Effects of Selected Practices on Project Cost Performance

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Effects of Selected Practices on Project Cost Performance

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Dedication

This work is dedicated to the many fine educators that I have had the privilege to be associated with throughout my life. It is their tireless and often less than appropriately rewarded efforts that have provided me with the tools to undertake this study. For these efforts, I am most thankful and hope that I may positively influence the life of others as they have influenced mine.

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Effects of Selected Practices on Project Cost Performance

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The purpose of this study is an investigation into the effects of selected construction industry practices on project cost performance. The practices addressed in the study include pre-project planning, project change management, team building, constructability, percent design complete at project authorization, project cost incentives, project compensation strategy, and project organization strategy. A literature review of the selected practices is provided. Quantitative analyses of the relationship between project cost growth and use of the various practices is provided. Regression and analysis of variance methods are used to identify and measure statistically significant relationships between project cost performance and practice use. The data utilized in the analysis is from the Construction Industry Institute Benchmarking and Metrics database. The study focuses on industrial projects constructed in the United States that were complete between 1994 and 1997.

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Chapter 1: Introduction

Owners and constructors of capital facility projects want to appropriately use practices during project development and execution that enhance their competitiveness through improved project cost performance. Information based on analysis of quantitative data is needed to make informed decisions concerning practice implementation. Considerable research has been conducted to identify practices that are believed to affect project cost performance, and in many cases analyses have been performed to measure the relationships between practice use and project performance. Practices that have received notable attention in the literature include pre-project planning, project change management, team building, constructability, contract compensation strategy, and many others.

The effects of using these types of practices may be categorized as direct or indirect with regard to project performance. Indirect effects refer to accomplishments or events that in turn result in other effects. For the purpose of this study, the final effect of interest is improved cost performance. As an example, holding a project team building retreat most likely does not directly affect the cost performance of a project, but may be an important step on the path to that end. A team building retreat may in fact lead to an indirect effect of enhanced project team communications. Enhanced project team communications in turn leads to a final effect of improved cost performance through reduced construction delays or rework caused by misunderstandings. The indirect effects of these practices are generally intuitively understood in a qualitative form and, in many cases, are well documented through previous research utilizing interviews with industry experts. However, quantitative analyses of the final effects of practice use are quite limited for many practices of interest. A need exists in the industry for additional quantitative information related to the effects of practice use on project cost performance so managers can gauge the value of using individual practices.

Documentation that quantitatively illustrates the benefits of practice use is required to justify the expenditures of resources necessary to implement practices. The costs of implementation may be easily identified, even on a single project basis, but the potential improvements to be realized from practice use may require a substantial data set of projects with variation in practice use. The development of a large data set is generally not possible within a single company, since even the largest of companies only perform a relatively small number of projects per year. Therefore, it is not possible for companies to develop adequate information internally in a useful time period and it must come from external sources.

Provided with results of research for several of these practices, managers of capital facility projects have difficulty in deciding which of the several practices to implement and where to focus resources. Managers want information based on quantitative data to assess the relative effects of practice use. They need to know which practices have the greatest potential to influence project cost performance. This understanding allows for rational decision-making as to which practices should be implemented first in a best practices program and where emphasis should be focused given limited resources.

Finally, there is a need in the construction industry for follow-up research on the value of using best practices using more sophisticated analysis models than have been used in many past research efforts. Analysis models in this area of research need to include the many relevant variables simultaneously to understand the various effects of the many practices, other variables, and their interrelationships.

The Construction Industry Institute (CII) Benchmarking and Metrics (BM&M) Program is developing a large construction industry project database that contains quantitative project performance, practice use, and project environment data. Through the CII BM&M database, it is possible to perform analyses that provide many project management information needs discussed above. The purpose of this study is to build upon previous research in understanding the effects of selected construction industry practice use on project cost performance through analysis of the CII database.

1.1 THE CONSTRUCTION INDUSTRY INSTITUTE

The Construction Industry Institute was established in 1983 to improve the cost effectiveness of the construction industry. Located at The University of Texas at Austin, its membership consists of both owner and contractor organizations representing a broad range of construction industry interests. The mission of the CII is to improve the total quality and cost effectiveness of the North American construction industry from project conception to successful start-up operation. To support this mission, member companies provide guidance for specific research activities and volunteer support to staff research teams.

Research teams conduct the research with assistance from university academics and graduate students.

Since its inception, CII has identified, investigated, and reported on numerous industry topics and practices that may lead to benefits that include reduced costs, shortened delivery time, and improved quality and safety. This research has resulted in over 200 publications available for benefit of the construction industry at large. In general, research team publications provide a listing of recommended practices that are believed to enhance the probability of project success.

1.1.1 CII Benchmarking and Metrics Program

The Benchmarking and Metrics Committee, a standing committee of CII, guides the CII Benchmarking and Metrics Program activities. The CII Board of Advisors chartered the Committee in November 1993, and the committee met for the first time in February 1994. The Committee has well-balanced representation of owner and contractor organizations. Appendix I contains a listing of the committee membership during the development of this study.

1.1.2 Program Objectives

The Benchmarking and Metrics Program includes the following three objectives.

1. To provide "the industry" (defined broadly as heavy industry, light industry, buildings and infrastructure) with "norms."
2. To quantify the "use" of recommended practices.
3. To quantify the "value" of implementing recommended practices.

This study has been carried out in conjunction with the CII BM&M Program with guidance and expert industry knowledge provided by members of the BM&M Committee. The purpose of this work is to further the CII BM&M efforts related to the third objective above: to quantify the value of implementing recommended practices.

1.2 Opportunity to Model the Effects of Multiple Practice Use

Research concerning the effects of construction industry practice use on project performance has generally been focused on single practices. Analyses have normally been performed without regard to the relationship between a practice of interest and other relevant variables that may include other practices used on the projects investigated. Focus on a single practice is understandable due to the increased burden of collecting data for numerous practices with a single survey. Also, research efforts are generally interested in developing detailed knowledge of a single practice and its effects. However, if there is correlation among the use of all practices that affect project cost performance, then analyses that specify a model with only a single practice can result in misleading estimates of the practice effects. The CII Benchmarking and Metrics Program database provides an opportunity to develop models that are more inclusive than those developed in many of the specific research studies.

1.3 Research Objective

The primary objective of this study is to enhance the cost performance of the construction industry. The route through which this objective is pursued consists of a contribution to the body of knowledge concerning the relationship between use of selected construction industry practices and project cost performance. The resource constraints under which all managers must operate dictate the use of practices that are most effective in achieving desirable project cost performance. Managers charged with development of capital facilities similar to those investigated in this study can use this quantitative information to enable rational decision making regarding resource allocation to use of the selected practices.

1.4 Research Hypotheses

This study is focused on measuring the effects of construction industry practice implementation on project cost performance. Analyses are performed to identify statistically significant relationships between the use of selected practices and project cost performance on capital facility construction projects. The following research hypotheses were developed to guide the investigation.

1. Cost performance of capital facility construction projects is significantly improved through the use of practices that enhance project definition prior to authorization, improve the management of project change, develop effective relationships among project team members, and enhance project constructability. Use of these practices is negatively correlated with project cost growth and results in reduced project cost growth variability.
2. The use of pre-project planning, project change management, team building, and constructability is positively correlated with the use of each of the others. Therefore, it is appropriate to model the effects of the use of the practices with

multivariate analyses to develop an understanding of the contribution of each of the practices.

3. While several of the practices considered in this study may significantly effect project cost performance, the effects of the various practices on project cost performance are not equal in magnitude. Some practices have significantly greater effects on project cost performance than others do. In accordance with previous research, practices that occur early in the project life cycle and facilitate project definition prior to project authorization have the greatest potential to influence project cost performance.
4. Projects that utilize multiple best practices in combination to a high degree experience significantly less project cost growth and less project cost growth variability than projects that use only a single best practice or multiple best practices in combination to a lesser degree.
5. The effects of best practice use on project cost growth are influenced by other practices and the project environment.

1.5 Analysis Framework

A framework has been developed to guide formulation of analyses to test the research hypotheses. This study is concerned with quantifying the relationships between three categories of measurement variables: project performance, practice use, and project environment. Figure 1 illustrates the analysis framework and the relationships between the three categories. The arrows in this simple causal diagram represent the possibility of influence one set of variables may have on another. Project performance is commonly represented by a set of outcome measures concerning cost, schedule, quality, and safety. This study is focused only on cost performance and, in particular, project cost growth. Cost performance is the dependent variable in the analyses and is influenced directly by both practice use and the project environment. Practice use refers to the degree of use of the selected practices during project planning and execution.

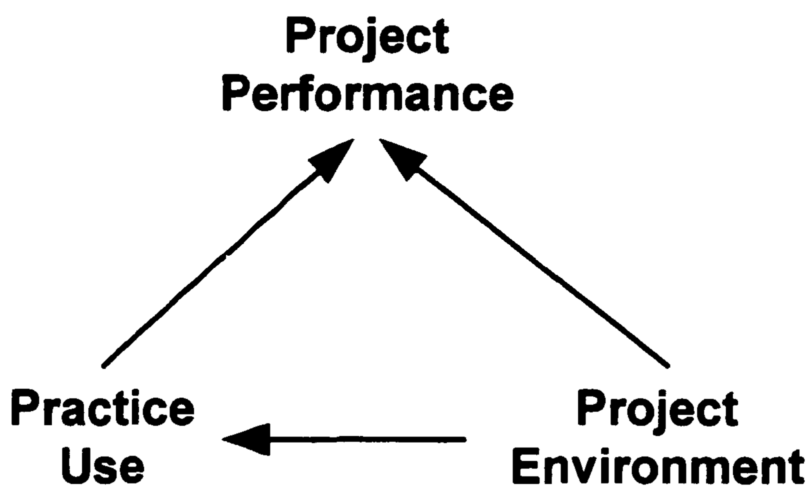


Figure 1: Analysis Framework

It is believed that the use of these practices influences project performance and is influenced by the project environment. Measures of the project environment include quantification of project attributes that are generally inherent to the project and not within the control of project participants. The product, capacity, or type of facility required generally drives these attributes. The project environment is thought to have direct influence on project performance, as well as indirect influence on project performance through influence on the use of practices.

Table 1 provides a listing of the measurement level variables that compose each category included in the analysis framework. For this study, the only measurement of project performance is project cost performance. The practice use category consists of eight individual practices as shown. The project environment category consists of seven measures of project attributes. Detailed definition and discussion are provided for the measures in Chapter Four.

Table 1: Project Performance, Practice Use, and Project Environment Measurement Level Variables

Measurement Level Variables			
Project Performance	Practice Use		Project Environment
Project Cost Growth	Best Practices	Pre-Project Planning	Project Complexity
		Project Change Management	Project Nature
		Team Building	Project Cost
		Constructability	Project Duration
	Other Practices	Percent Design Complete	Cost Rate
		Contract Cost Incentives	Craft Workhours
		Contact Compensation Strategy	Equipment Cost Factor
		Contract Organization Strategy	

Throughout this document pre-project planning, project change management, team building, and constructability are referred to as "best practices." Percent design complete, contract cost incentives, contract compensation strategy, and contract organization strategy are referred to as "other practices." The reason for this categorization of practices stems from the idea that those four practices in the "best" category may be considered optional or not automatically required to carry out a project. However, they have been recommended through previous research as beneficial to project performance. An example is that team building is not necessary to carry out a project, but may lead to better project results. The other practices are not optional in that they represent some attribute of a project that requires selection of an alternative for project execution. An example is that a contract compensation strategy must be selected because project participants must be reimbursed for work performed. However, a particular contract compensation strategy may lead to better project performance than another type depending upon other project attributes.

Figure 2 illustrates the series of analysis steps performed in this study to investigate the relationships identified in the analysis framework. Step 1 involves the identification, definition, and calculation of values for variables within the dataset believed to have relevance concerning project cost growth. Steps 2 through 4 investigate the relationship between each of the measurement variables independently of all others. Step 5 involves a multivariate analysis of best practice implementation effects on project cost growth. The results of step 5 are utilized in step 6 to develop a single measure for the combined use of the four best practices. Finally, steps 7 and 8 investigate how the relationship between combined use of the best practices and project cost growth varies by the project environment and use of other practices.

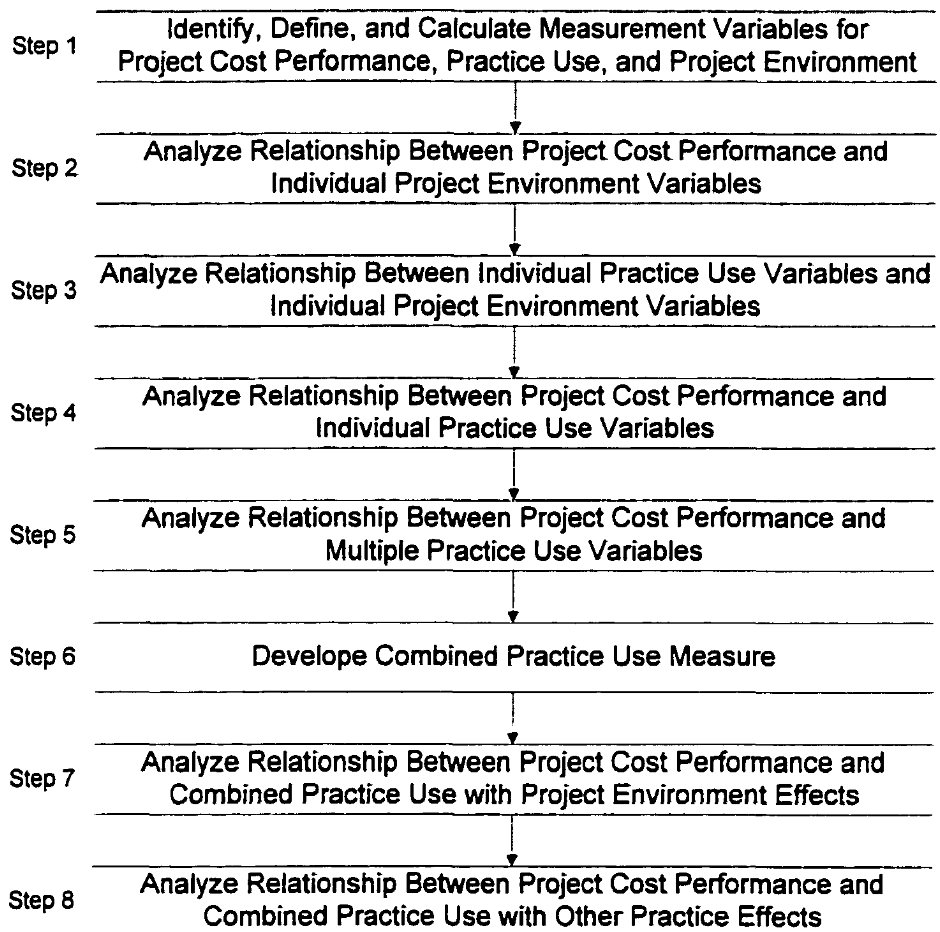


FIGURE 2: ANALYSIS FLOWCHART

1.6 PROJECT MODEL

To facilitate model development for the processes that comprise a capital facility construction project, most research efforts decompose the complete project into phases. The phases represent time periods during which similar project tasks are performed. Although there is no set standard for project phase terminology, Figure 3 illustrates five generally recognized phases and those used in this study. The phases consist of pre-project planning, detail design, procurement, construction, and startup. The project phases are imposed on a project cost influence curve. The premise behind the cost influence curve is that the ability to influence project costs is greater during early project phases and rapidly decreases as the project proceeds.

The time period during which the four best practices occur relative to the project phases is shown at the top of the figure. The arrows drawn from each phase to each subsequent phase along time represents the concept that outputs from each phase become inputs into later phases. The outputs take the form of information (plans) or physical deliverables (drawings/facilities).

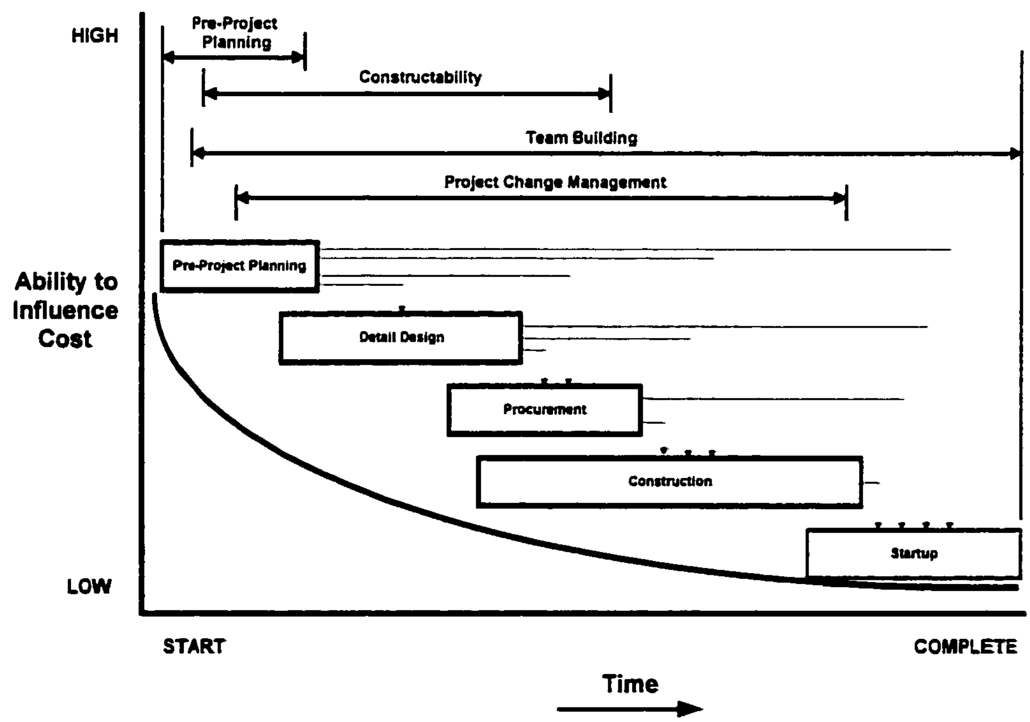


Figure 3: Cost-Influence Curve with Project Phases and Selected Best Practices

The opportunity for significant downstream effects from practice use early in the project is apparent in this illustration. The outputs from the upstream phases become inputs in later phases and influence processes that take place downstream. Thus, practice use and desirable performance in the early phases influence performance during later phases and the overall project. The purpose of this figure is to illustrate the concept that inputs in early phases of a project, including the use the practices illustrated, influence all later phases of the project.

1.7 Document Organization

This document consists of six chapters and a set of appendices that contain supporting information and results of data collection and analysis. Chapter Two provides a background review of previous research related to project performance and the selected construction industry practices. Chapter Three presents research methodology information for the collection of data and statistical analyses employed to test the research hypotheses, as well as descriptive information for the data set used in the analyses. Chapter Four defines each of the measurement variables and presents the data for each. Chapter Five provides discussion for the data analyses and the correlation between the measurement variables of interest in the data set. A summary of the research hypotheses, conclusions, industry recommendations, and recommendations for additional research are discussed in Chapter Six.

Chapter 2: Background

This study builds upon previous work related to the use of selected construction industry practices, project cost performance, and the relationship between these project attributes. Therefore, a thorough review of relevant literature was required to gain an understanding of the current knowledge concerning each of the selected practices and the measurement of project cost performance. The results of the literature review are discussed in this chapter.

2.1 Project Cost Performance

An appropriate measure of project cost performance may assume one of several forms depending upon its purpose. In this study, project cost performance is defined as a measure of project cost predictability and is referred to as project cost growth. This measure is concerned with the deviation of actual project cost from the initial predicted project cost. Therefore, for the purposes of this study, cost performance is a relative, rather than absolute measure. In contrast, an absolute measure of project cost performance may take the form of a unit cost. An example of that type of measurement is capital project expenditure per unit of facility production capability. Depending upon the intended purpose of measuring project cost performance, either the relative or absolute measure of project cost performance may provide more value to the user. This research focuses exclusively on the relative measure: project cost growth after project authorization.

The ability to accurately predict project cost is essential for planning of capital expenditures. Poor project cost predictive ability most usually results in project cost overruns; however, cost underruns are also possible and an occasional lucky project may come in exactly on budget. If the actual total cost of a project is significantly greater than the initial predicted project cost, then the economic viability of the project may be adversely affected. If so, in some instances, then the project should not have been authorized. Good cost prediction capability can help prevent such projects from unjustly moving forward. If the actual total cost of a project is significantly lower than the initial predicted cost, then funds have been held unnecessarily and could have been allocated to additional revenue generating projects.

Project cost growth may be attributed to two types of factors (Merrow 1981). Those that may affect estimation accuracy and those that may increase facility costs. Factors that affect estimation accuracy may include: the degree of project definition, process characteristics and knowledge, and incentives for accurate estimation. Factors that affect facility costs may include management practices, scope changes, unanticipated inflation/escalation, unanticipated regulatory changes, strikes, bad weather, etc. This research does not distinguish between these two categories of factors that lead to project cost growth. The purpose of this study is to quantify the effects of construction industry practices on project cost growth regardless of the initiating cause of the project cost growth. The practices under investigation are believed to influence both estimation accuracy and facility cost.

2.2 Selected Practices

The practices considered in this research include pre-project planning, project change management, team building, constructability, percent design complete, contract cost incentives, contract compensation strategy, and contract organization strategy. Pre-project planning, project change management, team building, and constructability are referred to in this study as "best practices." The four "best practices" were selected for inclusion in this research based on several factors. The first of these includes perceived interest with the industry. Second, considerable work has been performed by CII research teams related to each. This previous research provides a good foundation on which to build additional understanding of the effects these practices have on project cost performance. Third, these practices are sufficiently mature within the industry such that most survey respondents can provide the required information without face to face interview and little training. This allowed efforts to be focused on collecting a large sample of projects.

Percent design complete, contract cost incentives, contract compensation strategy, and contract organization strategy were included in the study because of perceived industry interest related to their individual effects on project cost performance, as well as how these variables might impact the relationships between the best practices and project cost performance.

2.2.1 Best Practices

The "best practices" represent actions or processes undertaken to improve project performance. These practices are generally not required to execute a project, but are optional efforts or levels of effort invested in a project that are believed to return improved project performance.

2.2.1.1 Pre-Project Planning

The CII Pre-Project Planning Research Team defined pre-project planning as the process of developing sufficient strategic information with which owners can address risk and decide to commit resources to maximize the chance for a successful project. The term pre-project planning is often perceived as synonymous with front-end loading, front-end planning, feasibility analysis, programming, and conceptual planning (Gibson 1995). A highly publicized postulate within the construction industry is that efforts made early in the project life-cycle can have much greater influence on a project's outcome than those made in later phases. Therefore, it is widely believed that pre-project planning has a significant impact on the outcome of capital facility cost performance. Research conducted by the Pre-Project Planning Research Team indicates that well-performed pre-project planning can reduce total project design and construction costs by as much as 20 percent versus the authorization estimate (Gibson 1994).

The CII Pre-Project Planning Research Team produced a number of publications that document elements that are critical in the pre-project planning effort to achieve desirable project performance. A follow-on research effort conducted by the Front End Planning Research Team produced a measurement of pre-project planning effort called the Project Definition Rating Index (PDRI). The purpose of the PDRI is to measure project definition prior to project authorization. The PDRI provides a definition for and a method to measure the level of definition for 70 individual project elements prior to project authorization. The measure of project definition provided by the PDRI score is directly related to the level of pre-project planning effort. Figure 4 illustrates the major pre-project planning sub-processes and the corresponding functions defined by the Pre-Project Planning Research Team.

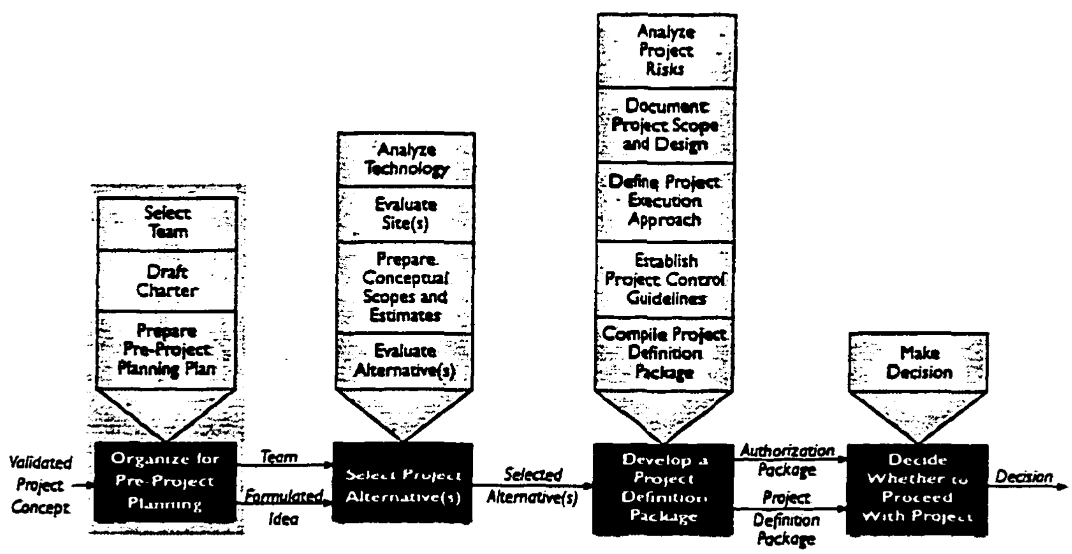


Figure 4: Pre-Project Planning Lifecycle (Gibson 1995).

The BM&M Committee reviewed the recommended pre-project planning items from previous research and the measure of pre-project planning effort provided by the PDRI. The twenty-three highest ranked PDRI elements and four other recommended items were selected for inclusion in the survey instrument as a basis for measuring pre-project planning use. The other items include: assessment of the pre-project planning team composition, project risk analysis, evaluation of alternative technologies, and alternative site consideration for the project. The pre-project planning section of the data collection instrument provided in Appendix A contains a listing of these items. Further information related to this practice is available in Gibson (1995) and Gibson and Dumont (1996).

2.2.1.2 Project Change Management

Changes are defined by the CII Project Change Management Research Team as additions, deletions, or other revisions within the general scope of a contract that cause an adjustment to the contract price or contract time. Throughout the construction industry there is little agreement among the various participants about what constitutes a change or the impact of changes. A major contributing cause of this lack of agreement stems from the way changes affect different parties in different ways. For the purposes of this study, changes are categorized as either project development changes or scope changes. Project development changes include those changes required to execute the original scope of work or obtain original process basis. Scope changes include changes in the base scope of work or process basis. Project change management practices focus on the management and control of both categories of change.

Elements of a project that are subject to change and that will affect the change management process include project scope, project organization, work execution methods, control methods, and contracts and risk allocation.

