the rejection of the null hypothesis. SWT-72 has SSL variation from the rest of the CA-CATCODEs.

Table 41

CA-CATCODE CPI*TPI One-Way ANOVA Results

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
			All CA-CATCODEs			
Between Groups	11.4567	28	0.4092	1.6970	0.0163	1.5061
Within Groups	91.3829	379	0.2411			
Total	102.8397	407				
			SWT-72 removed			
Between Groups	10.0139	27	0.3709	1.5058	0.0529	1.5161
Within Groups	90.6399	368	0.2463			
Total	100.6538	395				

MAJCOM-CA-CATCODE CPI Performance

Similar to the CA-CATCODE data, zero MAJCOM-CA-CATCODE combinations have accomplished 30 or more projects; therefore, the minimum number of projects executed was reduced to 10. Table 42 summarizes the descriptive statistics for each MAJCOM-CA-CATCODE.

Table 42

MAJCOM-CA-CATCODE CPI Descriptive Statistics N = 131

Groups	*Count*	*Sum*	*Average*	*Variance*
AETC-SWF-72	14	14.4786	1.0342	0.0212
AFMC-SPK-21	10	10.6034	1.0603	0.1116
AFRC-LRL-21	13	13.7736	1.0595	0.0208
AFSPC-NWO-61	12	12.1159	1.0097	0.0101
AMC-NWS-21	12	13.8938	1.1578	0.3878
PAF-POA-21	17	17.8526	1.0502	0.0167
PAF-POA-72	16	16.6083	1.0380	0.0109
PAF-POF-72	13	13.6741	1.0519	0.0311
USAFE-NAU-14	*12*	*12.9959*	*1.0830*	*0.0939*
USAFE-NAU-72	12	14.0469	1.1706	0.0557

Note. ***Bold and Italics*** indicate SSH peformance; **Bold** indicates SSL performance

Table 43 shows the results of the ANOVA test accomplished on the MAJCOM-CA-CATCODE data. The data fails to reject the hypothesis that all of the average values are not statistically different from each other.

Table 43

MAJCOM-CA-CATCODE CPI One-Way ANOVA Results

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
			All MAJCOM-CA-CATCODEs			
Between Groups	0.3072	9	0.0341	0.4942	0.8761	1.9581
Within Groups	8.3562	121	0.0691			
Total	8.6634	130				

MAJCOM-CA-CATCODE TPI Performance

The descriptive statistics for MAJCOM-CA-CATCODE TPI performance are shown in Table 44. Consistent with other TPI results in this research, 8 of the 10 IVs do not demonstrate average TPI performance that is greater than one. This indicates that 80 percent of the MAJCOM-CA construction teams evaluated do not deliver projects before their estimated completion dates for the CATCODEs tested in this research.

Table 44

MAJCOM-CA-CATCODE TPI Descriptive Statistics N = 131

Groups	*Count*	*Sum*	*Average*	*Variance*
AETC-SWF-72	14	12.4367	0.8883	0.0258
AFMC-SPK-21	10	8.7201	0.8720	0.0245
AFRC-LRL-21	13	9.3283	0.7176	0.0555
AFSPC-NWO-61	12	9.6009	0.8001	0.0335
AMC-NWS-21	12	10.8698	0.9058	0.0885
PAF-POA-21	17	20.6260	1.2133	0.9138
PAF-POA-72	***16***	***20.0519***	***1.2532***	***0.2900***
PAF-POF-72	13	10.7147	0.8242	0.0858
USAFE-NAU-14	12	9.5418	0.7951	0.0684
USAFE-NAU-72	12	10.2532	0.8544	0.1005

Note. ***Bold and Italics*** indicate SSH peformance; **Bold** indicates SSL performance

The results of the ANOVA tests accomplished on the MAJCOM-CA-CATCODE data are shown in Table 45. The first ANOVA test showed that there is statistically significant variation in the data. MAJCOM-CA-CATCODEs were then systematically removed from the dataset until the null ANOVA hypothesis failed to be rejected. PAF-POA-72 demonstrates SSH TPI performance.

Table 45

MAJCOM-CA-CATCODE TPI One-way ANOVA Results

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
All MAJCOM-CA-CATCODEs						
Between Groups	4.3218	9	0.4802	2.3792	0.0163	1.9581
Within Groups	24.4221	121	0.2018			
Total	28.7439	130				
PAF-POA-72 removed						
Between Groups	2.4455	8	0.3056911	1.614379	0.1292404	2.0269155
Within Groups	20.0717	106	0.1893552			
Total	22.51719	114				

MAJCOM-CA-CATCODE CPI*TPI Performance

Table 46 shows the descriptive statistics for the CPI*TPI data evaluated for this research. Consistent with other areas in this research, the CPI*TPI values are above and below one. This indicates that overall cost and schedule performance are mixed for the MAJCOM-CA-CATCODEs evaluated in this research.