Effective project change management requires a proactive approach to managing change and its impact in a timely manner and not simply procedures to handle changes after they occur. CII research on project change management shows that with regard to timing, the later a change occurs on a project, the less efficient is its implementation (Project Change Management 1994). The introduction of changes into a project, especially late in the project lifecycle, can lead to many problems that reduce the probability of project success. These problems may take the form of workflow interruption, delays, schedule growth, cost growth, claims, and litigation. Effective project change management is believed to reduce the impact of these problems.

The CII Project Change Management Research Team stated the following benefits of an effective change management program:

- Significant savings in total installed costs of construction projects,
- Owners and contractors can both profit from increased efficiency,
- Schedules can be made more reliable,
- End-user satisfaction can be enhanced.

Support of these benefits was based on expert opinion and experience of the research team members. An objective of this research is to provide quantitative information to test the claims related to the effects of project change management on project cost performance.

The principles of an effective project change management program, as recommended by the CII Project Change Management Research Team, are:

- Promote a balanced change culture. Changes may be "beneficial" or "detrimental." Those changes that actually help reduce cost, schedule, or degree of difficulty are beneficial and should be encouraged. Detrimental changes reduce owner value or have a negative impact on a project and should be avoided.

- Recognize change. A well defined scope of work is required to recognize and manage change. An original defined scope of work must be recognized as a baseline so that measurements and tests can be conducted to determine whether a change has occurred.

- Evaluate change. Evaluation of changes requires classifying the change as required or elective. Required changes must be implemented. Elective changes are those that are proposed to enhance the project, but are not required to meet the original project objective.

- Implement change. There should be a process agreed to early in the project for approving identified changes. The change management process should include a documentation system that adequately tracks the items and their flow through the system.

- Continuously improve from lessons learned. Project strategies and philosophies should take advantage of lessons learned from past, similar projects. Over the course of the project, the parties should agree to openly discuss problems arising from management of changes and opportunities for improvement.

Each phase of a project should have established change management procedures consistent with these principles. The CII Project Change Management Research Team provided a total of 74 recommendations related to these principles as they apply to the various phases of a project. The BM&M Committee reviewed these recommendations and selected 14 for inclusion in the data collection instrument as a basis for measuring project change management use. The project change management section of the data collection instrument provided in Appendix A contains a listing of these recommendations in question form. Project Change Management (1994) has more detail related to this practice.

2.2.1.3 Team Building

Team building is a process that brings together a diverse group of individuals and seeks to resolve differences, remove roadblocks and proactively build and develop the group into an aligned, focused and motivated work team that strives for a common mission and for shared goals, objectives, and priorities (Albanese 1993). In capital facility projects, typical members of the team building process include the owner, designer, and contractor. Other major stakeholders such as subcontractors, suppliers, and the construction manager may also be included. Adversarial relationships among these project participants are common but not inevitable. An adversarial relationship among a project's owner, designer, and contractor often adds significantly to project costs through inefficiencies resulting from poor communication. Team building seeks to eliminate or reduce adversarial relationships and the negative impacts they have on projects. Team building is a short-term process implemented on a specific project designed to improve project execution and results in effective relationships among team members.

Successful use of the team building process will bring to the design/construction process significant and cost effective short-term and long-term benefits. Previous research indicates that project team building was used successfully regardless of the type of commercial relationship ("lump sum" or "cost reimbursable" contract) among the parties (Albanese 1993).

In the opinion of experienced industry practitioners, the most important causes of adversarial relationships are: poorly defined scope of project, excessive change orders, changes not properly managed, lack of communication of objectives, unrealistic project schedule, and unrealistic project budget. The two causes cited as having the most severe impact on project costs and results are poorly defined scope and excessive change orders (Albanese 1993). Team building can only be successful in effecting scope definition and change orders if it is utilized early in the project lifecycle, during the pre-project planning phase.

There are both content and process benefits to be gained from using the team building process to manage projects. Content benefits are the positive effects on project cost, quality, and schedule and/or on dealing more promptly with changes. Process benefits are the positive effects of reducing adversarial relationships, developing trust and team spirit, opening communication, improving cooperation and cohesiveness and identifying problems early.

The CII Project Team Building Task Force identified a number of elements common to successful team building efforts studied during the course of their research. These elements are as follows:

- Use of a consultant who does not have a direct stake in the outcome of the project.
- At least one "retreat" type meeting of the group in which the shared goals are spelled out and essential decision-making and dispute resolution procedures are worked out.
- Regular job site meetings of the team (at which the consultant need not be present).

- Follow-up meetings to reinforce concepts and to integrate new members

The research team provided team building process recommendations in addition to the elements listed above. The BM&M Committee reviewed the recommendations and selected 8 for inclusion in the survey instrument as a basis for measuring team building use. The team building section of the survey instrument provided in Appendix A contains a listing of these recommendations in question form. Albanese (1993) has more detail related to this practice.

2.2.1.4 Constructability

The CII Constructability Task Force defines constructability as the optimum use of construction knowledge and experience in planning, design, procurement, and field operations to achieve overall project objectives (Constructability: A Primer, 1986). Maximum benefits of constructability are realized through the effective and timely integration of construction input into planning and design, as well as field operations. Constructability is achieved by fully exploiting construction experience in a timely and structured manner.

The CII Constructability Taskforce suggests that constructability can support all project objectives: reduced cost, shortened schedules, improved quality and safety, and enhanced management of risk. Implementing construction knowledge during the design of a project can be an effective tool in achieving project success in regards to cost and schedule. The largest savings originate from construction input addressing issues such as construction methods, sequencing, and procurement strategies. Documentation of constructability efforts shows that owners accrued an average reduction in total project cost and schedule of 4.3 percent and 7.5 percent, respectively (O'Connor and Russell 1993).

A constructability program strives to create interdependence between the designer and contractor at all phases of the facility delivery process. Maximum benefits occur when people with construction knowledge and experience become involved at the very beginning of a project. The constructability process should begin shortly after the owner's conception of the project and continue through project planning, design, procurement, construction, and start-up. The earlier in the facility delivery process that the constructability program begins, the higher the potential savings.

Construction considerations should be incorporated into every phase of a project, including feasibility studies, conceptual planning, design, procurement, and construction. The project execution plan should define the constructability objectives and explain in detail how the project team plans to function in order to accomplish traditional project objectives.

The Project Constructability Program Evaluation Matrix developed by the CII Constructability Implementation Task Force provides an excellent list of items on which to base a measure of constructability use (Constructability Implementation Guide, 1993). After review of this matrix and other constructability publications, the BM&M Committee selected 12 items for inclusion in the survey instrument as a basis for measuring constructability use. The constructability section of the data collection instrument provided in Appendix A contains a listing of these items. Several publications related to constructability are listed in the bibliography of this document for more detail related to this practice

2.2.2 Other Practices

The other practices for which data were collected include: percent design complete, contract cost incentives, contract compensation strategy, and contract organization strategy. A brief definition is provided below for each of these practices along with discussion related to their postulated effects on project cost growth. Data have been collected for these practices to determine if correlation exists between the individual practices and project cost growth and if these practices impact the relationship between the best practices and project cost growth.

2.2.2.1 Percent Design Complete

The percent design complete is measured as a ratio of the number of actual engineering workhours expended at project authorization to the total number of engineering workhours for the project. The percent design complete is directly related to the level of project definition prior to project authorization. It is a widely held belief within the industry that higher levels of design complete prior to project authorization leads to less project cost growth and improved project cost predictability.

2.2.2.2 Contract Cost Incentives

A review of the literature related to contract cost incentives reveals several potential project cost performance benefits. The potential for additional monetary reward may enhance contractor motivation and, therefore, performance and efficiency. Incentive plans may increase the level of management attention and may influence the selection of key personnel assigned to the project by both owner and contractor. Another important aspect of incentive plans is that they provide a mechanism for achieving alignment between the owner and contractor objectives. Through the use of incentive plans, owners may be required to define and communicate their objectives more clearly (Incentive Plans: Design & Application Consideration, 1988). For this study, project cost incentive data were collected regarding project participant function and whether the incentive was positive or negative in nature.

2.2.2.3 Contract Compensation Strategy

For purposes of this study, contract compensation strategy refers to the contractual method in which project participants are compensated for their services. The various categories of contract compensation strategy considered in the data collection instrument include lump sum, unit price, cost reimbursable, and guaranteed maximum price. The appropriate choice of contract compensation is generally thought to be highly project specific, depending on factors such as risk assignment, project definition prior to contract award, project schedule requirements, use of new technology, etc. Selecting the appropriate strategy is believed to have significant effects on project cost performance.

2.2.2.4 Contract Organization Strategy

For the purposes of this study, the term contract organization strategy relates to the functional responsibilities of the primary project participants. In regards to capital facility development, the project owner must decide how to best organize a project and delegate work to others. This decision affects not only the management of the project, but also the scope of work and responsibilities assigned to internal and external organizations involved. As an example, the Design/Build approach is a common strategy in the development of heavy industrial projects. With the Design/Build approach, owners select one firm to both design and construct a facility. Many other approaches are available and frequently used. This may include the award of separate contracts for design and construction to several firms, owner self-performance of design and award of contracts for construction, etc.

The selection of contract organization strategy should be based upon a number of project specific features and to a great extent upon availability of the owner's in-house resources. Data are collected in this study only in detail required to determine if the contract organization strategy is design/build or another unspecified type.

2.3 PROJECT ENVIRONMENT

The project environment variables considered in this study include project complexity, project cost, project nature, project duration, cost rate, craft workhours, and equipment cost factor. The project environment variables are generally considered to be attributes inherent to a project, and generally outside the control of project participants. The product or process defined by the business objectives generally controls these attributes. Data were collected for each of these variables to test for correlation with project cost performance and to investigate the impact of these variables on the relationship between the best practices and project cost performance. Definition for each of these measures is provided in Chapter Four.

2.4 Early Work by the CII Benchmarking and Metrics Program

The metric definitions, analysis framework, and data utilized in this study are based on early work performed by the CII BM&M Committee. Background information regarding program development can be found in Hudson (1997), Benchmarking and Metrics Report for 1996 (1997), and Benchmarking and Metrics Summary for 1996 (1997). These publications provide detail related to development of the survey instrument, metric definitions, data collection, and early data analyses.

Chapter 3: Methodology

This chapter provides discussion related to the methods employed in developing the data set, a descriptive summary of the data set, and analysis techniques used to test the research hypotheses.

3.1 Data Collection

The data used in this study are a subset of the CII Benchmarking and Metrics Program database that adheres to the investigation domain criteria described later in this chapter. The complete CII Benchmarking and Metrics Program database at the time of this writing consisted of 393 domestic and international projects provided by 59 CII member companies during two separate data collection efforts conducted in 1996 and 1997. The complete database represents a broad range of project types and scopes. The distribution of all projects within the CII database among industry groups by year of data collection and respondent type is shown in Table 2.

Table 2: CII Benchmarking and Metrics Database (As of December 1997)

	1996		1997		
	Owner	Contractor	Owner	Contractor	Totals
Buildings	20	13	21	4	58
Heavy Industrial	52	71	48	76	247
Infrastructure	9	23	6	2	40
Light Industrial	14	12	15	7	48
Totals	95	119	90	89	393

To provide an "apples-to-apples" analysis, this study focuses on fifty-five domestic industrial projects submitted in 1997 by sixteen owner companies. The fifty-five projects represent those within the shaded cells in Table 2 that meet the investigation domain criteria. Eight projects represented in the shaded area of Table 2 are not included in the study because they are located outside the United States/Canada, are environmental projects, or did not meet the minimum specified total installed cost. The investigation domain is limited to 1997 data only because of significant changes in the survey instrument between the 1996 and 1997 data collection efforts. Questions related to several of the practices considered in this study were not included in the survey instrument prior to 1997.

In general, a single contractor is not involved in the complete scope of a project and therefore cannot provide complete project information regarding either cost or practice use. Since this study utilizes measures of total project cost and use of practices that occur throughout the project lifecycle, it was decided to exclude the use of contractor data. Historical project data were self-reported by trained volunteer respondents by use of a data collection instrument. However, the sample under study is not random.

3.1.1 Data Collection Instrument

The data collection instrument and the accompanying glossary of terms used to collect the data for this study are provided in Appendix A. The current form of the survey instrument underwent two cycles of data collection and revision prior to the 1997 data collection effort used for this study. The first Benchmarking and Metrics Program survey instrument was developed and distributed for a pilot test in 1995. Data for approximately 45 projects were collected during the pilot test. These data were analyzed and respondents were contacted to solicit criticism that would lead to improvement of the survey instrument. The instrument was revised and distributed in March of 1996 for a full data collection effort. Data for 204 projects were collected with that version of the survey instrument. Subsequent to analyzing the data and reporting results for the 1996 data collection effort, the survey instrument was again modified to improve question wording and format. Also, additional questions related to project performance and practice use were added for the 1997 data collection effort. A glossary of terms was developed and distributed with the survey instrument in 1997 to promote standard interpretation of key words and phrases.

In general, the survey instrument focuses on three types of historical project data: project performance, use of practices, and the project environment. The data are referred to as historical because the survey instrument is intended to collect data for projects that are complete, rather than in progress. The current version of the survey instrument is 21 pages in length including instructions. A detailed discussion related to the development of the original survey instrument can be found in Hudson (1997).

3.1.2 Respondent Training

A letter of invitation to participate in the CII Benchmarking and Metrics Program was sent to all CII member companies in February of 1997. Each company that agreed to participate in the program, and therefore, provide project data was encouraged to have a representative attend a full day training session developed by the Benchmarking and Metrics Committee. The representatives for companies that participate in the program are referred to as Benchmarking Associates. Three Benchmarking Associate training sessions were held prior to the 1997 data collection effort. Approximately 75 percent of the companies that participated in the 1997 data collection effort were represented at the training sessions. Benchmarking Associates for the remaining 25 percent of the companies attended training in the prior year or received detailed instruction by phone. As a part of the training, the following topics were discussed.

- Background and purpose of the CII Benchmarking and Metrics Program
- Review of the data collection instrument
- Instruction on project selection
- A question and answer session to discuss Benchmarking Associate concerns and responsibilities.

As a part of the training sessions, considerable time and emphasis were allocated to the discussion concerning the responsibility of the Benchmarking Associate. Benchmarking Associate responsibilities include: selecting appropriate projects, providing training and guidance to project managers who are charged with the task of filling out the data collection instrument, and performing a data quality review prior to submitting the data collection instrument to CII. Benchmarking Associates allow the CII Benchmarking and Metrics Program to leverage the use of company resources in the effort to obtain data of higher quality than is generally associated with the use of self performed data collection instruments. Each company was asked to provide data for at least five projects. Figure 5 illustrates the flow of information and training from the Benchmarking and Metrics Program through the Benchmarking Associate to the ultimate respondent, who was generally a project manager.

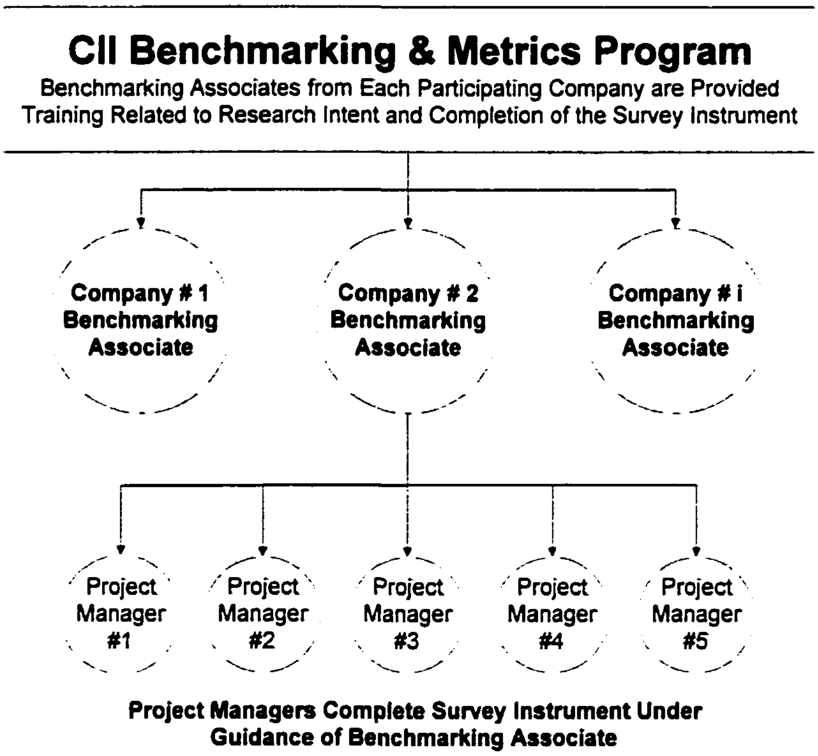


Figure 5: Respondent Training

3.2 INVESTIGATION DOMAIN

The construction industry is diverse, with various industry segments utilizing markedly different approaches to development of capital facilities. Examples of these differences include: project team organization, assignment of risk and responsibility, contracting strategies, and contract payment type. The nature of the work concerning facility complexity and construction methods employed also vary to a great extent. The primary purpose of this study is to quantify the effects of selected industry practices on project cost performance. All of the aforementioned variables associated with the various types of construction projects may influence the relationships under investigation. In order to provide analysis results that are meaningful and representative, the investigation domain must be well defined. Criteria were identified and utilized in a query of the complete CII Benchmarking and Metrics Program database such that a group of projects with similar attributes were selected for this study. The projects included in the sample extracted have the attributes as listed below.

- Industrial Projects
- Submitted by Owners
- Total Installed Cost Greater than $5,000,000
- Facilities Located in U.S.A. or Canada
- No Environmental Projects
- Completed Within the Last Three Years

This group of industrial projects is the largest subset of similar projects within the Benchmarking and Metrics Program database. CII member companies submitted all projects in the data set. This group of respondents may be considered more progressive in the use industry practices than the industry as a whole, and therefore, the analysis of use of these practices may not be representative of the overall construction industry.

3.3 Data Sample and Project Characteristics

As described previously, the data sample used in this study is a subset of the complete CII Benchmarking and Metrics Program database that meets criteria specified in the investigation domain. This section provides information that describes the resulting data set. The data sample consists of 55 industrial projects submitted by 16 owner companies. Table 3 lists the companies represented in the data sample.

Table 3: Companies Represented in the Dataset

Amoco Chemical	Eli Lilly
Anheuser-Busch	General Motors
ARCO	Hoechst Celanese
Bayer	Procter & Gamble
CITGO Petroleum	Rohm & Haas
Champion International	TVA
DuPont	U.S. Steel
Eastman Chemical	Union Carbide

The investigation domain specifies only industrial projects. Figure 6 shows the distribution of projects by project type and industry group. All projects may be classified as either heavy or light industrial. The data set consists of 40 heavy industrial projects and 15 light industrial projects. Chemical manufacturing projects have the greatest representation with 18 observations.

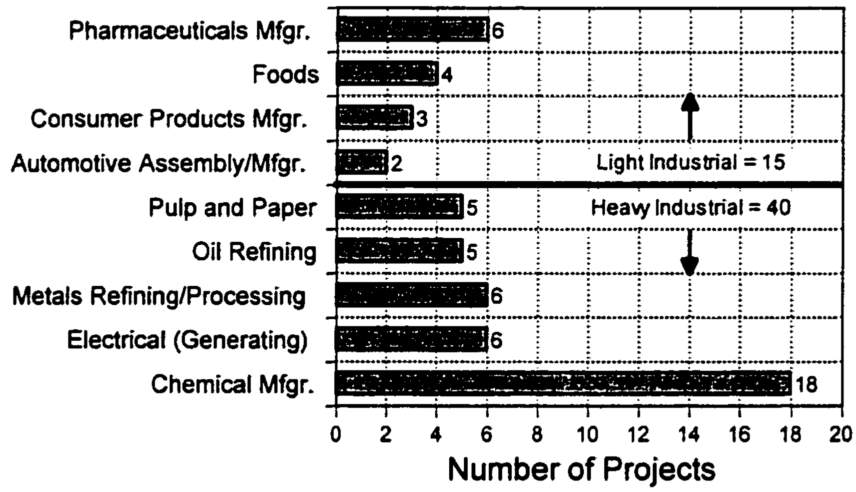


Figure 6: Data Set by Project Type

Figure 7 illustrates the classification of the data set by the nature of the projects. The survey instrument defines addition projects as new construction that ties in to an existing facility, often intended to expand capacity. Grass roots projects are defined as completely new facilities. A project requiring demolition

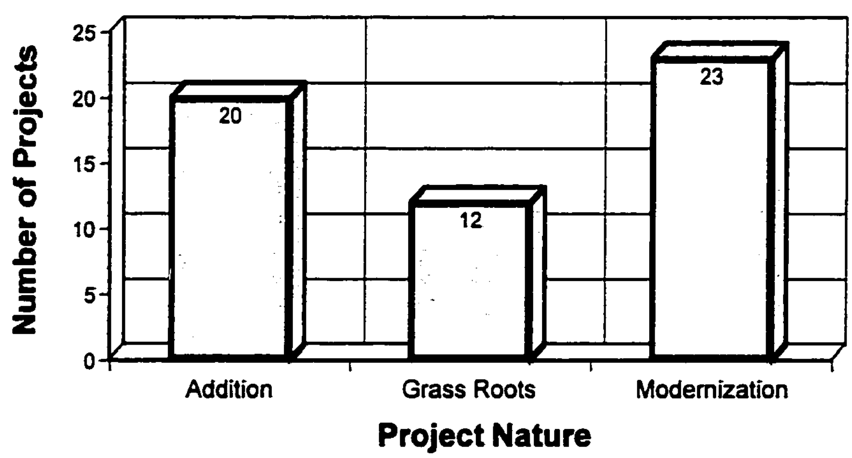


Figure 7: Data Set by Project Nature

of an existing facility before new construction begins is also classified as grass roots. Modernization projects are defined as facilities for which a substantial amount of the equipment, structure, or other components is replaced or modified, and which may expand capacity and improve the process or facility.

The total cost of projects represented in the sample data set is $2.1 billion, with an average and median project cost of $38.6 million and $22.8 million, respectively. Figure 8 illustrates the distribution of projects by cost.

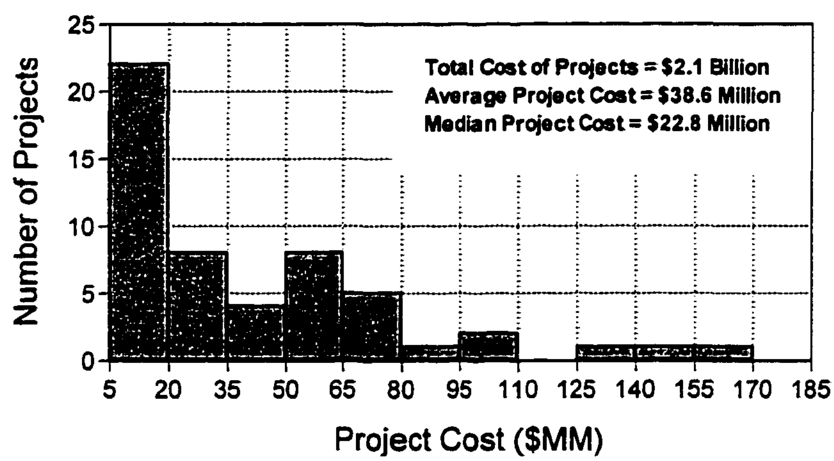


Figure 8: Data Set by Project Cost

The average and median project duration is 91.4 weeks and 86.9 weeks, respectively. Figure 9 provides a distribution for the projects in the data set by project duration in weeks. It approximates a normal distribution, with a few high value outliers.

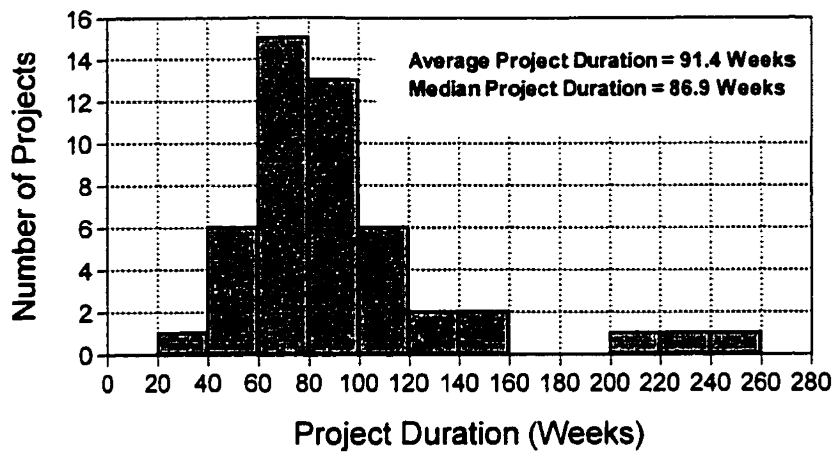


Figure 9: Data Set by Project Duration

All projects in the data set represent facilities constructed in the United States or Canada. Figure 10 illustrates the distribution of projects within the United States. The majority of projects are concentrated in the Gulf and East Coast regions of the United States. One project is located in Canada.

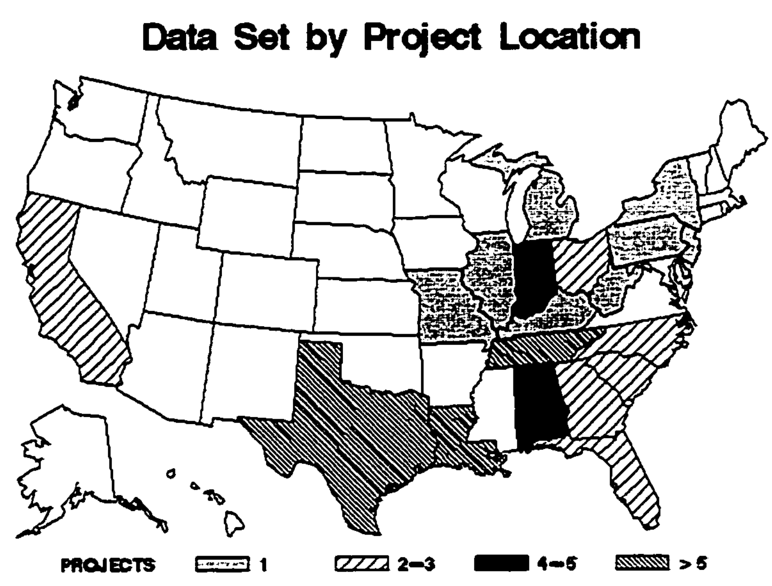


Figure 10: Data Set by Project Location

Section 4.3 of this document provides additional descriptive information related to the data set in terms of the environment in which the projects were constructed.

3.4 Analysis and Data Presentation

This section provides a basic overview of the analysis procedures and methods of data presentation used in the study to investigate the research hypotheses. The primary analysis procedures include One-Way Analysis of Variance (ANOVA) and Ordinary Least Squares (OLS) regression. These procedures are used to quantify relationships between the variables of interest.

3.4.1 One-Way Analysis of Variance

Analysis of variance (ANOVA) is a statistical test of the difference in means for two or more groups. It is an appropriate statistical test where the independent variable is a set of discrete categories and the dependent variable is a continuous measure. An ANOVA model offers a technique to test the null hypothesis that all sample means come from the same population and therefore all equal one another. The alternative hypothesis is that at least one sample mean comes from a population whose mean differs from the other population means (Knoke and Bohrnstedt 1994). A significance level must be established that represents the probability level at which one is willing to reject the null hypothesis. In general, this study uses a significance level of 0.05 as criteria for rejecting the null hypothesis. However, a few analyses are reported with a significance level of 0.10. For each use of an ANOVA in this study, the mean value of the dependent variable for each group is provided along with the appropriate test statistics to allow determination if the difference in means is statistically significant. The value of the F-statistic and the calculated significance level (Prob>F) are given.

An example use of ANOVA in this study is to examine the difference in the mean value for project cost growth for groups of projects categorized by a project attribute of interest. The project attributes of interest generally include the use of construction industry practices and the various project environment variables.

3.4.2 Regression Analysis and Diagnostics

Bivariate and multiple regression analysis methods are used in this study to examine the relationship between the variables of interest and test the research hypotheses. A brief overview of these methods and the diagnostics used to evaluate the models produced are provided in this section.

Scatterplots and bivariate regression analyses provide a useful way to examine the relationships among pairs of continuous variables. Scatterplots are provided within Chapter Five to display the relationship between pairs of continuous variables such as project cost growth and the use of pre-project planning as measured through the use of an index. A linear representation of the relationship between the pair of variables is plotted on each of the scatter plots. The linear relationship shown is a plot of the linear prediction equation developed through the use of bivariate regression analysis.

Multiple regression analysis provides a statistical technique for estimating the relationship between a continuous dependent variable and two or more continuous or discrete independent variables. It is an extension of bivariate regression and the discussion of regression analysis that follows pertains to both bivariate and multiple regression models. Construction projects are complex events, and it is reasonable to expect that the variation in cost performance is influenced by more than one independent variable. Multiple regression is used to develop models that explain more variation in the dependent variable than can be accounted for by its covariation with a single independent variable. Therefore, this study utilizes multiple regression techniques to estimate the relationship between project cost growth and several variables that are believed to have significant influence. The following discussion of multiple regression is based on *Multiple Regression in Practice*, by William D. Berry and Stanley Feldman (1985), which is an excellent reference if more details concerning regression analysis are required.

In the general form of the linear regression model, the dependent variable, Y, is assumed to be a function of a set of k independent variables, X_1, X_2, ... X_k, in a population.

The general form of the multiple regression model for a sample is as follows:

$$Y_j = a + b_1X_{1j} + b_2X_{2j} + \ldots\ldots + b_kX_{kj} + e_j$$

Where:

Y_j = dependent variable

a = intercept

b_k = partial slope coefficient for k independent variables

X_{kj} = set of k independent variables

e_j = error term

The intercept, a, represents the expected value of Y when all the independent variables equal zero. The partial slope coefficent, b_i, represents the relationships between the independent variable X_i and the dependent variable Y holding all other independent variables constant. Stated another way, b_i represents the change in the expected value of Y associated with a one unit change in X_i when all other independent variables in the model are held constant. The error term, e_j, is the deviation of the value Y_j from the mean value of the distribution obtained by repeated observations of Y values for cases each with fixed values for each of the independent variables. The error term represents the effects on Y of variables not explicitly included in the equation and a residual random element in the dependent variable.

The method used to estimate the values of a and b_i (i=1,2,...k) is ordinary least squares (OLS) regression. The estimates of a and b_i (i=1,2,...k) are those values that minimize the sum of the squared deviations of the observations, Y_j, from the predicted values of Y, $\hat{Y}_j$.

The coefficient of determination, R^2, provides a measure of the goodness-of-fit of the regression model and is calculated by the following formula:

$$R^2 = \frac{\sum(Y_i - \overline{Y})^2 - \sum(Y_i - \hat{Y})^2}{\sum(Y_i - \overline{Y})^2}$$

$$= \frac{SS_{total} - SS_{error}}{SS_{total}}$$

R^2 will always vary between 0 and 1. It can be interpreted as the proportion of the original variance in Y that is accounted for by the regression equation. The value of R^2 is reported for each regression model developed in this study.

Regression analysis provides a way to estimate population parameters from a sample of data. Tests of statistical significance provide information as to how likely it is that the estimates are close to the true population parameters. A test of statistical significance is based on a null hypothesis. The null hypothesis for the analyses in this study is that the regression coefficient equals zero. The null hypothesis is tested against the alternative hypothesis that the regression coefficient is not zero. A significance level must be established that represents the probability level at which one is willing to reject the null hypothesis. A test statistic can then be compared against a known probability distribution. For each occurrence of a regression model in this study, the appropriate test statistics are provided and the probability level at which the null hypothesis can be rejected is also provided. A "t" statistic is provided to test statistical significance for each of the regression coefficients and an "F" statistic is provided to test the statistical significance of the overall model. Calculated significance levels are provided for both the "t" and "F" statistics. A significance level of 0.05 is generally used in this study as the criteria to reject the null hypothesis, however several analyses are reported with a significance level of 0.10.

The appropriate interpretation of regression analysis is dependent on how well certain underlying assumptions of the regression model are met. Although regression analysis methods are considered to be quite robust, whenever these methods are employed, consideration should be given to how well the model subscribes to the underlying assumptions. These assumptions are as follows:

- All variables must be measured at the interval level and without error.
- For each set of values for the k independent variables, $E(\varepsilon_j)=0$. This assumption considers that the error term has a mean or expected value of zero.
- For each set of values for the k independent variables, $VAR(\varepsilon_j)=\sigma^2$. This assumption considers that the variance of the error term is constant.
- For any two sets of values for the k independent variables, $COV(\varepsilon_j,\varepsilon_h)=0$. This assumption considers that the values of the error term are uncorrelated; thus there is no autocorrelation.
- For each X_i, $COV(X_i,\varepsilon) = 0$ (i.e., each independent variable is uncorrelated with the error term).
- There is no perfect collinearity – no independent variable is perfectly linearly related to one or more of the other independent variables in the model.
- For each set of values for the k independent variables, ε_j is normally distributed.
- The model is properly specified with all relevant variables included and all irrelevant variables excluded from the model. This assumption considers that the model is properly specified.

- The relationship between the dependent variable and each independent variable is linear and that the effects of the independent variables are additive.

Discussion is provided for each of the regression models developed in this study related to how well the model conforms to the assumptions. Appendix H provides regression diagnostic plots for each of the models related to constant variance of the error term, normal distribution of the error term, and influential observations.

3.4.3 Box and Whisker Diagrams

The box and whisker diagram (sometimes referred to as a "box plot") is a useful tool to graphically represent univariate data in a concise manner. It provides information about the distribution of a single variable with focus on the data quartiles. The distribution is divided into four equal intervals. The lower and upper horizontal edges of the box are located at the first and third quartiles of the data respectively. The height of the box corresponds to the interquartile range or middle 50 percent of the distribution. The horizontal line within the interior of the box is placed at the vertical scale position corresponding to the median value. The vertical lines ("whiskers") above and below the central box extend to a defined point in the data distribution. This may vary depending on user specification or the software used to create the diagram. In this report, the whiskers extend to the 10^{th} and 90^{th} percentiles of the distribution. A single point represents the mean value of the distribution. Figure 11 illustrates each of the components of the box and whisker diagram.

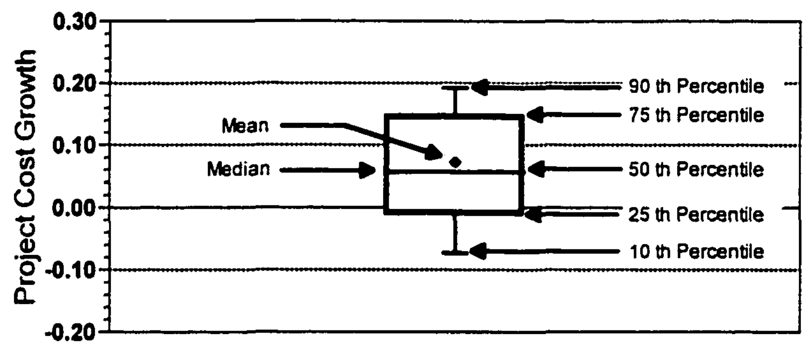


Figure 11: Box and Whisker Diagram Illustration

The box and whisker diagram is used in this study to graphically illustrate the difference in the distribution of project cost growth for projects categorized by another variable. The diagram is a useful way to illustrate differences in the project cost growth distribution for projects that either did or did not use a practice item or if an overall practice was or was not used to an extensive degree. The diagram is beneficial in illustrating the differences in central tendency and variance between the two distributions.

3.5 Limitations of this Study

Appropriate interpretation of the analyses performed in this study requires addressing several potential limitations involved in the data collection and analysis procedures. Due to the confidential nature of the data, accessibility of the target respondents, and the resources required to compile the requested data, the observations (projects) obtained are of a voluntary nature. The inclusion of projects in the data set is not based on a random sample of a known population. The implications of this type of sampling include potential bias concerning the issue of good performance desirability. There may have been a tendency of respondents to select projects that represent outcomes that the respondents consider desirable. Therefore, the cost performance of projects in the sample may be biased towards good performance and the sample indicates better performance than the population it is intended to represent.

A similar potential bias, separate from the sampling issue, involves responses to questions concerning the use of practices. The responses may be biased toward higher use of the practices than actually occurred because use of the practices may be thought of as a desirable trait of a progressive company. This type of bias is a recognized data gathering problem in the social sciences referred to as social desirability. It is simply human nature for people to represent themselves, or projects they are involved with, in a positive way.

Efforts were taken during the data collection process to minimize these effects. During the survey respondent training, instruction was given for the respondents to select projects that experienced both good and poor cost performance. Also, respondents were instructed to provide accurate responses concerning practice use. It was explained that more meaningful analyses would be achieved through accurate reporting, thus leading to better information available to the respondents as a result. All respondents were informed that data would be kept confidential such that no reprisals could occur through reporting of undesirable practice use.

The projects in the sample represent a fairly narrow domain when compared to all types of construction projects. Caution should be used if the analysis results are generalized to include projects that exhibit other attributes.

Chapter 4: Measurement of Project Cost Performance, Practice Use, and Project Environment

This chapter provides definition and discussion for each measure used to quantify the variables included in the research hypotheses. The measures are categorized by project cost performance, practice use, and project environment. A distribution of data and descriptive statistics for each measure are presented for the sample dataset.

4.1 Project Cost Performance

The measure of project cost performance used in this study is termed project cost growth. Project cost growth is a measure of project cost predictability. Project contingency is a subject closely related to project cost predictability. This section provides definition and data presentation for the project cost growth and contingency measures.

4.1.1 Project Cost Growth Definition

The calculating formula for project cost growth, as defined for this study, is:

$$\text{Project Cost Growth} = \frac{\text{Actual Total Project Cost} - \text{Initial Predicted Project Cost}}{\text{Initial Predicted Project Cost}}$$

A positive project cost growth value indicates that the actual total project cost exceeds the initial predicted project cost. In effect, the project overran the corresponding project budget. A project cost growth value of zero indicates that the project was executed on budget, while a negative value indicates cost underrun.

Many estimates of project cost may be prepared during the life of a project. Generally the level of predictability associated with an estimate improves through time in the project lifecycle. Therefore, for a measure of project cost growth to be meaningful across a sample of projects, the point during the project life at which an estimate was developed must be specified. For this study, the initial predicted project cost corresponds to the estimate prepared as near as practicable to the beginning of detail design. Figure 12 illustrates the five-phase project model used in this study and the point in time at which the initial predicted project cost and actual total project cost used in the project cost growth formula should correspond. The initial predicted project cost does not include an

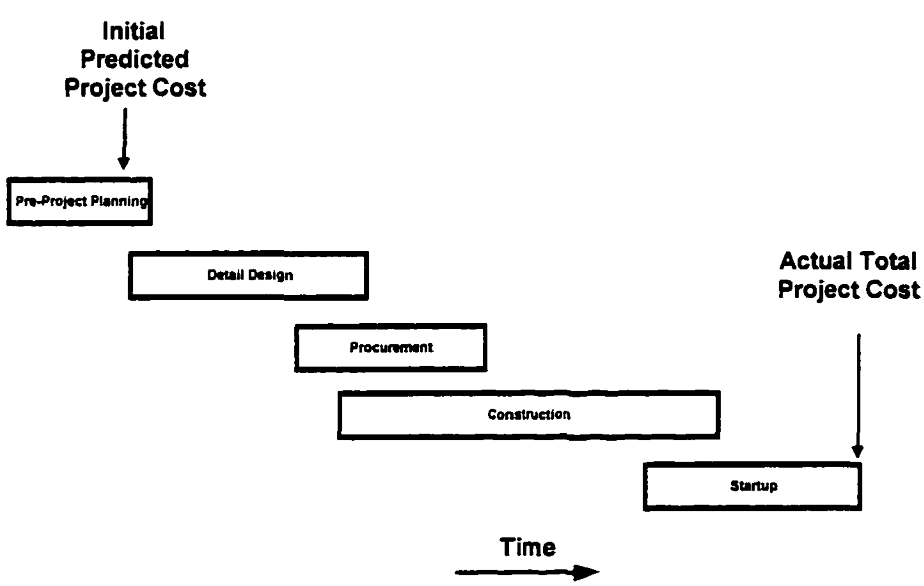


Figure 12: Timing of Project Cost Growth Data

allowance for contingency. The actual total project cost is defined as the total installed cost of the project at turnover excluding the cost of land. The project phase table on pages 2 and 3 of the data collection instrument provides typical project cost elements for each project phase. The project phase table was provided to respondents as guidance concerning what project costs should be included in the reported initial predicted project cost and actual total project cost. Appendix A contains a copy of the data collection instrument including the project phase table.

4.1.2 Project Cost Growth Data Presentation

The histogram in Figure 13 provides a graphical representation of the distribution of project cost growth for the sample dataset. It approximates a normal distribution with two outliers. The two projects with project cost growth

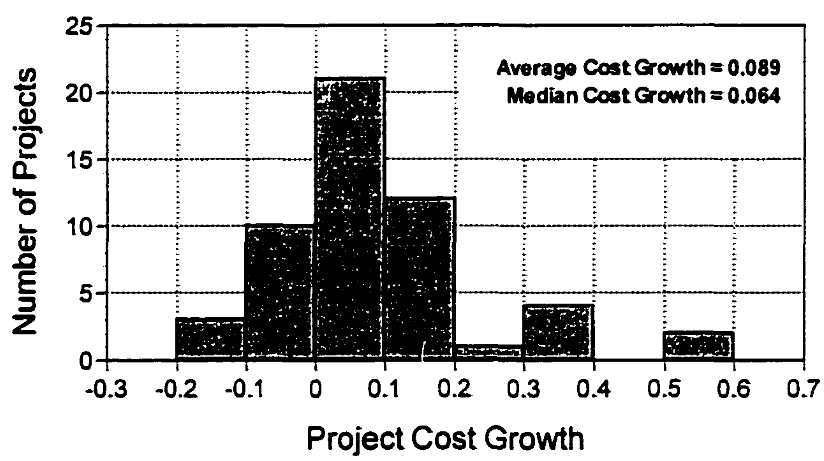


Figure 13: Project Cost Growth Histogram

values between 50 percent and 60 percent were reviewed in detail to determine if they should be removed from the analysis due to extraordinary circumstances. It was determined that there was no compelling reason to exclude the data. The average project cost growth for this sample of projects is 8.9 percent and the median is 6.4 percent.

Table 4 provides additional information related to the distribution of project cost growth values. The maximum project cost growth value (shown as 100% in the table) is 58.0 percent and the minimum value (shown as 0% in the table) is –17.0 percent. Each of the quartile values for the distribution is also shown (25%, 50%, 75%).

Table 4: Project Cost Growth Distribution

Project Cost Growth Distribution	
100%	0.580
75%	0.151
50%	0.064
25%	0.000
0%	-0.170
Average	0.089
SD	0.154
n	53

Note that seventy-five percent of the projects experienced positive cost growth. The standard deviation, represented by "SD" in the table, is 0.154. Only 53 projects are included in the distribution because two of the 55 projects in the data set did not submit sufficient data to calculate the project cost growth metric. If the two projects with cost growth values between 50 percent and 60 percent are removed from the analysis, then the average cost growth value for this group of projects is 7.1 percent and the standard deviation is 0.125.

4.1.3 Project Contingency

The treatment of contingency is important in analyzing project cost performance. Contingency allowances are generally established on projects to compensate for deviations in actual project cost from the cost estimate due to unfavorable or unforeseeable conditions. The data collection instrument defined project contingency to include all costs in contingency accounts including but not limited to normal contingency, allowances, reserves, indirect costs for schedule contingency, escalation, etc.

In part, contingency should be based on how well a project is defined when the estimate is prepared and what management practices are used during project planning and execution. The use of best practices and project definition are closely related in that many of the best practice items are intended to enhance project definition either directly or indirectly. If project definition and the best practices are considered in setting contingency, then contingency and practice use are correlated. Therefore, if the contingency component of the estimate is included in the calculation of project cost growth, then a portion of the best practice effects on project cost growth will be concealed. For example, projects with less pre-project planning effort at project authorization may include a larger contingency than projects with greater pre-project planning, thus offsetting a portion of the project cost growth that may by attributable to poor pre-project planning. To account for this, throughout this study, contingency is excluded from the initial predicted project cost used to calculate project cost growth.

A measure of contingency was defined as a ratio of project contingency to initial predicted project cost. This measure is called project contingency factor. As shown in Figure 14, the average project contingency reported for the data set is 8.5 percent of the initial predicted project cost and the median value is 7.5 percent. The distribution is positively skewed.

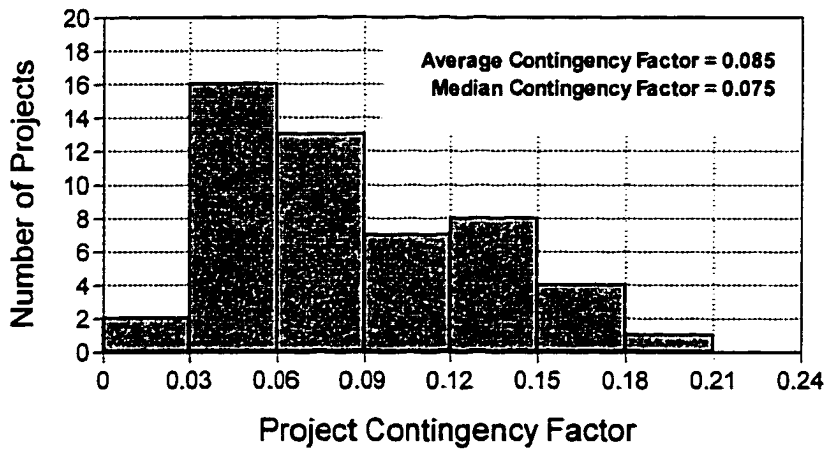


Figure 14: Project Contingency Factor Histogram

Table 5 provides additional information related to the project contingency factor distribution. The measure exhibits a high level of variation in the sample with a project that reported a project contingency factor as high as 18.7 percent of the estimated project cost and another project that reported only 2.0 percent.

Table 5: Project Contingency Factor Distribution

Project Contingency Factor Distribution	
100%	0.187
75%	0.121
50%	0.075
25%	0.046
0%	0.020
Average	0.085
SD	0.045
n	53

4.2 Practice Use

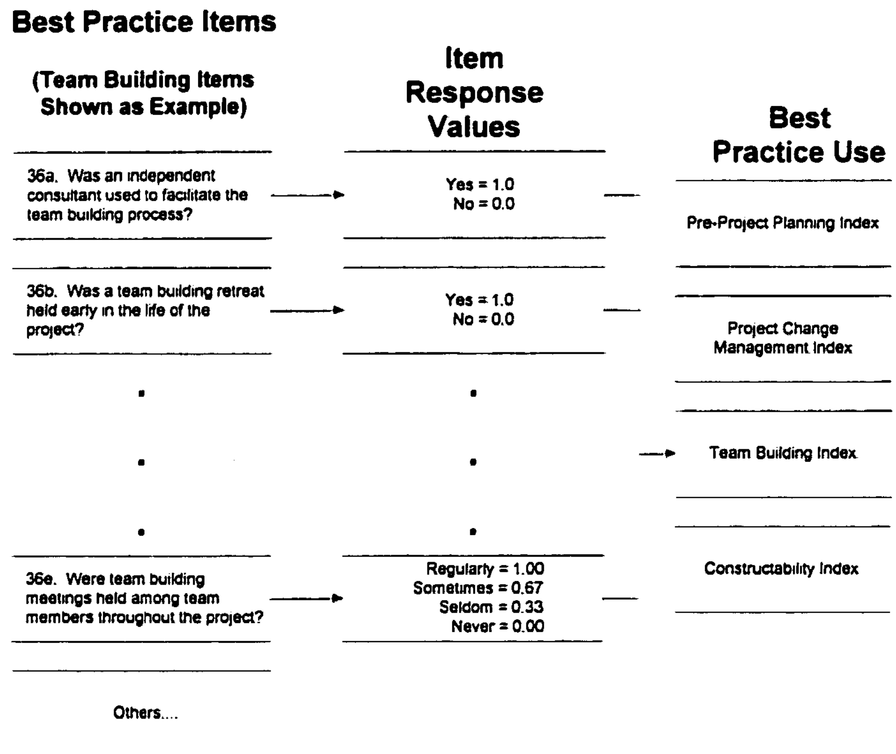
Eight construction industry practices were selected for investigation of their effects on project cost performance. This section provides detailed information concerning the measurement of each of the practices.

4.2.1 Best Practice Use Index Development

This section describes the methodology used to develop measures for pre-project planning, project change management, team building, and constructability. The definitions and discussion are based on *Summated Rating Scale Construction, An Introduction* by Paul E. Spector, 1992 and *The Practice of Social Research*, Seventh Edition, by Earl Babbie, 1995.

The summated rating scale is a frequently used measurement tool in the social sciences. The goal is development of an individual rating on a single attitude, value, or opinion based on responses to multiple items. Scores are assigned to each individual item depending on the response and these are added up to form an index. Rensis Lickert developed the technique for the assessment of attitudes. A very similar technique has been utilized to assess the use of the four best practices under consideration in this study. The scales measure the use of pre-project planning, project change management, team building, and constructability. The individual question items on which the scales are based correspond to specific practice recommendations developed by CII research teams. For project change management, team building, and constructability, each best practice consists of multiple items that are recommended as a part of utilizing the overall practice. Items that constitute the measure of pre-project planning consist of the level of definition for many project elements, an assessment of the pre-project planning team composition, and assessment of several other pre-project planning activities discussed previously in Chapter Two.

The measurement scale for each of these practices ranges from an index value of 0 (representing no use of a practice) through 10 (representing extensive use of a practice). Using team building as an example, Figure 15 illustrates the steps involved in calculating an index score for best practice use. Each item in the scale is assigned a value based on the response to the item statement or question. These values are added and the sum is multiplied by a scale factor selected to result in values between 0 and 10. The response values for the pre-project planning items are based on work performed by the pre-project planning research team. The response values correspond to weights assigned these items by a panel of experts during the development of the Project Definition Rating Index (PDRI). The items used in this study to develop the pre-project planning index are based on items from the PDRI. The item response values for the other practices are generally equal in weight. However, for items with very little response variation,



Best Practice Use Index = Σ(Item Response Value) x Scale Factor

Figure 15: Best Practice Use Index Calculation

the weight was reduced to provide a greater level of differentiation between practice use. Also, greater weight was given to individual items that were found to have significant impact on project cost growth in an assessment of the individual items. Appendix D provides the formulas used to calculate index values for each of the best practices. Item response values are also provided.

Several characteristics common to a traditional summated rating scale include: 1) A scale must contain multiple items, 2) Each individual item must measure something that has an underlying, quantitative measurement continuum,

3) Each item in a scale is a statement and respondents are asked to give ratings about each statement. This involves asking subjects to indicate which of several response choices best reflects their response to the item. Most summated rating scales offer 4 to 7 response choices. The scales used in this study to measure project change management, team building, and constructability differ from this description of traditional summated rating scales in that several of the elements pose questions (rather than statements) and some items have only two response choices. Another variation from the standard summated rating scale procedure is the use of multiple response category types within the same scale. For example, four category response questions and yes/no responses are roled into the same scale. These differences, however, should not diminish the desirable properties of the summated rating scale.

This measurement technique was chosen because properly formed summated rating scales can have good reliability and validity. Unreliability and inconsistency in responses can be produced in several ways. Ambivalent respondents may make essentially random responses to a question. If respondents were simply asked if a practice were used on a project, those reporting on projects with minimal or ineffective use of the practice in question may respond yes or no depending upon their interpretation of the question. Respondents making mistakes in their responses also can produce unreliability. They can respond yes instead of no, they may misread the question, misunderstand the question, or be uncertain about what the question means. The possibility of these types of mistakes or essentially random responses depending upon interpretation for borderline cases result in poor reliability if only a single question is asked concerning the use of a best practice

Two features of the summated rating scale will solve these problems. First, the use of more than two response choices will increase precision. The data collection instrument uses multiple response and yes/no response choices as appropriate. The use of multiple items (questions) can address several problems. A variety of questions enlarges the scope of what is measured and provides a degree of education for the respondent concerning the attribute being measured. Multiple items improve reliability by allowing random errors of measurement to be averaged out. For example, when using a 20-item scale, if a respondent makes a mistake on one item the impact on the total score is quite minimal. Multiple items provide improved precision. With a single 5-choice question, projects can be placed in 5 groups on the basis of their responses. With 20 5-choice items over five times the precision is available (Spector 1992).

A good summated rating scale is both reliable and valid. Internal-consistency reliability means that multiple items meant to measure the same things will intercorrelate with one another. Reliability means that a scale can consistently measure something, but it does not assure it will measure what it is intended to measure. Validity means that a scale will measure its intended construct. Discussion related to efforts undertaken in this study to assure the scales developed for the best practices are reliable and valid follow.

4.2.1.1 Reliability

Internal-consistency reliability is an indicator of how well the individual items of a scale reflect a common, underlying construct. Coefficient Alpha is a measure of the internal consistency of a scale. It is a direct function of both the number of items and their magnitude of intercorrelation. Coefficient Alpha can be raised by increasing the number of items or by raising their intercorrelation. Coefficient Alpha reflects internal-consistency reliability.

Values of Coefficient Alpha look like correlation coefficients, but Alpha is not a correlation. It is usually positive, taking on values from 0 to just under 1.0, where larger numbers indicate higher levels of internal consistency. Nunnaly provides a widely accepted rule of thumb that Alpha should be at least 0.70 for a scale to demonstrate internal consistency. Coefficient Alpha involves comparison of the variance of a total scale score (sum of all items) with the variances of the individual items. Mathematically, when items are uncorrelated, the variance of the total scale will be equal to the sum of variances for each item that comprised the total scale.

To ensure reliability in choosing items for a scale, consideration is given to both item-remainder coefficients and Coefficient Alpha. An iterative process may be involved in which items are deleted and Alpha is rechecked until a final set of items is chosen.