Table 46

MAJCOM-CA-CATCODE CPI*TPI Descriptive Statistics N = 131

Groups	*Count*	*Sum*	*Average*	*Variance*
AETC-SWF-72	14	12.7916	0.9137	0.0401
AFMC-SPK-21	10	9.4389	0.9439	0.1433
AFRC-LRL-21	**13**	**9.8613**	**0.7586**	**0.0681**
AFSPC-NWO-61	12	9.6665	0.8055	0.0377
AMC-NWS-21	12	12.6309	1.0526	0.3355
PAF-POA-21	17	22.3315	1.3136	1.2649
PAF-POA-72	16	20.7262	1.2954	0.3029
PAF-POF-72	13	11.1060	0.8543	0.0941
USAFE-NAU-14	12	9.7727	0.8144	0.0310
USAFE-NAU-72	12	11.8310	0.9859	0.1441

Note. ***Bold and Italics*** indicate SSH peformance; **Bold** indicates SSL performance

Table 47 shows the ANOVA test on all of the MAJCOM-CA-CATCODE data represented in Table 46 resulted in the rejection of the null hypothesis; there is statistically significant variation present in the data. MAJCOM-CA-CATCODEs were systematically removed from the data until the null ANOVA hypothesis failed to be rejected. When AFRC-LRL-21 was removed from the data, the null failed to be rejected; therefore AFRC-LRL-21 exhibits statistically significant variation from the rest of the sample.

Table 47

MAJCOM-CA-CATCODE CPI*TPI One-Way ANOVA Results

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
All MAJCOM-CA-CATCODEs						
Between Groups	3.1338	8	0.3917	2.8700	0.0063	2.0278
Within Groups	14.3317	105	0.1365			
Total	17.46554	113				
AFRC-LRL-21 removed						
Between Groups	4.3379	8	0.5422	1.7511	0.0947	2.0244
Within Groups	33.7534	109	0.3097			
Total	38.0913	117				

V. Conclusions and Recommendations

Conclusions

The results show that there is statistically significant variation in the cost and schedule performance of Major Commands (MAJCOMs) and Construction Agents (CAs). Overall, the AF MILCON program consistently delivers projects that are under budget; the vast majority of IVs had average Cost Performance Index (CPI) values that were greater than one. In contrast with the cost performance, most of the IVs were not able to deliver projects in their allotted time; the vast majority of IVs had average TPI values that were less than one. The average CPI*TPI values were typically evenly mixed between above and below one. This indicates that most IVs were exchanging cost performance for time performance, with varying degrees of success. The results from this research are summarized in Tables 6A and 6B. Table 48 summarizes the results associated with research questions one and two; Table 49 summarizes the results for research question three.

The MAJCOM, CA, and MAJCOM-CA that demonstrates the greatest degree of cost and schedule success in this research are Pacific Air Forces (PAF), the Alaska district (POA) of the United States Army Corps of Engineers (USACE), and PAF-POA. Table 48 shows that either PAF or POA appear as SSH in every category. The team of PAF and POA are able to consistently deliver projects that are below their respective budgets and before their respective estimated completion dates. No other MAJCOM, CA, or MAJCOM-CA combination considered from this dataset has produced similar results.

United States Air Forces in Europe (USAFE) and its primary CAs, the Air Force Center for Engineering and the Environment (AF) and the European district (NAU) of the USACE, have produced mixed results. USAFE, AF, and NAU all produced Statistically Significant High (SSH) CPI performance. However, the CAs NAU and AF, and the MAJCOM-CAs USAFE-NAU and USAFE-AF, all exhibit Statistically Significant Low (SSL) TPI performance in the data. Additionally, NAU's CPI*TPI metrics were also SSL. In contrast with the PAF and POA results, USAFE, AF, and NAU were not able to deliver both cost and schedule performance; they were only able to deliver cost performance.

The SSL TPI performance of some CAs appears to be a major factor in CPI*TPI performance; the Louisville district (LRL), Mobile district (SAM), and Tulsa district (SWT) all appear SSL in TPI and CPI*TPI even though they are absent from the SSL CPI category. Also, Air Force Special Operations Command (AFSOC) SAM and Air Education and Training Command (AETC) LRL both have SSL TPI and CPI*TPI metrics. Since the same CAs and MAJCOM-CAs do not display SSL CPI performance, one explanation might be that time performance is not being traded equally for cost performance. The Omaha district (NWO) appears in the SSL CPI*TPI metric; this may indicate that while its CPI and TPI performance individually are not much less than one, both are likely less than one simultaneously; this effect was demonstrated in Chapter 3, Figure 3.