Appendix E provides Coefficient Alpha and item-remainder coefficients for the indexes developed for pre-project planning, project change management, team building, and constructability. No items were deleted from the index for any of the best practices to improve Coefficient Alpha. Based on the coefficient alpha statistic, all four best practice indexes exhibit desirable levels of internal consistency.

4.2.1.2 Validity

The validity of a measurement relates to whether or not the measure represents the construct of interest. Developing and testing hypothesized relationships between the construct of interest and other constructs may provide validation. Hypotheses are developed about the causes, effects, and correlates of the construct. Empirical support for the hypotheses implies validity of the scale.

In support of the validity of the pre-project planning index, it is hypothesized that a relationship exists between pre-project planning effort and the percent of total design workhours expended before project authorization. Higher levels of percent design complete prior to project authorization should correspond to higher scores on the pre-project planning index because both measures relate to the degree of project definition prior to project authorization. Table 6 provides ANOVA results to compare the average pre-project planning index for the 50 percent of the projects that had the least amount of design complete with the 50 percent of the projects that had the most design complete. Thirty-seven projects with complete pre-project planning and percent design complete information are included in this analysis. The number of projects in each comparison group is represented in the table under the heading "n." The average pre-project planning index score for the upper 50 percent is 8.5 compared to 7.8 for the lower 50 percent. The difference in averages is statistically significant at the 0.10 level.

This simple analysis provides support in favor of the validity of the pre-project planning index. Due to a lack of data for measures to perform validity checks for project change management, team building, and constructability, no evidence supporting the validity of these indices is provided as a part of this study.

Table 6: ANOVA for Percent Design Complete Prior to Project Authorization and Pre-Project Planning Index

Percent Design Complete Prior to Project Authorization Level								
Low 50 Percent			High 50 Percent					
n	Pre-Project Planning Index	SD	n	Pre-Project Planning Index	SD	R-Square	F Stat	Prob>F
19	7.8	1.36	18	8.5	0.85	0.092	3.53	0.0688

4.2.1.3 Handling Missing Data

Data sets generated through survey research inevitably suffer from missing data. This study is not an exception. In some instances, the respondent simply did not know the answer to a question and responded with an "unknown" or provided no response at all. This section provides documentation related to the treatment of missing data in the analyses. Fifty-five projects from the CII Benchmarking and Metrics Program database met the investigation domain criteria specified for this study. Two of those projects did not provide sufficient cost data to compute project cost growth. Those two projects are necessarily excluded from all analyses including project cost growth. The response rate for questions related to the use of pre-project planning, project change management, team building, and constructability was very good. For each best practice item, only one or two projects did not respond or gave an "unknown" response. For projects that did not respond or gave an "unknown" response for only one or two items within a single best practice, values were generated in order to calculate a best practice index score for the project. The value provided was based on the average item value for the remainder of the data set. Due to the fairly large number of items used in each index, generating missing item values for only one or two items introduces the possibility of little error yet allows these projects to be included in the analyses. If data were omitted for more than two of the items within a single best practice, then no best practice index score was computed for the project and the project was excluded from all analyses related to the best practice. One project provided an insufficient response to compute the pre-project planning index and is omitted from all related analysis.

Response rates for the other practice questions and the project environment questions were also good. Projects with missing data for these variables are excluded from related analyses. Question 17a in the data collection instrument, concerning the percent of design workhours complete prior to project authorization had the worst response rate of approximately 69 percent. For analyses involving this measure, only 38 observations are available.

4.2.2 Best Practice Use Data Presentation

An index value representing the degree of use for each of the best practices was developed for each project in the data sample utilizing the procedure discussed previously. This section provides information that summarizes the reported use of pre-project planning, project change management, team building, and constructability. The distribution of index scores for each of the best practices reveals a level of variation within the sample sufficient to allow correlation analysis with other variables to test the research hypotheses.

4.2.2.1 Pre-Project Planning

In general, the projects in the sample dataset reported high levels of use for the pre-project planning best practice. Figure 16 illustrates the distribution of pre-project planning index values. The average value is 8.0 and the median value is 8.3. No project scored less than 5.0 on the pre-project planning index. Several projects received scores approaching 10.0, indicating a very high level of pre-project planning effort.

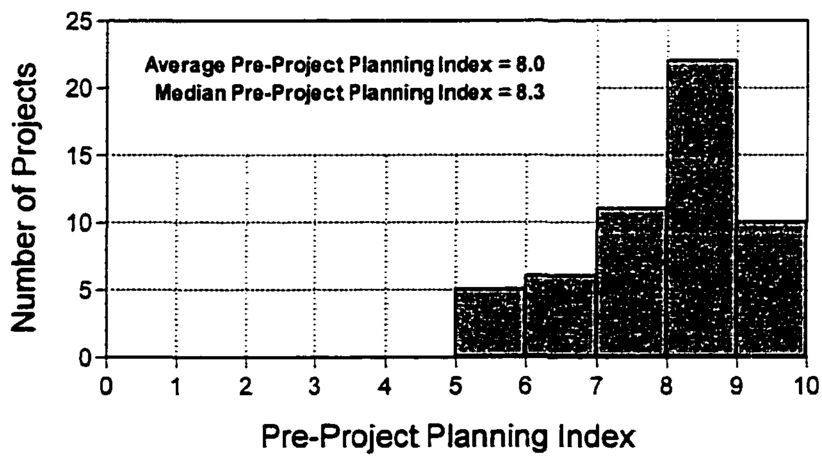


Figure 16: Pre-Project Planning Use

Table 7 provides additional information concerning the distribution of pre-project planning index values. One project did not report sufficient data to calculate a pre-project planning index score.

Table 7: Pre-Project Planning Index Distribution

Pre-Project Planning Index Distribution	
100%	9.7
75%	8.9
50%	8.3
25%	7.1
0%	5.2
Average	8.0
SD	1.2
n	54

4.2.2.2 Project Change Management

Figure 17 illustrates the distribution of project change management index values for the sample dataset. In general, the distribution of scores represents a high reported use of project change management. However, several projects report relatively low effort in the area of project change management by receiving scores ranging between 3.0 and 5.0. The average value is 7.8 and the median value is 8.4.

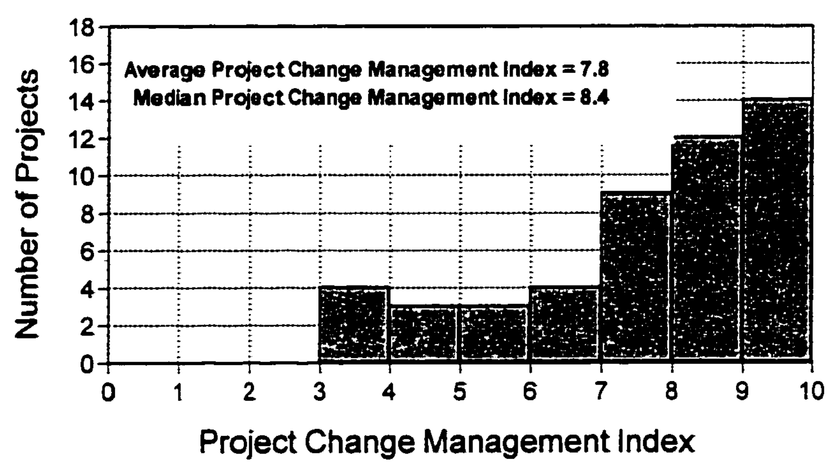


Figure 17: Project Change Management Use

Table 8 provides additional information concerning the distribution of project change management index values. All fifty-five projects provided complete project change management data.

Table 8: Project Change Management Index Distribution

Project Change Management Index Distribution	
100%	10.0
75%	9.5
50%	8.4
25%	6.7
0%	3.0
Average	7.8
SD	2.0
n	55

4.2.2.3 Team Building

Figure 18 illustrates the distribution of team building index values for the sample dataset. The distribution of scores represents a great deal of variation concerning the use of team building. Approximately 30 percent of the projects in

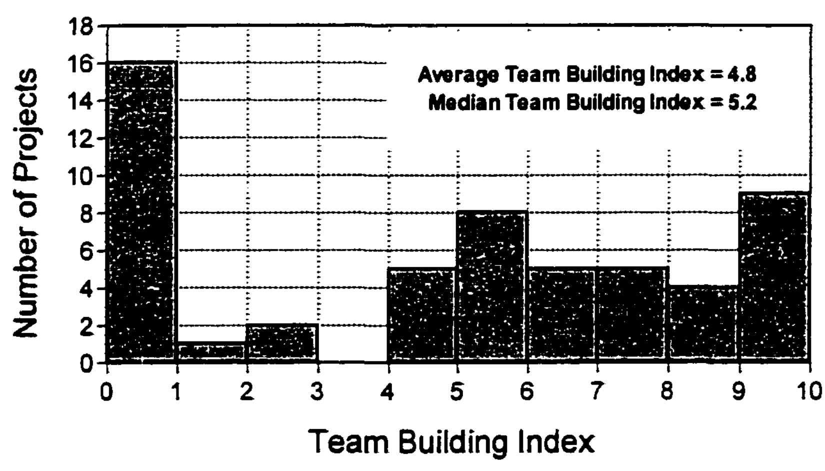


Figure 18: Team Building Use

the sample data set did not use this practice at all. The average value is 4.8 and the median value is 5.2.

Table 9 provides additional information concerning the distribution of team building index values.

Table 9: Team Building Index Distribution

Team Building Index Distribution	
100%	10.0
75%	7.9
50%	5.2
25%	0.6
0%	0.0
Average	4.8
SD	3.5
n	55

4.2.2.4 Constructability

Figure 19 illustrates the distribution of constructability index values for the sample dataset. The distribution of scores represents a great deal of variation

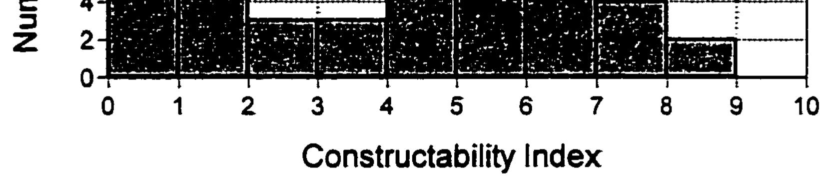


Figure 19: Constructability Use

concerning the use of constructability, with a considerable number of projects reporting little or no use of this practice.

The average value is 3.5 and the median value is 3.6. Table 10 provides additional information concerning the distribution of constructability index values.

Table 10: Constructability Index Distribution

Constructability Index Distribution	
100%	8.2
75%	5.7
50%	3.6
25%	1.0
0%	0.0
Average	3.5
SD	2.6
n	55

4.2.3 Other Practice Use Data Presentation

This section provides information related to percent design complete, contract cost incentives, contract compensation strategy, and contract organization strategy for the sample of projects in the dataset.

4.2.3.1 Percent Design Complete

Percent design complete is measured as a ratio of the total engineering workhours expended prior to project authorization to the total engineering workhours expended for the project. Figure 20 illustrates the distribution of values for this measure. A large variation is evident for this measure, with values ranging from 0 percent to 99 percent. The average value is 24.0 percent and median value is 19 percent. The average value is skewed to the high end of the scale by the several projects that reported in excess of 70 percent design complete prior to project authorization.

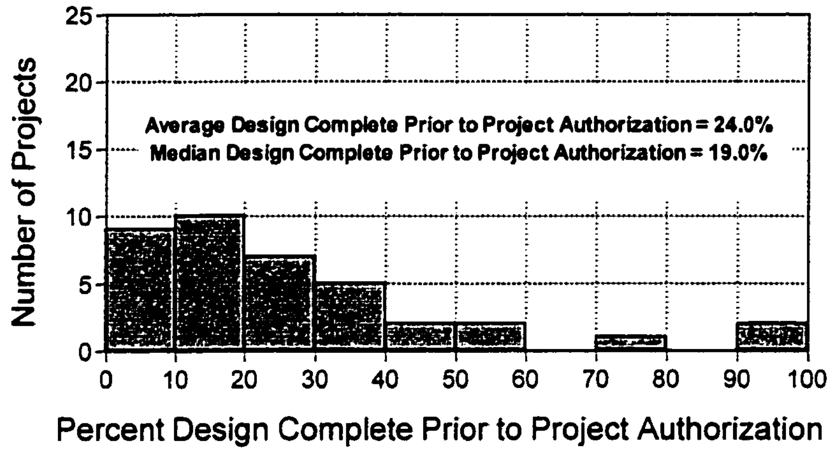


Figure 20: Percent Design Complete

Table 11 provides additional information related to the distribution of percent design complete values. The second column from the left provides distribution quartile values, average, standard deviation (SD), and the number of observation represented (n). Only thirty-eight projects provided data for this measure, therefore analysis utilizing this variable is somewhat restricted compared to the other variables in the dataset. For analysis involving this measure, it is useful to divide the complete data set into two groups based on the median percent design complete value. This allows the use of categorical analysis procedures that compare the group of projects that reported a high level of design complete prior to project authorization to projects that reported a low level. The columns in the right half of Table 11 represent the average value and number of observations for the projects categorized in this manner.

Table 11: Percent Design Complete Distribution

Percent Design Complete Distribution	
Distribution Statistic	**% Design Complete**
100%	99.0
75%	33.0
50%	19.0
25%	10.0
0%	0.0
Average	24.0
SD	24.4
n	38

% Design Complete Group	Average % Design Complete	n .
High	41.0	19
Low	6.0	19

4.2.3.2 Contract Cost Incentives

Table 12 provides information related to the use of contract incentives by type of incentive and project function. The values in the table represent the percent of projects in the sample dataset that reported use of each type of incentive with the project participant that performed the function listed. For example, 31 percent of the projects in the sample reported the use of contract incentives aimed at improving cost performance with the party that designed the project. The incentive may have been either positive or negative in form. The far right column indicates that the owner performed the design for 17 percent of the projects in the dataset. The projects for which the owner performed design were not included in the percentage calculation for incentive use.

Table 12: Contract Incentives Distribution

	Type of Incentive				
Function	**Cost**	**Schedule**	**Safety**	**Quality**	**By Owner**
Design	31%	35%	23%	23%	17%
Construction	38%	38%	32%	28%	0%

4.2.3.3 Contract Compensation Strategy

Information related to the type of contractor compensation used in the sample of projects is provided in Table 13. A form of cost reimbursable compensation was the most frequently reported type. Forty-eight percent of the sample projects reported the use of cost reimbursable compensation for contractors that performed project design. Fifty-one percent reported cost reimbursable compensation for contractors that performed construction. Lump sum compensation was the second most frequently reported type.

Table 13: Contract Compensation Strategy Distribution

	Compensation Strategy				
Function	**Cost Reimbursable**	**Lump Sum**	**Unit Price**	**Guaranteed Maximum Price**	**By Owner**
Design	48%	21%	8%	6%	17%
Construction	51%	33%	8%	8%	0%

4.2.3.4 Contract Organization Strategy

Information related to the contract organization strategy used by the sample of projects is illustrated in Table 14. Seventeen percent of the projects were organized such that the same contractor performed both the design and construction function for the project. Eighty-three percent of the projects used some other type of organization. The unequal distribution of projects among categories does not facilitate analysis based on this variable. The Design/Construction category contains only nine projects, which are not enough observations on which to base credible interpretation of analyses.

Table 14: Contract Organization Strategy Distribution

Strategy	% of Projects
Design/Construction	17%
Other	83%

4.3 Project Environment Measurement Variables

This section provides information related to the project environment variables of interest in the research hypotheses. Brief discussion is provided for each variable concerning its postulated effects on project cost performance. For each of the variables that are continuous in nature a histogram is provided to illustrate the distribution of the measurements values. A table is also provided with additional distribution information that is not available from a histogram. It includes distribution quartile values, average, standard deviation (SD), and number of observations (n). For analysis involving continuous measures, it is often useful to divide the complete data set into two groups based on the measure's median value. This allows the use of categorical analysis procedures that compare the groups of projects that reported either relatively high or low values for the measure. The sample of projects has been categorized in this way for each of these measures to facilitate analysis in Chapter Five. The median value used to categorize the sample, the average value, and the number of observations in the resulting groups are provided in tabular form.

4.3.1 Project Complexity

Respondents were asked to indicate Project Complexity on a scale of 0 to 10, representing low complexity to high complexity respectively. Guidance was provided related to project parameters that should be considered in assessing project complexity. Previous research has indicated a significant relationship between project complexity and project cost performance (Merrow 1991). Figure 21 illustrates the distribution of project complexity values. The average and median values for project complexity are 6.5 with the vast majority of projects reporting complexity values greater than 5.0.

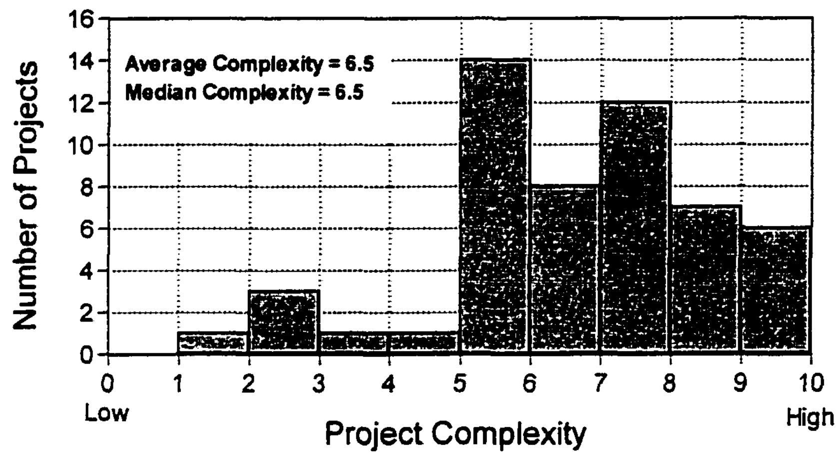


Figure 21: Project Complexity Histogram

Table 15 provides additional information related to the distribution of project complexity values for the sample of projects. The projects are categorized by relative complexity. The median project complexity value of 6.5 is used to categorize the projects. Twenty-seven projects fall within the high complexity group with an average complexity of 8.1, while 28 projects are identified as low complexity with an average value of 4.9.

Table 15: Project Complexity Distribution

Project Complexity Distribution	
Distribution Statistic	Project Complexity
100%	10.0
75%	8.0
50%	6.5
25%	5.0
0%	1.5
Average	6.5
SD	2.0
n	55

Complexity Group	Average	n
High	8.1	27
Low	4.9	28

4.3.2 Project Nature

A common industry belief is that modernization projects, and to a slightly lesser extent addition projects, are generally more difficult concerning interfaces than grass roots projects and may therefore experience relatively worse project cost performance. The term interfaces, as used in this context, refers to a number of potential sources of interference that may be encountered during project planning and execution. The problems that modernization and addition projects encounter that are not a concern on grass roots projects may include the requirement to work around existing operations in regard to both time and space constraints. Design and construction requirements that enable new construction to tie-in with existing equipment and utilities, for which adequate as-built drawing may not exist, are also potential problem sources.

The distribution of projects by project nature for the sample used in this study is shown in Figure 7 on page 37. The sample has good representation in each project nature category.

4.3.3 Project Cost

Research has shown that very high cost projects, commonly called mega projects, tend to suffer from poor project cost performance when compared to smaller projects. The cost of a project and other project attributes that are directly related to cost may significantly influence project cost performance. Although none of the projects in this dataset is of the size commonly referred to as mega projects (usually > $1.0 billion), a correlation may still exist between project cost and project cost performance.

The sample of fifty-five projects represents $2.1 billion in total installed cost. The average project cost is $38.6 million and the median project cost is $22.8 million. As specified in the investigation domain, the sample dataset does not include any projects with a total installed cost of less than $5.0 million. The dataset contains several large projects in excess of $100 million. The distribution of project cost values for the sample dataset is illustrated in Figure 8 on page 38.

Table 16 provides additional information related to the distribution of project cost values for the complete sample dataset, as well as the sample of projects categorized in the high and low cost groups.

Table 16: Project Cost Distribution

Project Cost Distribution	
Distribution Statistic	**Project Cost**
100%	$161.0 MM
75%	$56.6 MM
50%	$22.8 MM
25%	$8.7 MM
0%	$4.8 MM
Average	$38.6 MM
SD	$37.5 MM
n	55

Cost Group	Average	n
High	$67.3MM	27
Low	$11.0MM	28

4.3.4 Project Duration

The distribution of project duration values for the sample dataset is shown in Figure 9 on page 39. The average project duration is 91.4 weeks and the median project duration is 86.9 weeks. In general, projects of shorter duration may be more susceptible to poor project cost performance because the short duration schedules allow less opportunity to recover from delays in work progress. Additional costs may be incurred through attempts to recover time, thus leading to poor project cost performance.

Table 17 provides additional information related to the distribution of projects duration values for the complete sample dataset, as well as, the sample of projects categorized in the high and low project duration groups.

Table 17: Project Duration Distribution

Project Duration Distribution	
Distribution Statistic	**Project Duration**
100%	250.1 Wks
75%	99.7 Wks
50%	86.9 Wks
25%	66.3 Wks
0%	30.4 Wks
Average	91.4 Wks
SD	43.2 Wks
n	48

Duration Group	Average	n
High	120.3 Wks	23
Low	64.8 Wks	25

4.3.5 Project Cost Rate

Project cost rate is defined as the ratio of total actual project cost to the total actual project duration in weeks. It is believed that high cost rate projects, those that consume high levels of resources in relatively short periods of time, may have a greater tendency to experience poor cost performance. Figure 22 illustrates the distribution of project cost rate values for the sample of projects.

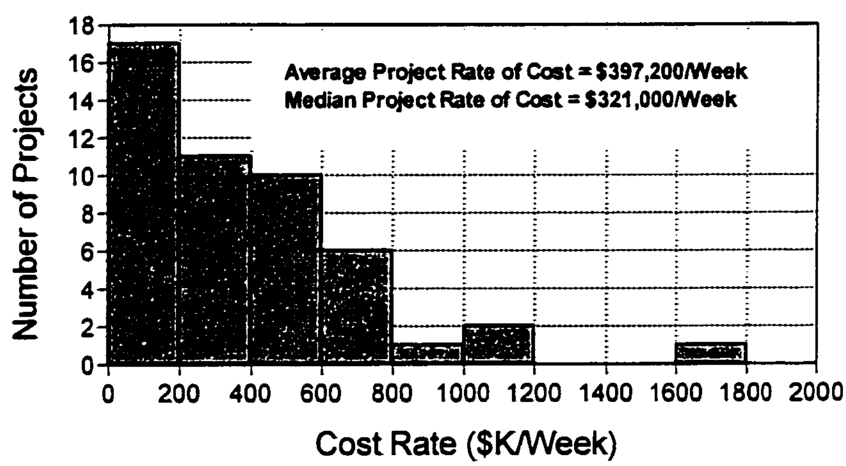


Figure 22: Cost Rate Histogram

The average cost rate value is $397, 200 per week and the median value is $321,000 per week.

Table 18 provides additional information related to the distribution of project cost rate values for the complete sample dataset, as well as the sample of projects categorized in the high and low project cost rate groups.

Table 18: Cost Rate Distribution

Cost Rate Distribution	
Distribution Statistic	**Cost Rate**
100%	$1,612.8 K/Wk
75%	$581.1 K/Wk
50%	$321.0 K/Wk
25%	$144.3 K/Wk
0%	$57.3 K/Wk
Average	$397.2 K/Wk
SD	$316.0 K/Wk
n	48

Cost Rate Group	Average	n
High	$635.5 K/Wk	24
Low	$158.9 K/Wk	24

4.3.6 Craft Workhours

Craft labor productivity has the ability to significantly influence a project's cost performance. Projects that experience productivity rates worse than predicted as a basis for the project estimate incur more labor cost than predicted, which may contribute to overall poor project cost performance. Projects that employ a large number of craft workhours have the opportunity to suffer to a greater extent from worse than expected productivity than projects with a smaller number of craft workhours. The converse of this is also true. High craft workhour projects may have greater opportunities to experience communication problems that result in inefficiencies and thus poor project cost performance compared to their small craft workhour counterparts. Therefore, the level of craft workhours may have significant influence on project cost performance. Figure 23 illustrates the distribution of craft workhours for the sample dataset of projects. The forty-nine projects in the sample dataset that provided craft workhour data represent 17,300,000 craft workhours. The average number of craft workhours for the sample of projects is 310,400 and the median value is 174,300. Several projects reported very high craft workhours, in excess of 1,000,000 hours. These projects raise the average value such that the average does not represent the sample well.

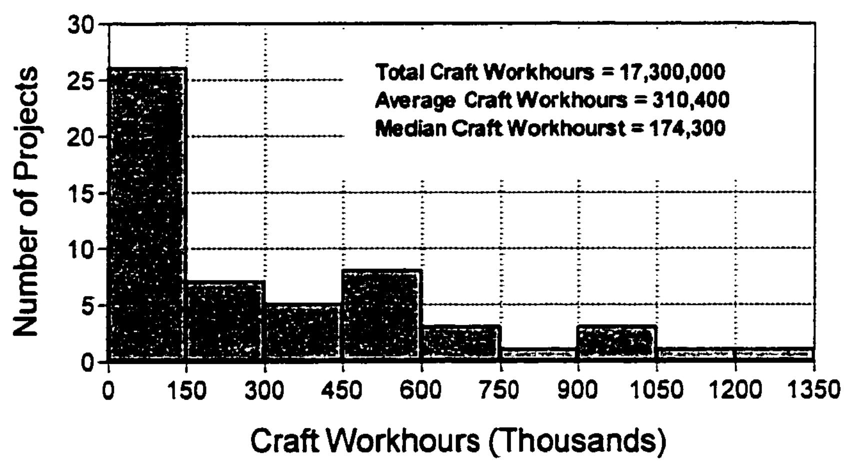


Figure 23: Craft Workhour Histogram

Table 19 provides additional information related to the distribution of craft workhour values for the complete sample dataset, as well as the sample of projects categorized in the high and low craft workhour groups.

Table 19: Craft Workhour Distribution

Craft Workhour Distribution	
Distribution Statistic	**Craft Workhours**
100%	1,200,000
75%	521,000
50%	174,300
25%	49,100
0%	24,043
Average	310,400
SD	319,300
n	49

Craft Workhour Group	Average	n
High	578,400	23
Low	73,200	26

4.3.7 Equipment Cost Factor

The equipment cost factor is defined as the ratio of actual total cost of major equipment to the actual total project cost. By definition, projects with higher equipment cost factors have a higher portion of total cost attributed to major equipment and therefore less attributed to other sources of cost such as labor, construction equipment, and materials. If costs associated with major equipment are more readily estimated and controlled than other sources of cost, then it may be postulated that projects with higher equipment cost factor will in general tend to achieve better cost predictability performance. Figure 24 illustrates the distribution of equipment cost factor values for the sample of projects. The average equipment cost factor is 0.28 and the median value is 0.25.

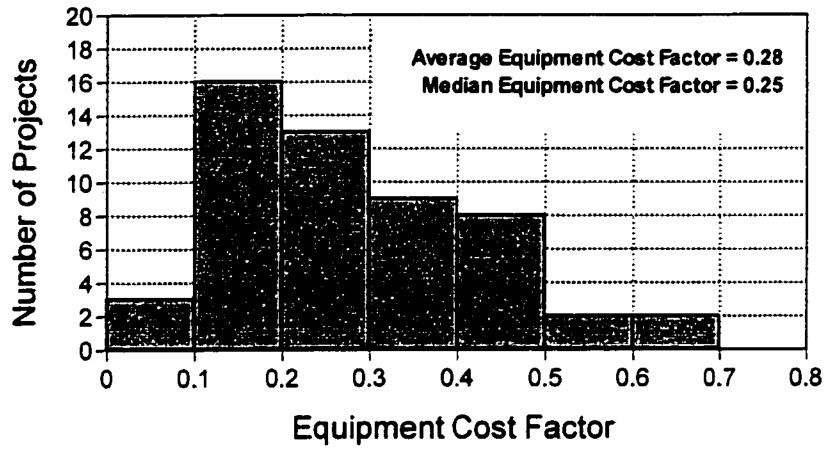


Figure 24: Equipment Cost Factor Histogram

Table 20 provides additional information related to the distribution of equipment cost factor values for the sample of projects. A large degree of variation is evident in the sample with the actual cost of major equipment ranging from less than 5 percent to over 65 percent of total actual project cost. Fifty-one projects provided data for total cost of major equipment. The average equipment cost factor values for the high and low equipment cost factor group are 40.0 percent and 16.6 percent respectively.

Table 20: Equipment Cost Factor Distribution

Equipment Cost FactorDistribution	
Distribution Statistic	**Equipment Cost Factor**
100%	0.6577
75%	0.3951
50%	0.2525
25%	0.1622
0%	0.0468
Average	0.2857
SD	0.1480
n	51

Equipment Cost Factor Group	Average	n
High	0.4005	26
Low	0.1664	25

Chapter 5: Project Cost Performance, Practice Use, and Project Environment Correlation

This chapter provides results of various statistical analyses performed to identify and measure significant relationships among project cost performance, use of selected practices, and the project environment. The categories of investigation include: 1) project cost growth versus project environment, 2) best practice use versus project environment, 3) project cost growth versus use of individual practices, 4) project cost growth versus use of multiple best practices, 5) project cost growth versus use of multiple best practices controlling for project environment and other practices.

5.1 PROJECT COST GROWTH BY PROJECT ENVIRONMENT

Analyses were performed to assess differences in project cost growth for the sample projects categorized by the project environment variables. An Analysis of Variance (ANOVA) was used to test the strength of these relationships. Table 21 provides an example of this analysis. The sample of projects is categorized by project nature. The number of projects and mean project cost growth are provided for each category.

Table 21: ANOVA for Project Cost Growth by Project Nature

Level								
Addition		Grass Roots		Modernization				
n	Project Cost Growth Mean	n	Project Cost Growth Mean	n	Project Cost Growth Mean	R^2	F	Prob > F
19	0.128	12	0.022	22	0.093	0.068	1.83	0.171

The ANOVA level of significance statistics are provided in the two far right columns. The difference in project cost growth means for the sample of projects categorized by each of the seven project environment variables was analyzed. The difference in project cost growth means was not found to be significant at the 0.05 level for any of the project environment variables. This should not be interpreted as meaning that the project environment does not affect project cost performance. Instead, the effects of the project environment on cost performance may not be detectable utilizing a simple bivariate model specification. The model may need to include or control for other factors in order to recognize the effects of the project environment. It may very well be that the effects of the project environment on project cost growth are compensated for by use of appropriate practices or other factors. In this case, it is not possible to measure the effects of the project environment on project cost growth using a model that excludes other relevant variables. This investigation into the effects of the project environment on project cost growth is not conclusive, however insight can be gained into more sophisticated analysis that may lead to meaningful results.

Although the difference in project cost growth mean was not found to be statistically significant at the 0.05 level in the analysis of project environment variables, the difference in a few cases was large enough to be of interest. The project environment variables found to have the strongest relationship with project cost growth through bivariate investigation are project nature and the level of craft workhours. As shown in Table 21, the addition and modernization projects experienced a greater mean project cost growth than the grass roots projects. The difference in project cost growth mean for projects with high and low levels of craft workhours is shown in Table 22. The projects with a low level of craft workhours experienced greater project cost growth than those projects with a high level.

Table 22: ANOVA for Project Cost Growth by Craft Workhours

Project Craft Workhours Level						
High		Low				
n	Project Cost Growth Mean	n	Project Cost Growth Mean	R^2	F	Prob > F
22	0.036	26	0.101	0.061	2.99	0.090

Similar tables are provided for each of the project environment variables in Appendix F.

5.2 Best Practice Use by Project Environment

Analyses were performed to assess the difference in use of the selected best practices for projects in the sample categorized by the project environment variables. An ANOVA was used to test the strength of the relationship between practice use and the project environment. Table 23 provides an example of this analysis. The projects are categorized by project nature with the mean value for the team building best practice index given for each category. The ANOVA level of significance statistics are provided in the two far right columns. The difference in mean practice use was analyzed for the sample of projects categorized by each of the four best practices. The only relationship significant at the 0.05 level is the use of team building by project nature. As illustrated in Table 23, the use of team building is much higher for grass roots projects than for either addition or modernization projects.

Table 23: ANOVA for Team Building Practice Use by Project Nature

Project Nature Level								
Addition		Grass Roots		Modernization				
n	Team Building Index Mean	n	Team Building Index Mean	n	Team Building Index Mean	R^2	F	Prob > F
20	3.6	12	7.2	23	4.6	0.149	4.56	0.014

Tables for the use of each of the four best practices by project environment variables are provided in Appendix F.

5.3 Item Analysis of Project Cost Growth and Best Practice Use

This section provides analyses that measure the effects of best practice use on project cost growth by individual practice item. Each of the best practices considered in this study consists of a number of underlying items that make up the overall practice. In the data collection instrument, response choices for each best practice item generally consists of two or more categories that indicate a level of use for an item on a project. Two categories are available if a "yes" or "no" response is required. Multiple categories are available if the use of an item may be measured over several levels. For analysis purposes, the sample of projects was categorized according to levels of use for each item such that as close as possible to an equal number of observations populate each level of use category.

Appendix B provides information related to the categorization of projects for this analysis. An Analysis of Variance (ANOVA) was used to test the strength of the relationship between the use of each item and project cost growth. This information is summarized in Appendix C. As discussed in Chapter Four, a significance level of 0.05 is generally used in this study as criteria to reject the null hypothesis of no difference between category means. The following section provides discussion of these analyses. Box plots are provided to graphically illustrate the distribution of project cost growth values categorized by level of use for best practice items.

5.3.1 Pre-Project Planning

The data collection instrument used in this study includes twenty-seven individual items related to the use of pre-project planning. Through the use of ANOVA, thirteen of the twenty-seven pre-project planning items were found to have a statistically significant relationship with project cost growth at the 0.05 level. For all items, the group of projects with a high level of use consistently had less average project cost growth than the group of projects with a lesser degree of use. The items with a statistically significant effect at the 0.05 level are as follows:

- **Definition of Processes at Project Authorization**
- **Definition of Project Control Requirements at Project Authorization**
- **Definition of Technology at Project Authorization**
- **Composition of the Pre-Project Planning Team**
- **Definition of P&ID's at Project Authorization**

- **Site Characteristics Available vs. Required**
- **Risk Analysis Performed for Project Alternatives**
- **Evaluation of Alternate Siting Locations**
- **Definition of Process Flow Sheets at Project Authorization**
- **Definition of Project Objectives Statement at Project Authorization**
- **Definition of Project Strategy at Project Authorization**
- **Technology Evaluation**
- **Definition of Plot Plan at Project Authorization**

Although many of the pre-project planning items have a significant relationship with project cost growth, only the five items identified to have the strongest relationship with project cost growth are illustrated below. The items that constitute pre-project planning represent a stronger relationship with project cost growth than items within any of the other best practices, both in number of significant items and strength of the relationships.

Figure 25 illustrates the difference in project cost growth distribution for the sample of projects categorized by response to "item 39n" of the data collection instrument. This item concerns the definition level of project processes at project authorization. The high category corresponds to complete or near complete definition of processes at project authorization. The mean project cost growth for the 34 projects in the high category is 4.1 percent while that for the 17 projects in the low category is 18.9 percent.

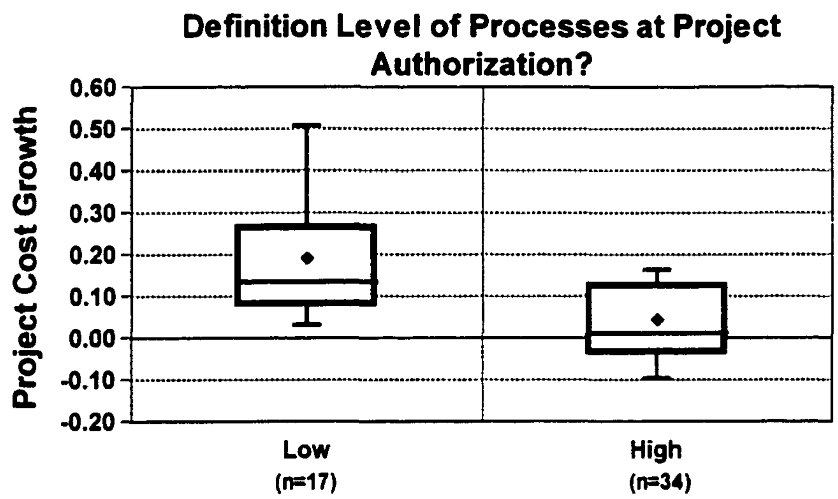


Figure 25: Pre-Project Planning Item Analysis for Project Cost Growth: Data Collection Instrument "Item 39n"

Over 90 percent of the projects in the low definition group experienced positive cost growth while almost 50 percent of the projects in the high definition group experienced negative cost growth. The projects in this sample that reported a high level of definition of processes at project authorization experienced significantly less average cost growth and less cost growth variability than the other projects.

Figure 26 illustrates the distribution of project cost growth for the sample of projects categorized by responses to "item 39v" of the data collection instrument. This item relates to the definition level of project control requirements at project authorization. The group of projects reporting a high definition level experienced 5.1 percent project cost growth, while the low definition group had an average project cost growth of 20.5 percent. It should also be noted that the high definition group experienced considerably less project cost growth variation.

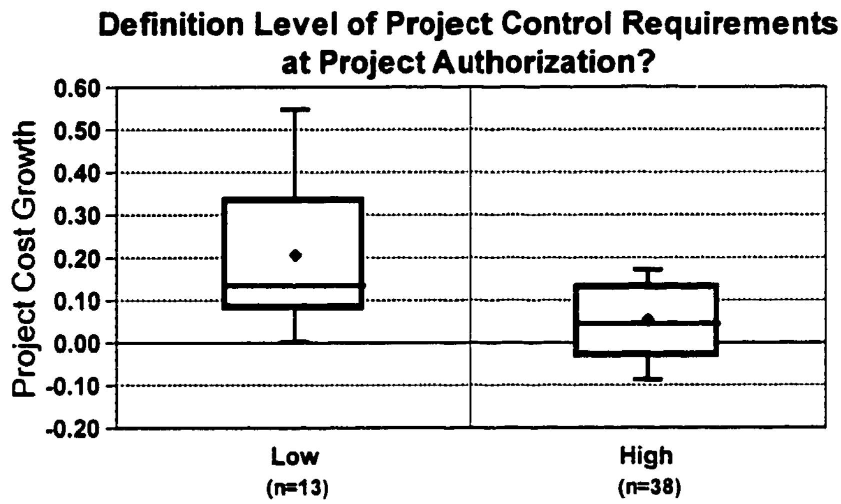


Figure 26: Pre-Project Planning Item Analysis for Project Cost Growth: Data Collection Instrument "Item 39v"

Figure 27 illustrates the distribution of project cost growth for the sample of projects categorized by responses to "item 39m" of the data collection instrument. This item concerns the definition level of technology at project authorization. The group of projects reporting a high definition level experienced 4.2 percent project cost growth, while the low definition group had 17.9 percent. In this case, again, the high definition group experienced considerably less variation in project cost growth.

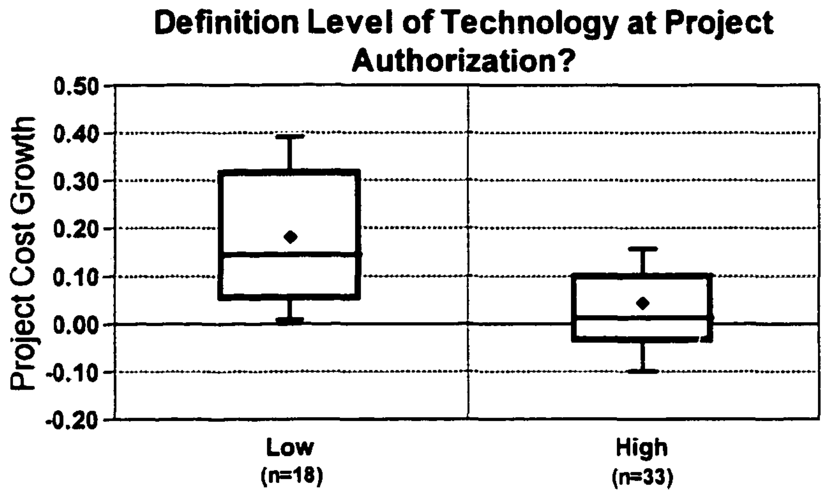


Figure 27: Pre-Project Planning Item Analysis for Project Cost Growth: Data Collection Instrument "Item 39m"

Pre-project planning team composition has been found to be an important determinant of project success in previous research (Gibson 1995). Desirable pre-project planning team attributes include: 1) appropriate representation of various groups within the organization, 2) individuals with the authority to make necessary decisions, 3) individuals with appropriate experience/skills, and 4) responsiveness to both project and business objectives. "Item 38e" of the data collection instrument requests respondents to rate the composition of the pre-project planning team with regard to desirable team attributes. The rating was based on a 0 to 10 scale with 0 representing a project team with few or no desirable attributes and 10 representing the ideal team. The sample of projects was divided into two groups based on the median score for "item 38e." In Figure 28, the high category represents projects that had a pre-project planning team with attributes that more closely adhere to those recommended as desirable. The mean project cost growth for the high category is 2.6 percent and the mean for the low group is 14.6 percent.

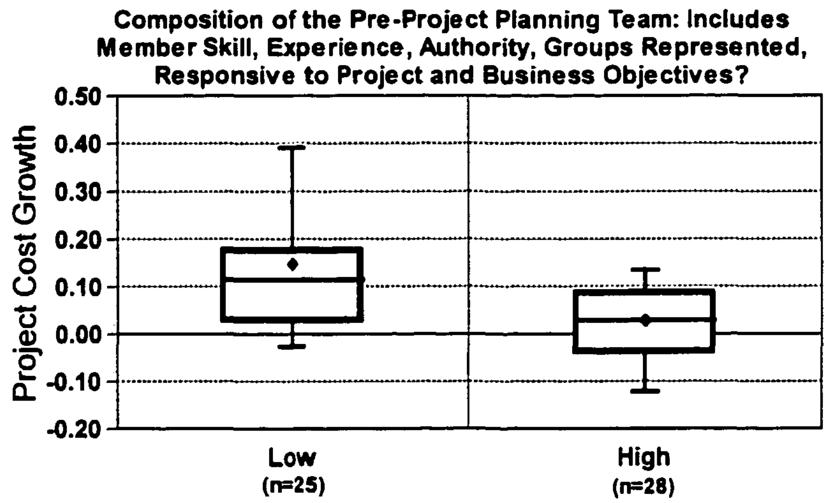


Figure 28: Pre-Project Planning Item Analysis for Project Cost Growth: Data collection Instrument "Item 38e"

Figure 29 illustrates the project cost growth distributions for the sample of projects categorized by the definition level of piping and instrumentation diagrams (P&IDs) at project authorization. The group of projects with the high definition level for P&IDs experienced a mean project cost growth of 4.4 percent while the low definition group experienced a considerably higher mean project cost growth of 15.7 percent.

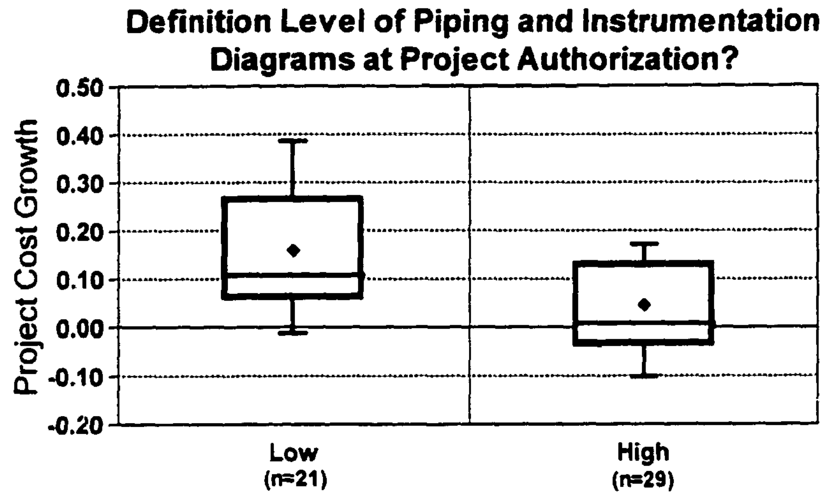


Figure 29: Pre-Project Planning Item Analysis for Project Cost Growth: Data Collection Instrument "Item 39c"

5.3.2 Project Change Management

The data collection instrument includes fourteen items related to project change management. An ANOVA was performed for each of these items to identify and measure the significance of their effects on project cost growth. For all but two items, the group of projects with a high level of use consistently had less average project cost growth than the group of projects with a lesser degree of use. The difference between category means was found to be significant for three items at the 0.05 level. The three project change management items found to have the strongest relationship with project cost growth in this sample of projects include:

- **Changes Required to go through a Formal Change Justification Procedure**
- **Tolerance Level for Changes Established/Communicated to Participants**
- **Baseline Scope Established Early/Frozen; Changes Managed Against Base**

The strongest individual item relationship between project change management and project cost growth is illustrated in Figure 30. The group of projects that required all changes to go through a formal change justification procedure in general experienced significantly less project cost growth as compared to the other group. Seventy-five percent of the projects with a negative response to this item had project cost growth of 10 percent or more and a mean value of 22.2 percent. Of the projects with a positive response, nearly 75 percent had project cost growth of less than 10 percent and a mean project cost growth value of 4.6 percent. A strong positive correlation may exist between this item and the formality and rigor of the overall change management program for the project.

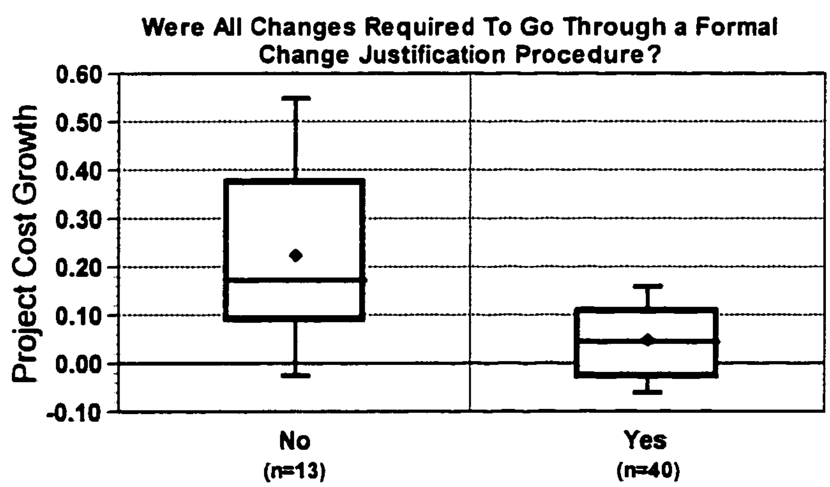


Figure 30: Project Change Management Item Analysis for Project Cost Growth: Data Collection Instrument "Item 41f"

The second strongest relationship between a project change management item and project cost growth is illustrated in Figure 31. This item concerns establishing a tolerance level for changes and communicating this to all project participants. In general, projects in this sample with a positive response to this item experienced lower values and less variation regarding project cost growth.

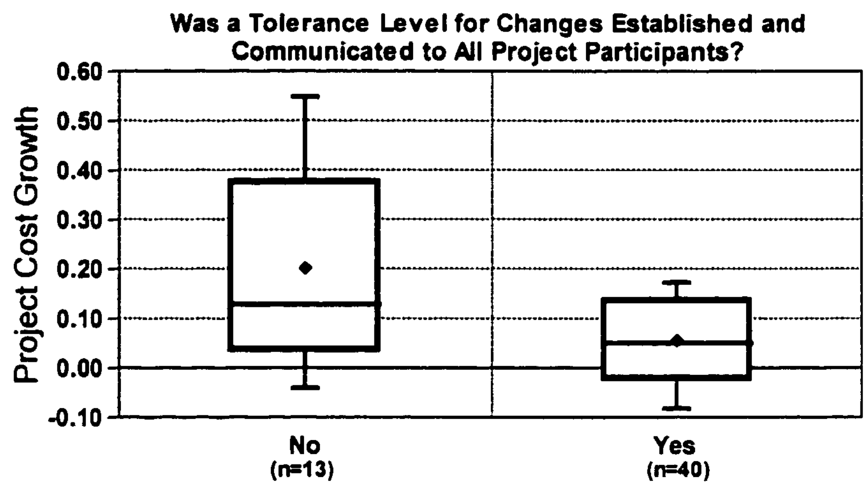


Figure 31: Project Change Management Item Analysis for Project Cost Growth: Data Collection Instrument "Item 41k"

5.3.3 Team Building

The data collection instrument used in this study includes eight items related to the use of team building. Through the use of an ANOVA, two of the eight team building items were found to have a statistically significant relationship with project cost growth at the 0.05 level. For all but one item, the group of projects reporting use or high use of the team building item had less average project cost growth than the group of projects with no or low use.

The items with a statistically significant effect at the 0.05 level are as follows:

- **Team Building Retreat Held Early in the Life of the Project**
- **Documented and Clearly Defined Team Building Objectives**

The group of projects in the sample that reported the use of a team building retreat early in the life of the project experienced less average project cost growth than the other group. Figure 32 illustrates the difference in project cost growth distribution for each of these groups. The group of 30 projects that did not utilize a retreat experienced a mean project cost growth of approximately 14 percent while the 23 projects that included a retreat as a part of a team building program had a mean project cost growth of less than 5 percent.

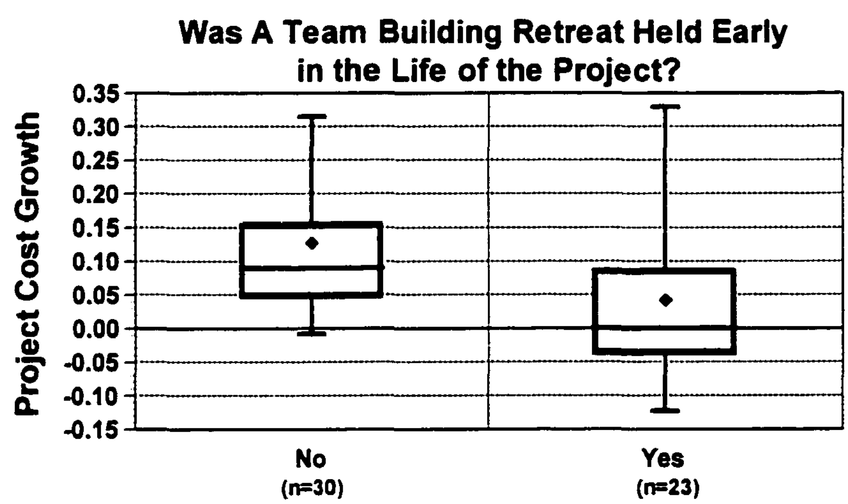


Figure 32: Team Building Item Analysis for Project Cost Growth: Data Collection Instrument "Item 36b"

Figure 33 illustrates the difference in project cost growth distribution between the group of projects that reported a positive or negative response to "item 36d." Projects in the "Yes" category used team building and indicated that the objectives of the team building process were documented and clearly identified. The other group either did not use team building or reported that team building objectives were not documented and clearly identified. The group of projects that used team building with clearly defined objectives experienced considerably less average project cost growth than the other projects.

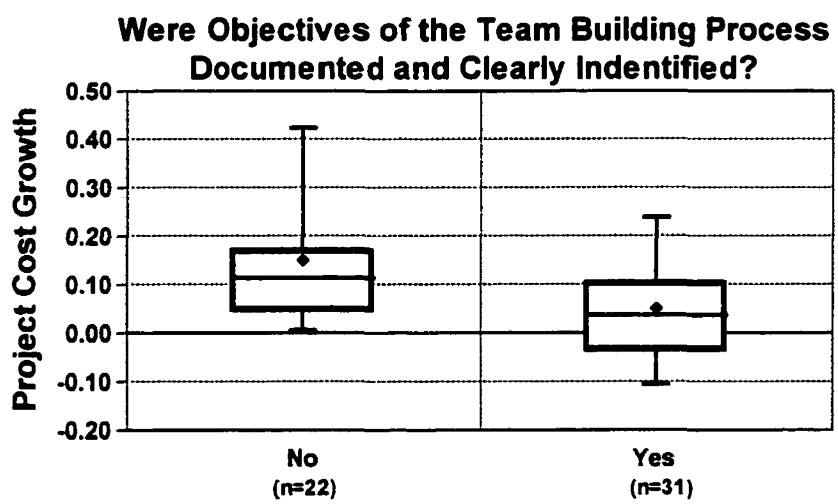


Figure 33: Team Building Item Analysis for Project Cost Growth: Data Collection Instrument "Item 36d"

5.3.4 Constructability

The data collection instrument used to collect data for this study includes twelve individual items related to the use of constructability. Through the use of an ANOVA, two of the twelve constructability items were found to have a statistically significant relationship with project cost growth at the 0.05 level. For all but two items, the group of projects reporting high use of constructability had less average project cost growth than the group of projects with low use. The items with a statistically significant effect at the 0.05 level are as follows:

- **Level of Constructability Program Designation for the Project**
- **Constructability Addressed in Formal Written Project Execution Plan**

As illustrated in Figure 34, the group of projects in the sample with a high-level constructability program designation experienced a considerably lower average project cost growth and less variation in project cost growth. In this context, program designation relates to the emphasis placed on the constructability program at the project level. The emphasis for a constructability program at the project level may range from no project designation to that on par with other highly recognized project level programs such as safety and quality.