Table 48

Summary of SSH and SSL performers

MAJCOM	CA	MAJCOM-CA
SSH CPI performers		
PAF	AF	None
USAFE	NAU	
SSL CPI performers		
None	SWF	AETC-SWF
SSH TPI performers		
ACC	None	PAF-POA
SSL TPI performers		
None	AF	USAFE-AF
	LRL	AFRC-LRL
	NAU	USAFE-NAU
	SAM	AFSOC-SAM
	SWT	AETC-SWF
SSH CPI*TPI performers		
None	POA	PAF-POA
SSL CPI*TPI performers		
None	LRL	AFRC-LRL
	NAU	
	NWO	
	SAM	AFSOC-SAM
	SAS	
	SWT	

The analysis of MAJCOMs, CAs, and CATCODEs reveals that there is not much variation in cost and schedule performance due to CATCODE. PAF-POA appears in the CATCODE data with SSH TPI performance in dormitories, officer quarters, and dining halls (CATCODE 72). Similarly, AFRC-LRL and SWT re-emerge with SSL CPI*TPI performance for maintenance facilities (CATCODE 21) and dormitories, officer quarters, and dining halls (CATCODE 72) respectively. Air Mobility Command makes its only appearance in these results for SSL TPI performance for maintenance facilities.

Table 49

Summary of SSH and SSL performers

CATCODE	MAJCOM-CATCODE	CA-CATCODE	MAJCOM-CA-CATCODE
SSH CPI performers			
11	None	None	None
SSL CPI performers			
73	None	None	None
74			
SSH TPI performers			
None	None	***POA***-72	***PAF-POA***-72
SSL TPI performers			
None	AMC-21	***SWT***-72	None
SSH CPI*TPI performers			
None	None	None	None
SSL CPI*TPI performers			
None	None	***SWT***-72	***AFRC-LRL***-21

Limitations

One limitation of this research lies in the analysis technique chosen. The ANOVA test is based on the assumption that the variances of all of the IVs are equal. The data was not tested to determine if the equal variance assumption was satisfied, nor were any control mechanisms implemented to compensate for unequal variances, if they exist.

The second limitation of this research is that it measures the efficacy of the project management effort, not the effectiveness of the projects in satisfying the needs of their intended customers. This research does not address why the variation that was discovered exists. The above or SSL performance of the IVs does not indicate why the particular metric becomes a certain value. Also, even though time performance is calculated, the metric does not indicate if the project was delivered fast enough to support the mission for which it was intended. For example, a new runway project is completed on time according to the project documents; it achieved a TPI score of one. Unfortunately, the aircraft the runway was designed to support arrived one year before the runway project was completed; this result degraded the mission but is not captured by the TPI metric as calculated in this research.

The third limitation of this research is that the cost and schedule metrics were relative in nature. The CPI measured how closely projects came to meeting their budgets and schedules, but the budgets and schedules are set by the MAJCOMs and CAs. There are no references to how much facilities should cost or how long they should take to construct compared to industry standards for similar activities.

Contributions

This research sought to find statistically significant variation in cost and schedule performance of AF Military Construction (MILCON) projects. Historical records of cost and schedule performance were analyzed using the analysis of variance (ANOVA) test to determine if statistically significant variation existed among MAJCOMs, CAs, CATCODES, or combination of these three IVs.

This research makes a contribution to the AF by objectively and systematically analyzing the cost and schedule performance of the AF MILCON program. This research can be used by AF project managers to investigate statistically significant variation in performance, share best practices and lessons learned across the AF. The academic contribution of this research lies in applying Earned Value Analysis techniques to actual project data.

Opportunities for Future Research

Future research could be accomplished to answer the "why" questions generated by this research. Case study research could investigate why PAF-POA consistently generates SSH CPI and TPI metric performance. Case study research could also be done to examine why USAFE consistently generates SSH CPI performance, but SSL TPI performance with two different construction agents. Lastly, further quantitative research could be done on this dataset to compare other measures of cost and schedule performance that take into account industry standards for construction costs and timelines.

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14. ABSTRACT

Cost and schedule performance are widely accepted in the literature and in industry as effective measures of the success of the project management effort expended. Earned Value Analysis (EVA) offers many metrics to objectively measure cost and schedule performance of many different types of projects. The author utilized EVA to objectively measure the cost and schedule performance of completed United States Air Force (AF) Military Construction (MILCON projects from 1990 to 2005. The impact of Major Command (MAJCOM), Construction Agent (CA), and facility type (CATCODE) and the combination of these variables on the EVA metrics of Cost Performance Index (CPI), Time Performance Index (TPI), and CPI*TPI were evaluated. The CPI results indicate that AF MILCON projects are typically executed either on or below their respective budgets. Conversely, the TPI results indicate that AF MILCON projects typically take more time than expected for construction. The CPI*TPI results indicate that the AF MILCON projects in this study typically exchange higher cost performance for lower time performance. However, when CPI and TPI are given equal weight, the sacrifice made in time performance is greater than the benefit gained in cost performance.

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