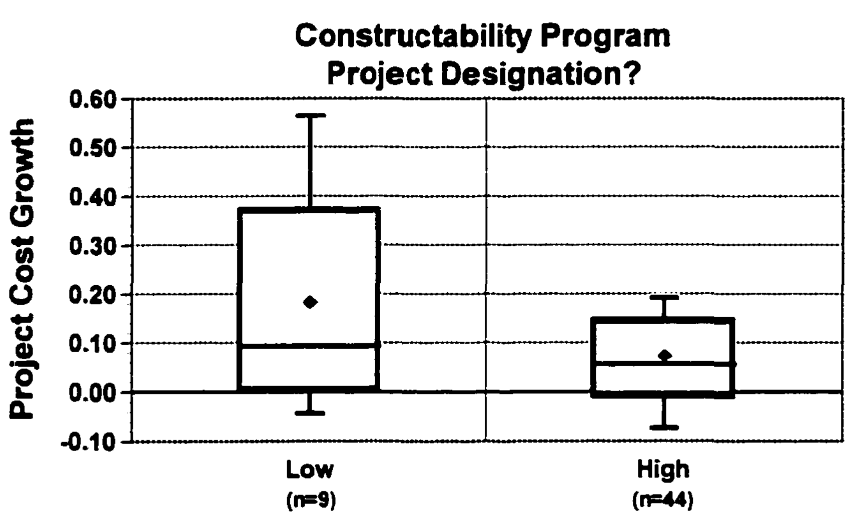


Figure 34: Constructability Item Analysis for Project Cost Growth: Data Collection Instrument "Item 37a"

Figure 35 illustrates the distribution of project cost growth values for the sample of projects categorized by response to "item 37k" of the data collection instrument. This item concerns whether or not constructability was an element addressed in the project's formal written execution plan. The group of projects that addressed constructability in a formal written execution plan experienced a lower average project cost growth than those that did not.

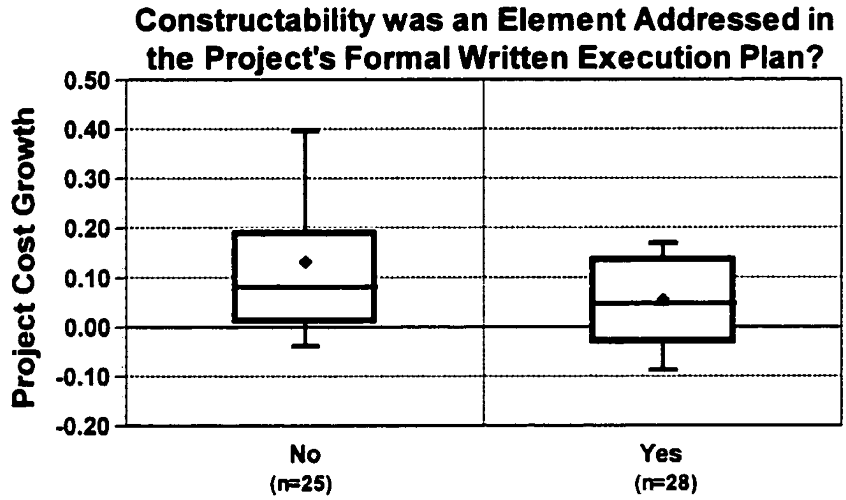


Figure 35: Constructability Item Analysis for Project Cost Growth: Data Collection Instrument "Item 37k"

5.4 Analysis of Project Cost Growth and Other Practice Use

Bivariate analyses are presented in this section regarding the relationship between the other practices considered in this study and project cost growth. These practices include 1) percent design complete, 2) contract cost incentives, 3) contract compensation strategy, and 4) contract organization strategy.

5.4.1 Percent Design Complete

Figure 36 illustrates the distribution of project cost growth for the sample of projects categorized by the percent of design complete prior to project authorization. The group of projects with less than 10 percent design complete experienced approximately 17.0 percent cost growth with a standard deviation of 0.22.

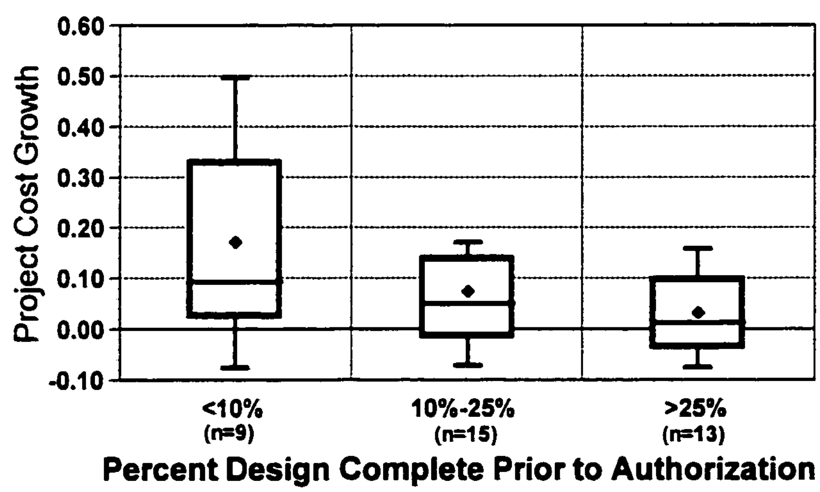


Figure 36: Project Cost Growth by Percent Design Complete

The groups with 10 percent through 25 percent and greater than 25 percent design complete reported lower average cost growth at 7 percent and 3 percent, respectively. These two groups also exhibit much lower variability in project cost growth. The standard deviation for the groups with 10 percent through 25 percent and greater than 25 percent design complete was 0.12 and 0.10 respectively. The differences in mean project cost growth are statistically significant at the 0.05 level.

5.4.2 Contract Cost Incentives

The data collection instrument utilized by the CII Benchmarking and Metrics Program captures a considerable amount of data related to the use of contract incentives. Table 24 provides ANOVA results for project cost growth by the use of contract incentives regarding project cost. For these purposes, the incentive may be positive or negative in nature. An example of a positive incentive may include a bonus resulting from owner and contractor shared savings from a budget underrun. A negative incentive might include a percentage loss of a contractor's fee resulting from budget overrun. The 15 projects that utilized contract cost incentives with the designer experienced an average project cost

Table 24: ANOVA for Project Cost Growth by Use of Contract Cost Incentives

	Level						
	Yes		No				
	n	Project Cost Growth Mean	n	Project Cost Growth Mean	R^2	F	Prob > F
Designer	15	0.037	26	0.130	0.102	4.41	0.042
Constructor	19	0.068	32	0.105	0.013	0.67	0.418

growth of 3.7 percent and those that did not had 13.0 percent. The difference in mean values is statistically significant at the 0.05 level. The group of projects that included a contract cost incentive with the construction contractor had a lower mean project cost growth than the group of projects that did not use contract cost incentives. However, the difference does not appear to be statistically significant.

5.4.3 Contract Compensation Strategy

Table 25 provides information related to the bivariate relationship between contract compensation strategy and project cost growth by project participant. The mean project cost growth for the group of projects that used a cost reimbursable compensation strategy was less than for the group that used other compensation strategies. Although the difference in group means is quite large, it is not statistically significant at the 0.05 level.

Table 25: ANOVA for Project Cost Growth by Contract Compensation Strategy

	Compensation Strategy						
	Cost Reimbursable		Other				
Project Participant	n	Project Cost Growth Mean	n	Project Cost Growth Mean	R^2	F	Prob > F
Designer	24	0.068	18	0.136	0.056	2.39	0.130
Constructor	26	0.067	25	0.116	0.025	1.24	0.271

5.4.4 Contract Organization Strategy

For analysis purposes the sample of projects was split into two groups representing those projects that utilized the Design/Build approach and those that did not. Of the 51 projects in the sample that provided complete project cost growth and contract organization strategy information, nine used the Design/Build approach while the other forty-two used some other unspecified approach. Table 26 shows the project cost growth mean for each of these two groups and the ANOVA statistics to measure the significance of the difference in means. While the difference in project cost growth mean is 6.6 percent, it is not statistically significant at the 0.05 level. The lack of statistical significance is most likely due to the small number of projects in this sample that utilized the Design/Build strategy

Table 26: ANOVA for Project Cost Growth by Contract Organization Strategy

	Level						
	Yes		No				
	n	Project Cost Growth Mean	n	Project Cost Growth Mean	R^2	F	Prob > F
Design/Build	9	0.027	42	0.093	0.032	1.61	0.211

5.5 Bivariate Regression Analysis of Project Cost Growth and Best Practice Use

Analyses were performed to model and measure the relationship between project cost growth and practice use for each of the best practices considered in this study. The best practices include pre-project planning, project change management, team building, and constructability. These analyses consider the overall use of the best practices as measured by the indexes discussed in Chapter Four.

5.5.1 Scatter Plots and Regression models

Ordinary least squares (OLS) regression was used to develop a bivariate linear model for project cost growth and each of the four best practices. A scatter plot of the data and plot of the OLS regression prediction equation is provided. Following each scatter plot, a table is provided that contains the regression model equation and inferential statistics.

5.5.1.1 Pre-Project Planning

The strongest relationship identified through this study between project cost growth and the use of an individual practice pertains to the use of pre-project planning. Figure 37 illustrates this relationship in a simple bivariate relationship. The concentration of pre-project planning index scores on the right side of the graph indicates that project respondents in general reported a high level of pre-project planning.

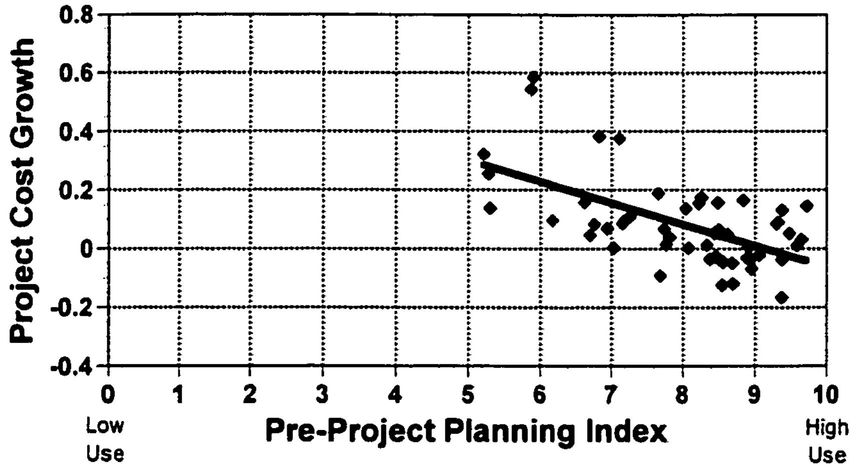


Figure 37: Project Cost Growth vs Pre-Project Planning Use Scatterplot

A strong statistical relationship between pre-project planning and project cost growth is evident in the sample. Projects with higher pre-project planning index scores in general not only had less average project cost growth, but also had less project cost growth variability. Table 27 provides the regression model equation and associated inferential statistics. Over the range of pre-project planning practice use that is well represented in this analysis, approximately 6.0 through 9.0, the average project cost growth decreases by 7.3 percent for each 1 point increase in the pre-project planning index value. This analysis includes the fifty-two projects from the sample data set that provided the required project cost growth and pre-project planning data. The R^2 value for the regression model is 0.34, indicating that 34 percent of the variation in project cost growth is explained by the pre-project planning index.

Table 27: Project Cost Growth vs Pre-Project Planning Use Bivariate Regression Model

Model Equation				
Cost Growth = 0.664 – 0.073 x Pre-Project Planning Index				
Regression Fit				
Degrees of Freedom		R-Square	F Stat	Prob > F
50		0.3447	26.30	0.0001
Parameter Estimates				
Variable	Estimate	Std. Error	T Stat	Prob > T
Intercept	0.664	0.1145	5.80	0.001
Pre-Project Planning Index	-0.073	0.0142	-5.13	0.001

To further examine the difference in project cost growth values in relation to the use of pre-project planning, the sample of projects was divided into two categories based on the pre-project planning index median value and analyses performed to measure the difference between these two groups. Figure 38 illustrates the distribution of project cost growth values for the groups. The average project cost growth values are 16.7 percent and 0.8 percent for the low and high pre-project planning use groups, respectively. This represents a difference in project cost growth of 15.9 percent. It can also be seen from the limits of the box plot that the variation in project cost growth values is less for the high use group. The standard deviation for the group of projects reporting the least pre-project planning effort is 0.166 and 0.087 for the other group. The difference in means is statistically significant to the 0.0001 level.

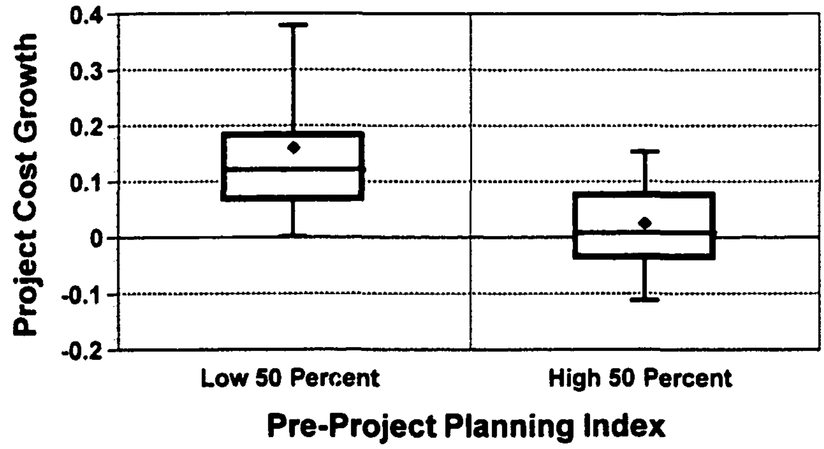


Figure 38: Project Cost Growth by Pre-Project Planning Use Box and Whisker Diagram

5.5.1.2 Project Change Management

The second strongest relationship between project cost growth and the use of an individual practice was found to be with the use of project change management. Figure 39 illustrates this bivariate relationship. Note that all of the projects with a project change management index score of less than 6 experienced positive cost growth and several of these projects report very high project cost growth. For this sample of projects, the linear regression prediction equation indicates a 4.3 percent reduction in cost growth per 1 point increase in the project change management index. However, the scatter plot reveals that for this sample of projects the relationship between project cost growth and project change management may not strictly adhere to a linear form. This observation is made due to the sharp drop in average project cost growth at a project change management index of approximately 6.

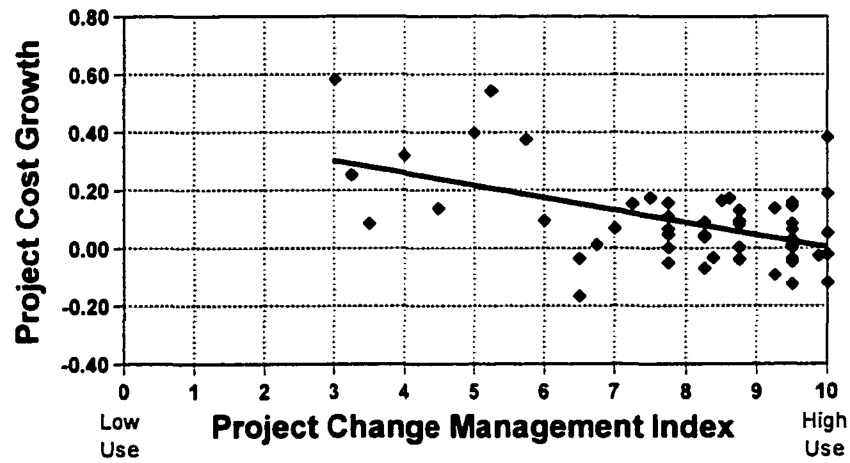


Figure 39: Project Cost Growth by Project Change Management Use Scatterplot

Table 28 provides the OLS regression model equation and statistics for the regression of project cost growth on the project change management index. This analysis represents fifty-three projects that supplied the required project cost growth and project change management use data. The R^2 value for the regression equation is approximately 0.28.

Table 28: Project Cost Growth vs Project Change Management Use Bivariate Regression Model

Model Equation				
Project Cost Growth = 0.429 – 0.043 x Project Change Management Index				
Regression Fit				
Degrees of Freedom		R-Square	F Stat	Prob > F
51		0.2773	19.57	0.0001
Parameter Estimates				
Variable	Estimate	Std. Error	T Stat	Prob > T
Intercept	0.429	0.079	5.44	0.0001
Project Change Management Index	-0.043	0.010	-4.42	0.0001

Figure 40 illustrates the difference in project cost growth distribution for the sample of projects grouped by project change management Use. The 50 percent of the projects with a higher degree of use for project change management experienced a lower mean project cost growth and less variation in project cost growth. The mean project cost growth values for the low and high project change management use groups are 13 percent and 5 percent, respectively. The standard deviation is 0.183 for the low group and 0.111 for the high group. The difference in group means is statistically significant at the 0.10 level.

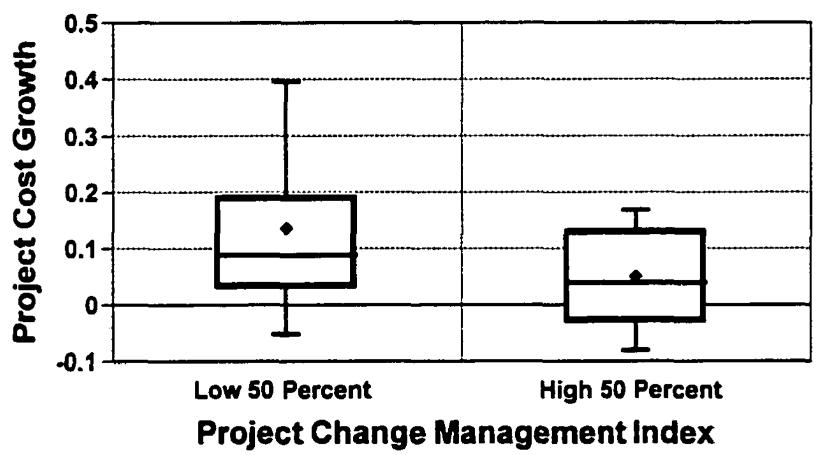


Figure 40: Project Cost Growth by Project Change Management Use Box and Whisker Diagram

5.5.1.3 Team Building

Figure 41 illustrates the bivariate relationship between project cost growth and the team building index for the sample dataset. The relationship does not appear to be strong when compared to that found between pre-project planning and project cost growth or project change management and project cost growth.

However, the relationship is statistically significant at the 0.05 level. All projects with a team building index of less than 5 reported positive cost growth. The projects at the upper end of the team building index scale are more equally distributed between positive and negative project cost growth.

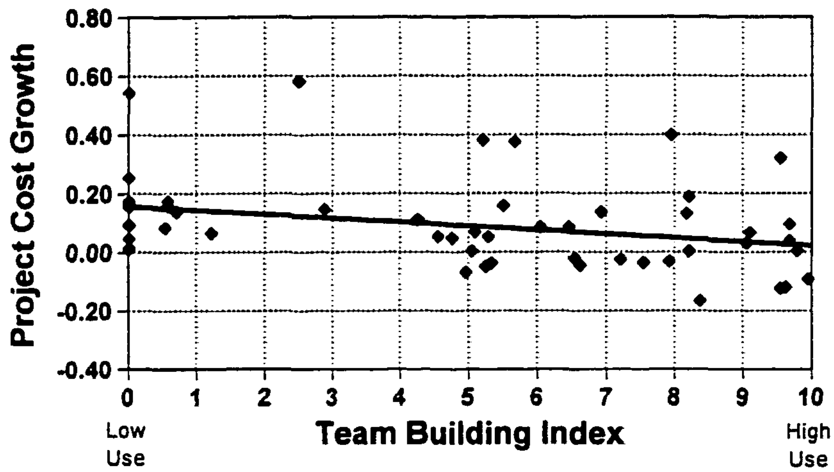


Figure 41: Project Cost Growth vs Team Building Use Scatterplot

Table 29 provides the regression model equation and associated inferential statistics for the regression of project cost growth on the team building index. Over the range of team building use that is represented in this analysis, 0.0 through 10.0, the average project cost growth decreases by 1.6 percent for each 1 point increase in the team building index value. This analysis includes the fifty-three projects from the sample data set that provided the required project cost growth and team building data. The R^2 value for the regression model is approximately 0.10. Indicating that 10 percent of the variation in project cost growth is explained by the team building index.

Table 29: Project Cost Growth vs Team Building Use Bivariate Regression Model

Model Equation				
Cost Growth = 0.155 – 0.013 x Team Building Index				

Regression Fit				
Degrees of Freedom		R-Square	F Stat	Prob > F
51		0.096	5.42	0.0240

Parameter Estimates				
Variable	Estimate	Std. Error	T Stat	Prob > T
Intercept	0.155	0.0349	4.46	0.0001
Team Building Index	-0.013	0.0058	-2.33	0.0240

Figure 42 illustrates the analysis of project cost growth and team building use by equally dividing the sample into two categories based on the use of team building. The group of projects that used team building to a higher degree experienced 5 percent project cost growth while the other group experienced 13 percent project cost growth. The standard deviation for the high use group is slightly less than the low use group with a value of 0.158 compared to 0.143.

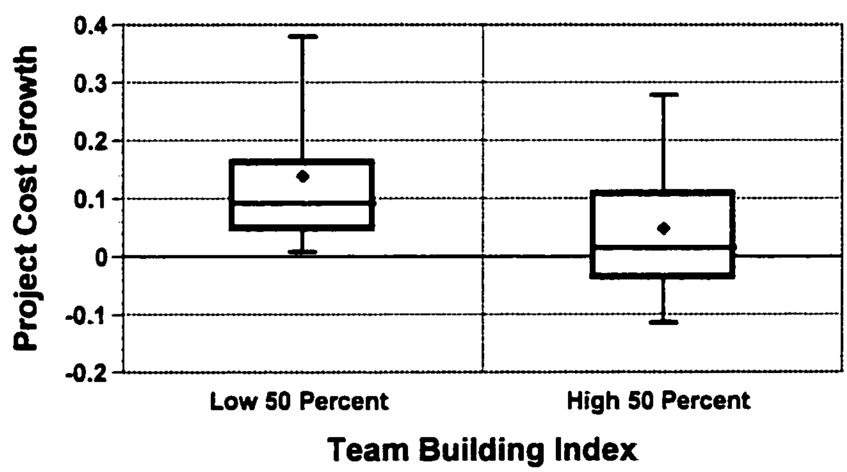


Figure 42: Project Cost Growth by Team Building Use Box and Whisker Diagram

5.5.1.4 Constructability

Figure 43 illustrates the bivariate relationship between project cost growth and the constructability index for the sample dataset. This represents the weakest relationship with project cost growth of the four best practices included in this study. The relationship is, however, statistically significant to the 0.10 level.

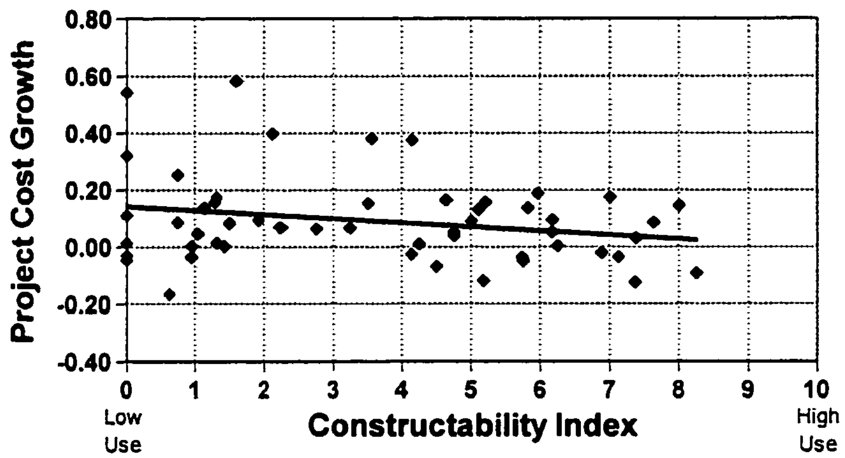


Figure 43: Project Cost Growth vs Constructability Use Scatterplot

Projects with high constructability index scores generally had less average project cost growth. Table 30 provides the regression model equation and associated inferential statistics. Over the range of constructability practice use that is well represented in this analysis, approximately 0.0 through 8.0, the average project cost growth decreases by 1.4 percent for each 1 point increase in the constructability index value. This analysis includes the fifty-three projects from the sample data set that provided the required project cost growth and constructability use data. The R^2 value for the regression model is 0.056.

Indicating that 5.6 percent of the variation in project cost growth is explained by the constructability index.

Table 30: Project Cost Growth vs Constructability Use Bivariate Regression Model.

Model Equation				
Cost Growth = 0.141 – 0.014 x Constructability Index				
Regression Fit				
Degrees of Freedom		R-Square	F Stat	Prob > F
51		0.0565	3.05	0.0865
Parameter Estimates				
Variable	Estimate	Std. Error	T Stat	Prob > T
Intercept	0.141	0.0361	3.91	0.0003
Constructability Index	-0.014	0.0082	-1.75	0.0865

Figure 44 illustrates the difference in project cost growth distribution for the sample of projects grouped by constructability Use. The 50 percent of the projects with the highest constructability use experienced a lower mean project cost growth and less variation in project cost growth. The mean project cost growth value for the low and high constructability use group is 13 percent and 5 percent respectively. The standard deviation is 0.181 for the low group and 0.112 for the high group. The difference in group means in statistically significant at the 0.05 level.

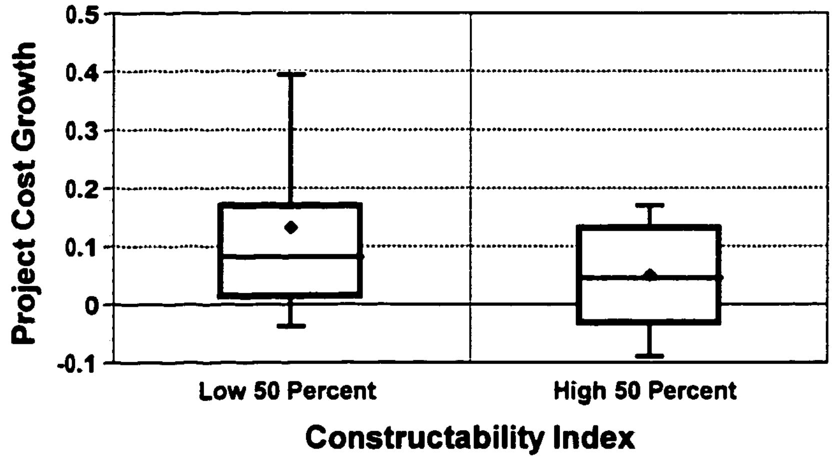


Figure 44: Project Cost Growth by Constructability Use Box and Whisker Diagrams

5.5.2 Regression Diagnostics

Regression diagnostics were performed to discern if the basic underlying assumptions of the OLS regression model were violated to a degree such that data treatments or additional analysis interpretation were required. The analyses were checked for influential observations, normally distributed errors, and constant variance of the errors.

The investigation related to influential observations was accomplished through the development of Studentized Residual vs Hat Value Plots for each of the analyses of best practice use and project cost growth. As recommended by Fox (1991), projects with Hat Values in excess of 2*(k+1)/n and Studentized Residuals in excess of 2 were identified and investigated to determine if they had undue influence on the regression parameters. No observations were found to have undue influence on the parameters determined in the analysis.

The diagnostic method used to determine if the errors are normally distributed consisted of examining Residual Normal Quantile Quantile Plots. The errors were found to be normally distributed within a reasonable tolerance.

The investigation performed to determine if the errors exhibited constant variance was conducted by graphical methods through the use of Studentized Residual vs Fitted Value Plots. The errors were found to have constant variance within a reasonable tolerance. Appendix H contains the plots developed for each these regression diagnostic tests.

5.6 Multiple Regression Analysis of Project Cost Growth and Best Practice Use

Bivariate regression analysis provides useful information regarding the relationship between two variables and may provide an adequate model for simple processes. For more complex processes, multiple regression methods can be used to explain more variation in the dependent variable than is possible through the use of bivariate methods. Also, multiple regression models provide more accurate estimates of independent variable effects if correlation exists between independent variables used in analysis. Capital facility construction projects consist of a complex set of inputs, many of which affect project cost performance. For the purposes of this study, multiple regression provides better estimates of the effects of best practice use on project cost performance than bivariate methods. Multiple regression provides for a more completely specified model and takes into account correlation among the use of the best practices. This section provides discussion related to the multiple regression models developed to measure the effects of the best practices on project cost growth.

5.6.1 Correlation Among Use of Best Practices

Correlation analysis was performed to measure the association of the use of the best practices. This information is useful in interpreting the results of the bivariate analysis discussed in earlier chapters. It also indicates a need for multiple regression procedures in developing models for best practice use effects on project cost growth. A strong correlation among these variables indicates that the parameter estimates developed through bivariate regression may be misleading due to omission of a relevant independent variable. Correlation analysis is also a useful regression diagnostic technique to determine if a multiple regression model suffers from multicolinearity.

The use of each of the best practices, as measured with the indexes, is positively correlated to the use of each of the other best practices. The use of pre-project planning, project change management, and constructability exhibit positive correlation to a relatively strong degree. The Pearson correlation coefficients given in Table 31 provide a measure of correlation between each of the four best practices. The correlation coefficients can assume values between 1 and -1. A correlation coefficient of 1 represents perfect positive correlation, -1 represent perfectly negative correlation, and 0 represents no correlation. The strongest correlation exists between pre-project planning and project change management with a Pearson correlation coefficient of 0.5151. The correlation between pre-project planning and constructability is the second strongest with a coefficient value of 0.5116. The weakest correlation is between team building and pre-project planning.

Table 31: Best Practice Index Pearson Correlation Coefficients

Pearson Correlation Coefficients				
	Pre-Project Planning Index	Project Change Management Index	Team Building Index	Constructability Index
Pre-Project Planning Index	1.0000	0.5151	0.1801	0.5116
Project Change Management Index	0.5151	1.0000	0.0825	0.4696
Team Building Index	0.1801	0.0825	1.0000	0.3433
Constructability Index	0.5116	0.4696	0.3433	1.0000

5.6.2 Multiple Regression Model

A multiple regression model was developed in which project cost growth was regressed on pre-project planning, project change management, team building, and constructability. The resulting model equation and inference statistics are provided in Table 32. Pre-project planning, project change management, and team building were all found to have significant effects on project cost growth. The overall model is statistically significant at the 0.0001 level with an R^2 value of 0.4524. This indicates that approximately 45 percent of the variation in project cost growth for this sample is explained by the use of pre-project planning, project change management, and team building. The estimate for each of the best practice use effects is statistically significant to the 0.05 level.

Table 32: Project Cost Growth vs Best Practice Use Multiple Regression Model

Model Equation

Project Cost Growth = 0.689 - 0.049 x Pre-Project Planning Index
- 0.020 x Proj. Chng. Mngmt. Index
- 0.011 x Team Building Index

Regression Fit				
Degrees of Freedom		R-Square	F Stat	Prob > F
48		0.4524	13.22	0.0001

Parameter Estimates					
Variable	Estimate	Std. Error	T Stat	Prob > T	Std. Est.
Intercept	0.689	0.1074	6.41	0.0001	0.000
Pre-Project Planning Index	-0.049	0.0163	-2.98	0.0045	-0.392
Proj. Chng. Mngmt. Index	-0.020	0.0103	-1.96	0.0554	-0.254
Team Building Index	-0.011	0.0046	-2.44	0.0185	-0.265

The estimated effect for constructability was not significant at the 0.10 level and was removed from the model.

The use of each best practice is measured using the same scale of 0 to 10. However, there is a large difference in range value for each of the best practices. The minimum and maximum values for the team building index are 0 and 10 respectively, while pre-project planning only varies between 5.2 and 9.7. This renders the standardized parameter estimate more useful than the unstandardized estimates in interpreting the relative effects of the best practices on project cost growth. The standardized estimates are provided in the far right column of Table 32. A standardized estimate indicates how many standard deviations the dependent variable changes per one standard deviation increase in the independent variable. As indicated by the standardized estimate value of 0.392, the use of pre-project planning has the strongest relationship with project cost growth. Project change management and team building have very similar standardized estimates of 0.254 and 0.265 respectively. This analysis includes 52 projects that provided complete data for all variables included in the analysis.

5.6.3 Regression Diagnostics

Regression diagnostics were performed to ensure that the basic underlying assumptions of the OLS regression model were not violated to a degree such that data treatments or additional analysis interpretation were required. The analysis was checked for influential observations, normally distributed errors, constant variance of the errors, and multicolinearity. None of the regression assumptions were found to be violated beyond tolerable limits. Additional discussion related to these diagnostics is provided in Section 5.5.2. Appendix H contains plots used in the analysis of influential observations, normally distributed errors, and constant variance of the errors.

5.7 BIVARIATE REGRESSION ANALYSIS OF PROJECT COST GROWTH AND COMBINED BEST PRACTICE USE

To facilitate interpretation, presentation, and further analysis of the combined effects of the best practices on project cost growth, a variable that summarizes the combined use of the best practices was developed. The variable is called the combined best practice index. Discussion related to the development of the combined best practice index and its relationship with project cost growth follow.

5.7.1 Combined Best Practice Index

The calculating formula for the combined best practice index is as follows:

Combined Best Practice Index = 0.60 x Pre-Project Planning Index +
0.25 x Project Change Management Index +
0.15 x Team Building Index

The weights used in the combined best practice index formula are based on the parameter estimates resulting from the multiple regression analysis performed for project cost growth, pre-project planning, project change management, and team building. The parameter estimates can be found in Table 32. Scaling the parameter estimates such that they sum to unity, therefore allowing the combined best practice index to assume values between 0 and 10 derives the weights in the above equation. Corresponding to the parameter estimates, the combined best practice index is heavily weighted for pre-project planning representing the strong relationship with project cost growth. The weights for project change management and team building are considerably less than for pre-project planning and represent their respective relationship with project cost growth.

5.7.2 Scatter Plot and Regression Model

Figure 45 illustrates the relationship between project cost growth and the combined best practice index. The center line through the scatterplot represents the OLS linear regression prediction equation. The two outer lines represent the 80 percent prediction intervals. In general, those projects in the sample dataset that scored higher on the combined best practice index experienced less project cost growth than those with lower scores. The combined use of pre-project planning, project change management, and team building significantly effects project cost growth. Based on the combined best practice index calculating formula, projects in the sample with scores between 8.5 and 10.0 necessarily used all three of the best practices included in the formula. Projects that used all three

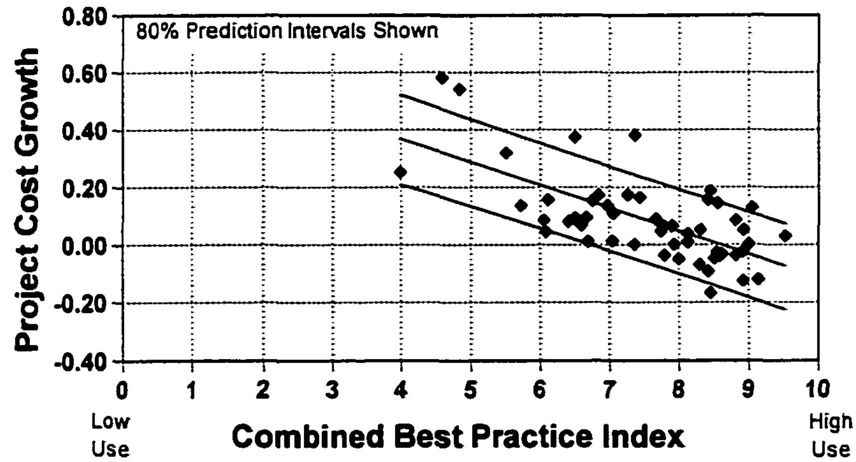


Figure 45: Project Cost Growth vs Combined Practice Use Scatterplot

of the best practices to a high degree experienced much better average project cost growth than the rest of the sample. The average project cost growth for projects with combined best practice index scores greater than 8.5 is negative. Although pre-project planning appears to be the most significant contributor to reduced project cost growth in this sample of projects, project change management and team building were also used to a significant degree for the projects that experienced the best project cost growth performance.

Table 33 provides the regression model equation and inference statistics for this analysis. This analysis includes the 52 projects from the sample dataset that provided sufficient data to compute project cost growth and the combined best practice ndex. The overall model and individual estimates are significant to the 0.0001 level and the R^2 value is 0.4520.

Table 33: Project Cost Growth vs Combined Best Practice Use Bivariate Regression Model

Model Equation				
Project Cost Growth = 0.682 – 0.079 x Combined Practice Index				
Regression Fit				
Degrees of Freedom		R-Square	F Stat	Prob > F
50		0.4520	41.24	0.0001
Parameter Estimates				
Variable	Estimate	Std. Error	T Stat	Prob > T
Intercept	0.682	0.0944	7.22	0.0001
Combined Practice Index	-0.079	0.0124	-6.42	0.0001

Figure 46 illustrates the distribution of project cost growth for the sample of projects categorized by the combined best practice index. The sample of projects is divided into two group of equal size based on combined best practice index values. The average project cost growth value is 17.0 percent for the group of projects with the lowest combined best practice index values. The average project cost growth for the group of projects with the highest values is 0.3 percent. A difference in project cost growth of 16.7 percent. It can also be seen from the limits of the box plot that the variation in project cost growth values is less for the high use group. The standard deviation for the group of projects reporting the least combined practice use is 0.155 and 0.088 for the other group. The difference in means is statistically significant to the 0.0001 level.

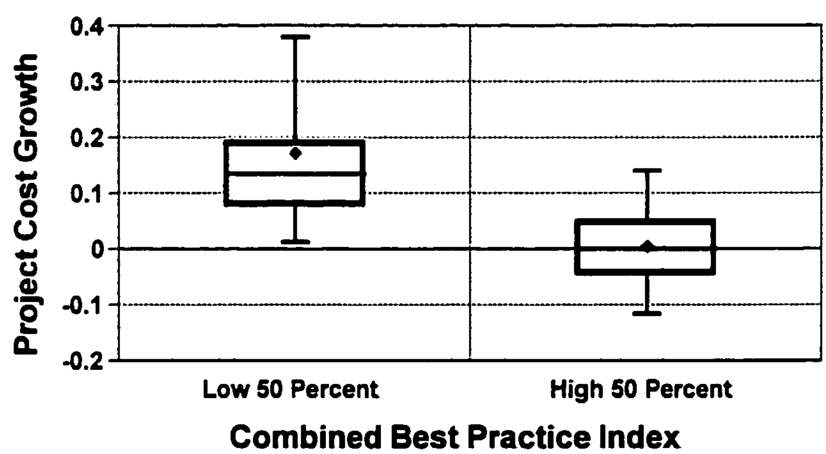


Figure 46: Project Cost Growth by Combined Best Practice Use Box and Whisker Diagrams

5.7.3 Regression Diagnostics

Regression diagnostics as previously discussed were performed to investigate violation of the basic underlying assumptions of the OLS regression model. The analysis was checked for influential observations, normally distributed errors, and constant variance of the errors. None of the regression assumptions were found to be violated beyond tolerable limits. Appendix H contains plots used in the analysis of influential observations, normally distributed errors, and constant variance of the errors.

5.7.4 Combined Best Practice Use and Contingency

Figure 47 illustrates the relationship between the project contingency factor and the combined best practice index for the projects in the sample dataset. Although there is considerable scatter in the data, a weak relationship exists between the project contingency factor and the combined best practice index. In general, projects that reported higher combined practice use had lower project contingency factors. The large degree of scatter in the data seems to indicate that decisions concerning contingency amounts included in the project budget are not closely related to pre-project planning, project change management, and team building efforts.

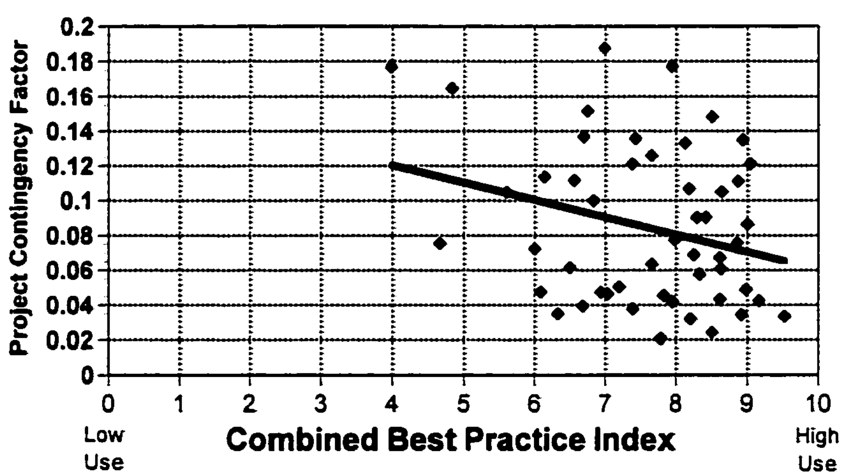


Figure 47: Project Contingency Factor vs Combined Best Practice Use Scatterplot

Table 34 provides the regression model equation and relevant inference statistics for this analysis. This analysis is based on 52 projects that provided complete project cost growth and project contingency factor data. The overall model is statistically significant to the 0.05 level and has an R^2 value of 0.078.

Table 34: Project Contingency Factor vs Combined Best Practice Use Bivariate Regression Model

Model Equation				
Project Contingency Factor = 0.162 – 0.010 x Combined Practice Index				

Regression Fit				
Degrees of Freedom		R-Square	F Stat	Prob > F
50		0.078	4.06	0.0495

Parameter Estimates				
Variable	Estimate	Std. Error	T Stat	Prob > T
Intercept	0.162	0.0384	4.20	0.0001
Combined Practice Index	-0.010	0.0050	-2.01	0.0495

Based upon the strong relationship between project cost growth and the combined best practice index and the relatively poor relationship between project contingency factor and the combined best practice index, it appears as though opportunity exists to match contingency to the probability of exceeding the authorization estimate. This could be accomplished by more closely matching contingency with the use of the practices considered in this study.

5.8 Multiple Regression Analysis of Project Cost Growth and Combined Best Practice Use with Project Environment Effects

Analyses were performed to measure the effects of the project environment variables on the relationship between project cost growth and the combined use of the best practices as measure by the combined best practice index. This analysis was conducted through the use of multiple regression with interaction effects. Dummy variables were used in the analysis to represent project environment variable levels. Jaccard, Turrisi, and Wan (1990) provide an excellent reference regarding this type of analysis. The project environment variables included in the analysis are: 1) project complexity, 2) project nature, 3) project cost, 4) project duration, 5) cost rate, 6) craft workhours and 7) equipment cost factor. For this sample of projects, only project complexity and project duration were found to have significant effects on the relationship between combined best practice use and project cost growth. Discussion for these analyses is provided in the following section. Scatterplots and regression results are provided in Appendix G for similar analyses related to the other five project environment variables.

5.8.1 Project Complexity

Figure 48 illustrates the relationship between project cost growth and combined best practice use with project complexity effects. Project cost growth was regressed on the combined best practice index and project complexity. Project complexity is represented in the model as a dummy variable with the sample of projects categorized as either high complexity or low complexity based on the median complexity value as discussed in Chapter Four. In the scatterplot, the "X"s represent the 50 percent of the projects in the sample with the lowest project complexity values. The solid line represents the regression prediction equation for this group of projects. The solid dots represent the remaining 50 percent of the projects with the highest project complexity values. The dashed line represents the regression prediction equation for the high project complexity group. The regression prediction equation for the low project complexity group has a larger intercept and steeper slope than the high project complexity group. The inference statistics provided in Table 35 for the regression model indicate that the difference in intercept and slope values for the two categories of projects is statistically significant. For this sample of projects, those reporting low project complexity exhibit a stronger relationship between project

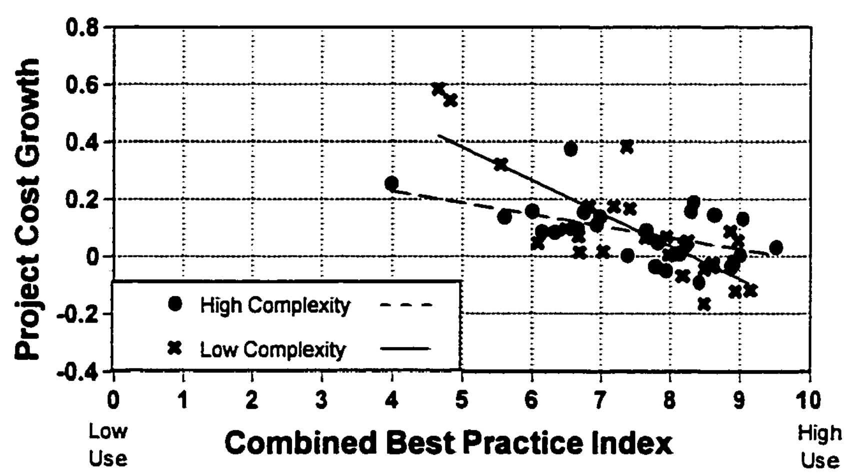


Figure 48: Project Cost Growth vs Combined Best Practice Use with Project Complexity Effects Scatterplot

cost growth and the combined use of the best practices than the high complexity projects. It may be that less complex projects are more responsive to increased practice use in regards to project cost growth. The difficulties associated with high complexity projects may act to offset the benefits of practice use on project cost growth. In comparison, for an equal increase in practice use for both categories of projects, the less complex projects most likely will enjoy the most benefit. The importance of this finding is twofold. First, it should be recognized that additional effort and resources may be required for high complexity projects to achieve the same project cost growth benefits through best practice use as projects of lower complexity. Second, the benefits are significant and because highly complex projects are generally more costly than their low complexity counterparts, the potential payoff for practice use is still high.

Table 35: Project Cost Growth vs Combined Practice Use with Project Complexity Effects Regression Model

Model Equation				
Project Cost Growth = 0.955 - 0.115 x Cmb. Practice Index - 0.564 x Complexity (High) + 0.075 x Complexity (High) x Cmb. Practice Index				
Regression Fit				
Degrees of Freedom		R-Square	F Stat	Prob > F
47		0.5511	19.64	0.0000
Parameter Estimates				
Variable	Estimate	Std. Error	T Stat	Prob > T
Intercept	0.955	0.1220	7.82	0.0000
Cmb.Practice Index	-0.115	0.0159	-7.26	0.0000
Complexity (High)	-0.564	0.1750	-3.23	0.0022
Complexity (Low)	0.000	.	.	.
Complexity (High) x Cmb. Practice Index	0.075	0.0229	3.25	0.0021
Complexity (Low) x Cmb. Practice Index	0.000	.	.	.

The R^2 value for this analysis is 0.551. Therefore, the combined practice use index and project complexity explain 55 percent of the variation in project cost growth in this model. The overall model is significant to the 0.0001 level and each of the parameter estimates is significant to the 0.05 level. The analysis includes 53 projects that provided complete project cost growth, combined best practice index, and project complexity data.

5.8.2 Project Duration

An analysis was performed in which project cost growth was regressed on the combined best practice index and project duration. Figure 49 illustrates the relationship between project cost growth and combined best practice use with project duration effects. Project duration is represented in the model as a dummy variable with the sample of projects categorized as either high duration or low duration. The project duration categorization is based on the median value of this variable for the sample dataset. In the scatterplot, the "X"'s represent the 50 percent of the projects in the sample with the lowest project duration values. The solid line represents the regression prediction equation for this group of projects. The solid dots represent the remaining 50 percent of the projects with the highest project duration values. The dashed line represents the regression prediction equation for the high project complexity group. The regression prediction equation for the low project duration group has a larger intercept and steeper slope than the high project duration group. The inference statistics provided in Table 36 for the regression model indicate that the difference in intercept and slope values for the two categories of projects is statistically significant. For this

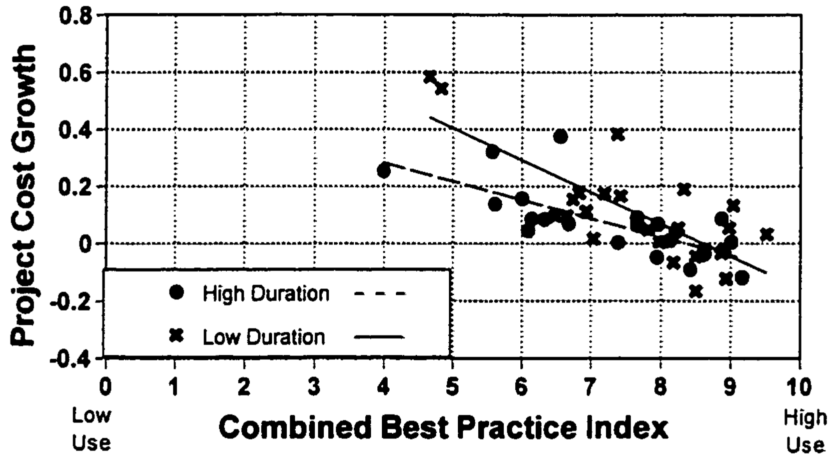


Figure 49: Project Cost Growth vs Combined Best Practice Use with Project Duration Effects Scatterplot

sample of projects, those reporting low project duration exhibit a stronger relationship between project cost growth and the combined use of the best practices than the high duration projects. With respect to project cost growth, short duration projects may be more sensitive to issues influenced by the use of best practices than longer duration projects. On longer duration projects, schedule problems resulting from poor planning or communication may be resolved with minimum cost impact because it may be possible to re-sequence activities such that time is not lost and extra cost are not incurred to make up time. However, for low duration projects and especially process facility turnaround projects, time is not available to make up for mistakes and therefore most always results in additional cost. This is one viable explanation for the difference in the relationship between project cost growth and combined practice use for high and low duration projects.

Table 36: Project Cost Growth vs Combined Best Practice Use with Project Duration Effects Regression Model

Model Equation				
Project Cost Growth = 0.962 – 0.112 x Combined Practice Index - 0.422 x Duration (High) + 0.047 x Duration (High) x Combined Practice Index				
Regression Fit				
Degrees of Freedom		R-Square	F Stat	Prob > F
43		0.5832	20.05	0.0000
Parameter Estimates				
Variable	Estimate	Std. Error	T Stat	Prob > T
Intercept	0.962	0.1320	7.28	0.0000
Combined Practice Index	-0.112	0.0170	-6.62	0.0000
Duration (High)	-0.422	0.1800	-2.34	0.0241
Duration (Low)	0.000	.	.	.
Duration (High) x Combined Practice Index	0.047	0.0240	2.01	0.0512
Duration (Low) x Combined Practice Index	0.000	.	.	.

Although both high and low duration projects exhibit less project cost growth at higher levels of best practice use, the relationship is significantly stronger for low duration projects. For the same increment in level of effort, use of pre-project planning, project change management, and team building may have the greatest potential to reduce project cost growth on low duration projects.

The R^2 value for this analysis, 0.583, indicates explanation of approximately 58 percent of project cost growth variation by the combined best practice index and project duration. The overall model is significant to the 0.0001 level and each of the parameter estimates is significant to the 0.05 level. This analysis represents 49 projects that provided complete project cost growth, combined best practice index, and project duration data

5.9 Multiple Regression Analysis of Project Cost Growth and Combined Best Practice Use with Other Practice Effects

Analyses were performed to measure the effects of the other practices considered in this study on the relationship between project cost growth and the combined use of the four best practices. This analysis was conducted through the use of multiple regression with interaction effects. Dummy variables were used in the analysis to represent use of the other practices. The other practices include: 1) percent design complete, 2) contract cost incentives, 3) contract compensation strategy, and 4) contract organization strategy. For this sample of projects, the only one of these four practices found to have significant effects on the relationship between combined best practice use and project cost growth is percent design complete. Discussion for this analysis is provided in the following section. Scatterplots and regression results are provided in Appendix G for similar analyses related to the other three practices.

5.9.1 Percent Design Complete

Figure 50 illustrates the regression of project cost growth on the combined best practice index and the percent design complete. The percent design complete is represented as a dummy variable with the sample of projects categorized as high or low based on the median value for this variable. The "X"s represent the 50 percent of the projects within the sample with the lowest percent design complete values. The solid line represents the regression prediction equation for this group of projects. The solid dots represent the remaining 50 percent of the projects with the highest percent design complete values. The dashed line represents the regression prediction equation for the high percent design complete group. Nine of the thirteen projects with combined best practice index scores less than 7 fall in the low percent design complete category. This project distribution should be expected due to: 1) the previously discussed relationship between percent design complete and the pre-project planning index and 2) the large weight given the pre-project planning index in the calculation of the combined practice use index. The regression prediction equation for the low group has a much larger intercept and steeper slope than the high group. The inference statistics provided in Table 37 for the regression model indicate that the difference in intercept and slope values for the two categories of projects is statistically significant. In general, the projects with a low percent of design complete at project authorization experienced high project cost growth if they also

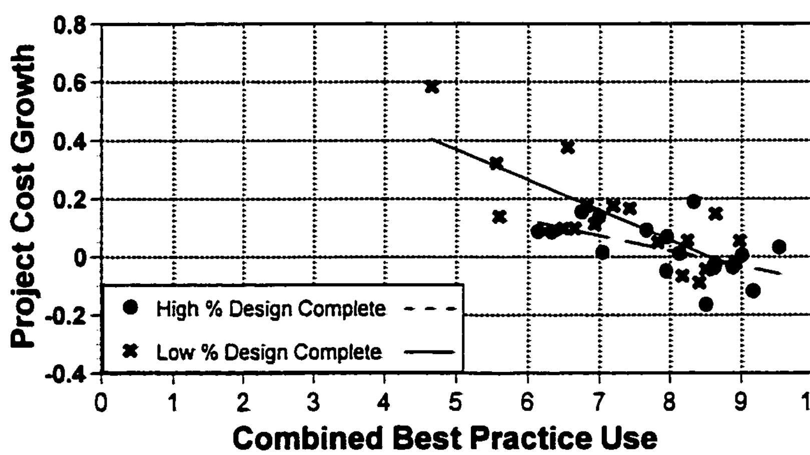


Figure 50: Project Cost Growth vs Combined Best Practice Use with Percent Design Complete Effects Scatterplot

utilized the three best practices included in the combined practice index to a low degree. However, projects with a low percent design complete that utilized the best practices to a high degree reported relatively low project cost growth values that are comparable to the projects with a high percent of design complete at project authorization. For the sample projects in the low percent design complete group, the relationship between project cost growth and combined best practice index is very strong. A much weaker relationship between project cost growth and combined best practice index is evident for the group of projects with a high percent design complete.

Table 37: Project Cost Growth vs Combined Best Practice Use with Percent Design Complete Effects Regression Model

Model Equation

Project Cost Growth = 0.888 – 0.104 x Cmb. Prct. Index - 0.452 x % Des. Comp. (High) + 0.052 x % Des. Comp. (High) x Cmb. Prct. Index

Regression Fit

Degrees of Freedom		R-Square	F Stat	Prob > F
32		0.6093	16.63	0.0000

Parameter Estimates

Variable	Estimate	Std. Error	T Stat	Prob > T
Intercept	0.888	0.1340	6.62	0.0000
Cmb. Prct. Index	-0.104	0.0181	-5.76	0.0000
% Des. Comp. (High)	-0.452	0.2280	-1.99	0.0556
% Des. Comp. (Low)	0	-	-	-
% Des. Comp. (High) x Cmb. Prct. Index	0.052	0.0291	1.80	0.0816
% Des. Comp. (Low) x Cmb. Prct. Index	0	-	-	-

The use of pre-project planning, project change management, and team building has the greatest potential to reduce project cost growth on projects that have a low percent design complete at project authorization. Although projects with a high percent design complete exhibit less project cost growth with higher best practice use levels, the relationship is not as strong as that for the low percent design complete group.

The R^2 value for this analysis, 0.609, indicates explanation of approximately 61 percent of project cost growth variation by the percent of design complete at authorization and the use of pre-project planning, project change management, and team building. This analysis represents 38 projects that provided complete project cost growth, combined best practice index, and percent design complete data.

5.10 Summary

The following list is provided to summarize key findings identified through analyses presented in this chapter.

- None of the bivariate relationships between project cost growth and the project environment variables were found to be significant.
- Team building was used on grass roots projects to a much higher degree than on addition or modification projects. No other significant bivariate relationships were found between best practice use and the project environment.
- Many bivariate relationships between individual best practice items and project cost growth were found to be significant. A significant relationship was found to exist for thirteen of the twenty-seven pre-project planning items. Two or three significant items were identified for each of the other three best practices. In general, projects that

utilized the individual best practice items experienced lower project cost growth values than those projects that did not.

- Projects in which the owner utilized a contract cost incentive with the designer, in general, experienced lower project cost growth.

- The use of pre-project planning, project change management, and constructability are positively correlated to a high degree.

- Both bivariate and multivariate regression models indicate pre-project planning, project change management, and team building significantly affect project cost growth. Pre-project planning exhibits the strongest relationship with project cost growth by a considerable margin over the other best practices. Higher use of each practice is associated with lower project cost growth values and less variation in project cost growth. The bivariate model indicated a significant relationship between constructability and project cost growth. However, this relationship was not apparent in the multivariate model.

- The project contingency factor exhibits a weak, yet significant, relationship with the combined best practice index. In general, projects with higher combined best practice index scores had lower project contingency factors.

- Project complexity and project duration were found to significantly affect the relationship between the combined best practice index and project cost growth. No other project environment variables were found to affect this relationship.

- Percent design complete was found to significantly affect the relationship between the combined best practice index and project cost growth. No other practices were found to affect this relationship.

Chapter 6: Conclusions and Recommendations

This study utilized an exploratory approach to examine the effects of many construction industry practices on project cost performance. An investigation such as this was possible only by building on the research of others. A review of the literature that provided a foundation for this work was given in Chapter Two. Data collection, statistical methods, and analyses used to test the research hypotheses were discussed in Chapters Three, Four, and Five. This chapter provides a review of the research hypotheses, conclusions derived from the analyses, industry recommendations, recommendations for additional research, and the contributions of this work.

6.1 Review of Research Hypotheses & Conclusions

Each research hypothesis, as discussed in Chapter 1, is listed below for review and is followed by related conclusions based on this study.

Hypothesis 1. Cost performance of capital facility construction projects is significantly improved through the use of practices that enhance project definition prior to authorization, improve the management of project change, develop effective relationships among project team members, and enhance project constructability. Use of these practices is negatively correlated with project cost growth and results in reduced project cost growth variability.

Conclusion 1. Both bivariate and multivariate analyses performed in this study indicate that use of pre-project planning, project change management, and team building practices have the potential to reduce project cost growth. Each of these practices was found to have significant negative correlation with project cost growth. The difference in average project cost growth for the group of projects with high and low pre-project planning use is approximately 16 percent. The difference in average project cost growth for the high and low use groups for both project change management and team building is approximately 8 percent. Project cost growth variability was found to be less for the high practice use group for each of the best practices. The relationship found between project cost growth and constructability did not meet the statistical significance threshold set for this study.

Hypothesis 2. The use of pre-project planning, project change management, team building, and constructabilty is positively correlated with the use of each of the others. Therefore, it is appropriate to model the effects of the use of the practices with multivariate analyses to develop an understanding of the contribution of each of the practices.

Conclusion 2. Correlation analysis performed as a part of this study indicates a strong positive correlation between pre-project planning, project change management, and constructability. Pearson correlation coefficients for these three practices range from approximately 0.47 to 0.51. Team building is positively correlated with the other best practices, but to a much lesser degree. Pearson correlation coefficients for team building and the other practices range from 0.08 to 0.34. The degree of correlation among the use of the practices is sufficient to warrant the use of multivariate analysis.

Hypothesis 3. While several of the practices considered in this study may significantly effect project cost performance, the effects of the various practices on project cost performance are not equal in magnitude. Some practices have significantly greater effects on project cost performance than do others. In accordance with previous research, practices that occur early in the project life cycle and facilitate project definition prior to project authorization have the greatest potential to influence project cost performance.

Conclusion 3. Multivariate analysis performed as a part of this study indicate that pre-project planning, project change management, and team building each significantly affect project cost growth. Based on the standardized regression coefficients for this model, the effects of pre-project planning on project cost growth are much greater than the other practices. The regression coefficient for pre-project planning is approximately fifty percent greater than for project change management and team building.

Hypothesis 4. Projects that utilize multiple best practices in combination to a high degree experience significantly less project cost growth and less project cost growth variability than projects that use only a single best practice or multiple best practices in combination to a lesser degree.

Conclusion 4. Based on an analysis of project cost growth and the combined best practice index, the group of projects with the highest combined best practice index scores experienced significantly less project cost growth and less variability in project cost growth values. The high best practice use group experienced an average project cost growth of 0.3 percent, while the low use group experienced 17.0 percent. This represents a difference of 16.7 percent in project cost growth between the two groups. The standard deviation of the high and low use groups is 0.088 and 0.155, respectively.

Hypothesis 5. The effects of best practice use on project cost growth are influenced by the project environment and other practices.

Conclusion 5. Multivariate analysis of project cost growth and the combined best practice index with project environment effects reveal that the relationship between project cost growth and the combined best practice index is significantly affected by project complexity and project duration. Similar analysis indicates that the relationship is significantly affected by the percent design complete at project authorization.

6.2 Industry Recommendations

The following recommendations for capital facility project planning and execution are based on the findings of this study. Each of the recommendations is intended to enhance project cost performance by lowering the probability of undesirable project cost growth and, therefore, improving project cost predictability.

1. Resources should be focused on the three issues listed below in amounts commiserate with the need for control of project cost growth and improvement of project cost predictability. Efforts should be concentrated on the best practice items identified in this research as having the strongest correlation with project cost growth. These three issues are highly interrelated and maximum benefits should accrue from combined use of all three.

    - Develop project definition to a high level through pre-project planning and engineering effort prior to project authorization. A system to measure and benchmark these efforts relative to historical project data should be utilized. Particular effort should be focused on the thirteen pre-project planning items found to have the strongest relationship with project cost growth. The level of design complete prior to project authorization should be greater than 10 percent for projects that require a high level of cost predictability.

    - A project change management program should be implemented to control and effectively manage change. This effort is highly related to the project definition efforts because a well-developed project definition is required as a baseline to identify and measure project change.

    - A team building program should be implemented early in the project to facilitate project team communications. Team building efforts are related to both project definition and project change management in that improved project team communications leads to better pre-project planning and project change management programs.

2. Project contingency decisions should be based in part on measures of project definition prior to project authorization and the use of best practices. The following measures should be included in a contingency assessment: pre-project planning effort, percent design complete prior to project authorization, the use of project change management practices, and team building. Efforts should be focused on pre-project planning effort and percent design complete to enhance project definition prior to project authorization.
3. Opportunities for project cost performance improvement through best practice implementation may be greater for projects with low percent design complete at authorization and projects of short duration. Additional best practice implementation effort should be considered for projects with these attributes.
4. A higher degree of best practice effort may be required for highly complex projects to realize project cost performance benefits similar to projects of low complexity. A higher level of resources should be allocated to best practice implementation on highly complex projects.

6.3 Recommendations for Additional Research

The following recommendations for additional research are based on experience gained through performing analyses discussed in this study, as well as working on the development of the complete CII Benchmarking and Metrics database. Many unexplored analysis and improvement opportunities exist.

1. This research represents only a small portion of the analysis possibilities within the CII Benchmarking and Metrics Program Database. It intentionally looks at a very narrow investigation domain. Similar analyses can be performed for other subsets of the data as the database grows. For example, in future years, sufficient data should be available to analyze building projects in a similar manner.
2. The data collection instrument should be revised such that it is more compatible with industry groups other than Heavy and Light Industrial. Most questions in the pre-project planning section of the data collection instrument are specific to the industrial sector. This may introduce considerable measurement error in the data for building and infrastructure projects. It also undermines respondents interest in providing data related to other types of projects. Other sections of the questionnaire should be reviewed for similar industry specific questions. Versions of the data collection instrument could be developed that are tailored specifically for Industrial, Building, and Infrastructure projects.
3. Additional work should be done to investigate the differences between projects reported by owners and contractors. Projects submitted by contractors represent a significantly different unit of analysis than projects submitted by owners. This is especially true for data related to the use of practices that are employed during various project phases in which a contractor may or may not have been involved. In the current database, many of the projects submitted by contractors indicate involvement in

only the design or the construction phase. Querying contractors concerning practices that occur during project phases in which they were not involved or only partially involved may introduce measurement error in the data. For this reason, projects submitted by contractors were not included in this analysis. A method to supplement data for these types of projects should be considered to increase the number of projects available for analysis of many of the practices.

4. Additional work should be performed concerning the weights assigned to individual items used in the development of the best practice indexes. A combination of expert opinion and correlation analysis should be used to further develop these weights as the CII BM&M database increases in size.
5. Consideration should be given to collecting data related to unusual events that affect project performance. This should include events or circumstance that are beyond control or reasonable expectations of the project team. Examples of this type of data may include: the effect on project performance attributed to delays in or cancellation of project funding, extreme weather, changes in project environmental requirements, labor problems, or prevailing economic conditions. These data would be beneficial in developing more sophisticated models for the relationship between practice use and project performance.
6. Consideration should be given to the development of a method to acquire random samples to reduce the effect of project selection bias. This sample

should be representative of the projects that are being constructed by the CII membership participating in the BM&M effort.

6.4 Contributions

The following discussion lists the primary contributions of this study to the body of knowledge regarding management of capital facility project planning and execution.

1. This work builds on previous research conducted to identify practices that improve project cost performance and to quantify the relationships between practice use and project cost performance. It is based on a quantitative data set collected by use of a thoroughly tested data collection instrument and statistical analysis of the data. The findings provide evidence in support of previous findings, confirm the validity of recommendations from previous research, and provide quantitative measurement regarding the relationships.
2. Previous research related to the effects of practice use on project cost performance generally focused on a single practice. The strong correlation between use of the various best practices identified in this study indicates a need for more sophisticated analysis methods that simultaneously consider the effects of multiple practice use. This study has developed more completely specified models than many used in the past by estimating the effects of multiple practices simultaneously. This provides new information related to the relative effects of the use of various practices and illustrates the need for this type of approach in future

research in this area. The study also provides new information regarding the effects of the project environment on the relationship between best practice use and project cost performance. This information can be used by project managers as guidance concerning the level of resources that should be applied to best practice use on projects with various environment attributes.

Appendix A: Data Collection Instrument and Glossary of Terms

CII Benchmarking and Metrics
Completed Project Data: Owners (Version 2.0)

The data collected by this form begins the second round of data collection for CII's benchmarking and metrics system. The data will be used to establish performance norms, to identify trends, and to correlate execution of project management processes to project outcomes. It will form part of a permanent database. Through such correlation across many companies and projects, opportunities for improving your company's project performance will be identified. CII will not analyze performance of individual companies, however. Each company will be provided the means to compare itself to the benchmarks. Therefore, it is important that you retain a copy of this questionnaire for your records. **All data will be held in strict confidence.**

When you have completed the questionnaire, please return it to your Company's Data Liaison by **May 1, 1997.**

The next 2 pages contain definitions for project phases. Please pay particular attention to the start and stop points which have been highlighted. All project costs should be given in U.S. dollars. If you need further assistance in interpreting the intent of a question, please call Ned Givens or Kirk Morrow of CII at (512) 471-4319 (E-mail: tkmorrow@mail.utexas.edu). Remember, conformance to the instructions and phase definitions is crucial for establishing reliable benchmarks.

Your company data liaison has been provided with a list of projects which were submitted by your company during the previous data collection effort. In order to maintain the integrity of the database, please ensure that projects which have been submitted previously are not reported again.

If the information required to answer a given question is not available, please write "UNK" (unknown) in the space provided. If the information requested does not apply to this project, please write "NA" (not applicable) in the space provided. However, keep in mind that too many "unknowns" or "not applicables" could render *the project unusable for analysis.*

This form should be completed under the direction of the project manager. The project manager should consult with colleagues who worked on the project. We urge that you carefully review the phase table on the next 2 pages before attempting to provide the requested information.

Definition is provided in the attached glossary for words and phrases that are both italicized and underlined.

CII Benchmarking and Metrics
Completed Project Data: Owners (Version 2.0)

Project Phase Table

Project Phase	Start/Stop	Typical Activities & Products	Typical Cost Elements
Pre-Project Planning Typical Participants: • Owner personnel • Planning Consultants • Constructability Consultant • Alliance / Partner	**Start: Defined Business Need that requires facilities** **Stop: Total Project Budget Authorized**	• Options Analysis • Life-cycle Cost Analysis • Project Execution Plan • Appropriation Submittal Pkg • P&IDs and Site Layout • Project Scoping • Procurement Plan • Arch. Rendering	• Owner Planning team personnel expenses • Consultant fees & expenses • Environmental Permitting costs • Project Manager / Construction Manager fees • Licensor Costs
Detail Design Typical Participants: • Owner personnel • Design Contractor • Constructability Expert • Alliance / Partner	**Start: Design Basis** **Stop: Release of all approved drawings and specs for construction (or last package for fast-track)**	• Drawing & spec preparation • Bill of material preparation • Procurement Status • Sequence of operations • Technical Review • Definitive Cost Estimate	• Owner project management personnel • Designer fees • Project Manager / Construction Manager fees
Demolition / Abatement (see note below) Typical Participants: • Owner personnel • General Contractor • Demolition Contractor • Remediation / Abatement Contractor	**Start: Mobilization for demolition** **Stop: Completion of demolition**	• Remove existing facility or portion of facility to allow construction or renovation to proceed • Perform cleanup or abatement / remediation	• Owner project management personnel • Project Manager / Construction Manager fees • General Contractor and/or Demolition specialist charges • Abatement / remediation contractor charges

Note: The demolition / abatement phase should be reported when the demolition / abatement work is a separate schedule activity (potentially paralleling the design and procurement phases) in preparation for new construction. Do not use the demolition / abatement phase if the work is integral with modernization or addition activities.

CII Benchmarking and Metrics
Completed Project Data: Owners (Version 2.0)

Project Phase Table (Cont.)

Project Phase	Start/Stop	Typical Activities & Products	Typical Cost Elements
Procurement Typical Participants: • Owner personnel • Design Contractor • Alliance / Partner	**Start: Procurement Plan for Engineered Equipment** **Stop: All engineered equipment has been delivered to site**	• Vendor Qualification • Vendor Inquiries • Bid Analysis • Purchasing • Expediting • Engineered Equipment • Transportation • Vendor QA/QC	• Owner project management personnel • Project Manager / Construction Manager fees • Procurement & Expediting personnel • Engineered Equipment • Transportation • Shop QA / QC
Construction Typical Participants: • Owner personnel • Design Contractor (Inspection) • Construction Contractor and its subcontractors	**Start: Beginning of continuous substantial construction activity** **Stop: *Mechanical Completion***	• Set up trailers • Site preparation • Procurement of bulks • Issue Subcontracts • Construction plan for Methods/Sequencing • Build Facility & Install Engineered Equipment • Complete Punchlist • Demobilize construction equipment • Warehousing	• Owner project management personnel • Project Manager / Construction Manager fees • Building permits • Inspection QA/QC • Construction labor, equipment & supplies • Bulk materials • Construction equipment • Contractor management personnel • Warranties
Start-up / Commissioning Note: Does not usually apply to infrastructure or building type projects Typical Participants: • Owner personnel • Design Contractor • Construction Contractor • Training Consultant • Equipment Vendors	**Start: *Mechanical Completion*** **Stop: Custody transfer to user/operator (steady state operation)**	• Testing Systems • Training Operators • Documenting Results • Introduce Feedstocks and obtain first Product • Hand-off to user/operator • Operating System • Functional Facility • Warranty Work	• Owner project management personnel • Project Manager / Construction Manager fees • Consultant fees & expenses • Operator training expenses • Wasted feedstocks • Vendor fees

CII Benchmarking and Metrics
Completed Project Data: Owners (Version 2.0)

1. Your Company: ______________________________

2. Your Project I.D. ______________ (You may use any reference to protect the project's identity. The purpose of this I.D. is to help you and CII personnel identify the questionnaire correctly if clarification of data is needed and to prevent duplicate project entries.)

3. Project Location: Domestic ______________, USA
   State
   International ______________
   Country

4. Contact Person (name of the person filling out this form): ______________

5. Contact Phone No.(   ) ______________ 6. Contact Fax No. (   ) ______________

7. Principal Type of Project (Check only one. If you feel the project does not have a principal type, but is an even mixture of two or more of those listed, please attach a short description of the project. If the project type does not appear in the list, please describe in the space next to "Other."):

Industrial	Infrastructure	Buildings
____Electrical (Generating)	____Electrical Distribution	____Lowrise Office
____Oil Exploration/Production	____Highway	____Highrise Office
____Oil Refining	____Navigation	____Warehouse
____Pulp and Paper	____Flood Control	____Hospital
____Chemical Mfg.	____Rail	____Laboratory
____Environmental	____Water/Wastewater	____School
____Pharmaceuticals Mfg.	____Airport	____Prison
____Metals Refining/Processing	____Tunneling	____Hotel
____Microelectronics Mfg.	____Marine Facilities	____Maintenance Facilities
____Consumer Products Mfg.	____Mining	____Parking Garage
____Natural Gas Processing		____Retail
____Automotive Mfg.		
____Foods		

____Other (Please describe)______________________________

____

8. This project was (check only one): Grass Roots____ Modernization____ Addition____

   Grass roots - a new facility from the foundations and up. A project requiring demolition of an existing facility before new construction begins is also classified as grass roots.

   Modernization - a facility for which a substantial amount of the equipment, structure, or other components is replaced or modified, and which may expand capacity and/or improve the process or facility.

   Addition - a new addition that ties in to an existing facility, often intended to expand capacity.

   ____Other (Please describe)______________________________

9. **Achieving Design Basis.** Please indicate in the following table the product or function of the completed facility, the unit of measure which best relates the product or function capacity of the completed facility, the planned capacity of the facility at the start of detail design, and the capacity achieved by the completed facility.

For process facilities, the measure is either one of input or output as appropriate.
Examples : crude oil refining unit - barrels per day throughput

For infrastructure or buildings, please include the measure that you feel is best. Please spell out this measure rather than using an abbreviation.

If the product produced or function provided by this facility is of a confidential nature, please write "Confidential" in the first column and provide the other data.

If you are unable to furnish a measure or units, please write "NA" (not applicable) in the "Product or Function" field and go to question 10.

Product or Function	Unit of Measure	Planned Start-up Capacity	Achieved Start-up Capacity	Planned Final Capacity	Achieved Final Capacity

9a. Please indicate the method of ***acceptance testing*** used on this project.

____ No Assessment
____ Demonstrated operations at achieved level
____ Formal documented acceptance test over a meaningful period of time

9b. Please indicate how the achieved capacity of the completed facility compares against expectations documented in the project execution plan. If the achieved capacity is much worse or much better than expected, please briefly comment on the primary cause of the deviation.

____ Much worse than expected Why? ____________________
____ Worse than expected ____________________
____ As expected
____ Better than expected
____ Much better than expected Why? ____________________
____

10. Project Participants. Please list the companies, including your company, that helped execute this project, but do not list any subcontractors. Indicate the function(s) each company performed and the approximate percent of that function to the nearest 10%. For each function, indicate the principle form of remuneration in use at the completion of the work. Please indicate if each participant was an alliance partner and if their contract contained incentives.

Please use the following codes to identify the **Function** performed by each project participant.

PPP	Pre-Project Planner	DM	Demolition/Abatement Contractor
PPC	Pre-Project Planning Consultant	GC	General Contractor
D	Designer	PC	Prime Contractor
PE	Procurement - Equipment	PM	Project Manager
PB	Procurement - Bulks	CM	Construction Manager

Percent of Function refers to the percent of the overall function contributed by the company listed. Estimate to the nearest 10 percent.

Type of Remuneration refers to the overall method of payment. Unit price refers to a price for in place units of work and does not refer to hourly charges for skill categories or time card mark-ups. Hourly rate payment schedules should be categorized as cost reimbursable. Please use the following codes to identify remuneration type. Record the form of remuneration for your own company's contribution, if any, as "I" (In House).

LS	Lump Sum	GP	Guaranteed Maximum Price
UP	Unit Price	I	In-house
CR	Cost Reimbursable/Target Price (Including Incentives)		

An ***Alliance Partner*** is a company with whom your company has a long-term formal strategic agreement that ordinarily covers multiple projects. Circle "Y" to indicate that a company was an alliance partner or circle "N" if the company was not an alliance partner.

If **Contract Incentives** were utilized, please indicate whether those incentives were positive (a financial incentive for attaining an objective), negative (a financial disincentive for failure to achieve an objective), or both. Circle "+" to indicate a positive incentive and circle "-" to indicate a negative incentive.

Company Name	Function	Approx. Percent of Function (Nearest 10%)	Type of Remun. (Contract End)	Was this company an alliance partner? (Yes/No)		Contract Incentives (circle as many as apply)							
						Cost		Schedule		Safety		Quality	
				Y	N	+	-	+	-	+	-	+	-
				Y	N	+	-	+	-	+	-	+	-
				Y	N	+	-	+	-	+	-	+	-
				Y	N	+	-	+	-	+	-	+	-
				Y	N	+	-	+	-	+	-	+	-
				Y	N	+	-	+	-	+	-	+	-
				Y	N	+	-	+	-	+	-	+	-

11a. ***Total Project Budget***

- The total project budget amount should correspond to the estimate at the start of detail design including ***contingency***.
- The total project budget amount should include all planned expenses from pre-project planning through startup or to a "ready for use" condition, excluding the ***cost of land***.
- State the project budget in U.S. dollars to the nearest $1000. (You may use a "k" to indicate thousands in lieu of "...,000".)

$________________________

11b. How much ***contingency*** does this budget contain? (to the nearest $1000. You may use a "k" to indicate thousands in lieu of "...,000".)

$________________________

12. ***Total Actual Project Cost:***

- The total actual project cost should include all actual project costs from pre-project planning through startup or to a "ready for use" condition, excluding the cost of land.
- Actual costs should correspond to those that were part of the budget. For example, if the budget included specific amounts for in-house personnel, then actual cost should include the actual amounts expended during the project for their salaries, overhead, travel, etc.
- State the project cost in U.S. dollars to the nearest $1000. (You may use a "k" to indicate thousands in lieu of "...,000".)

$________________________

13. Please indicate the budgeted and actual costs by project phase

- Phase budget amounts should correspond to the estimate at the start of detail design.
- Refer to the table on pages 2 and 3 for phase definitions and typical cost elements.
- State the phase costs in U.S. dollars to the nearest $1000. (You may use a "k" to indicate thousands in lieu of "...,000".)
- Include the cost of bulk materials in construction and the cost of engineered equipment in procurement.
- If this project did not involve Demolition/Abatement or Startup please write "NA" for those phases.
- The sum of phase budgets should equal the Total Project Budget and the sum of actual phase costs should equal Total Actual Project Cost from questions 11 & 12 above.

Project Phase	Phase Budget (Including Contingency)	Amount of Contingency in Budget	Actual Phase Cost
Pre-Project Planning	$	$	$
Detail Design	$	$	$
Procurement	$	$	$
Demolition/Abatement	$	$	$
Construction	$	$	$
Startup	$	$	$
Totals	$	$	$

14. Planned and Actual Project Schedule

- The dates for the planned schedule should be those in effect at the start of detail design. If you cannot provide an exact day for either the planned or actual, estimate to the nearest week in the form mm/dd/yy; for example, 1/8/96, 2/15/96, or 3/22/96.)
- Refer to the chart on pages 2 and 3 for a description of starting and stopping points for each Phase.
- If this project did not involve Demolition/Abatement or Startup please write "NA" for those phases.

Project Phase	Planned Schedule		Actual Schedule	
	Start mm / dd / yy	Stop mm / dd / yy	Start mm / dd / yy	Stop mm / dd / yy
Pre-Project Planning	/ /	/ /	/ /	/ /
Detail Design	/ /	/ /	/ /	/ /
Procurement	/ /	/ /	/ /	/ /
Demolition/Abatement	/ /	/ /	/ /	/ /
Construction	/ /	/ /	/ /	/ /
Startup	/ /	/ /	/ /	/ /

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14a. What percentage of the total engineering workhours for design were completed prior to total project budget authorization? (Write "UNK" in the blank if you don't have this information)

_________ %

14b. What percentage of the total engineering workhours for design were completed prior to start of the construction phase? (Write "UNK" in the blank if you don't have this information)

_________ %

15. ***Project Development Changes*** and ***Scope Changes.*** Please record the changes to your project by phase in the table provided below. For each phase indicate the total number, the net cost impact, and the net schedule impact resulting from project development changes and scope changes. Changes may be initiated by either the owner or contractor.

Project Development Changes include those changes required to execute the original scope of work or obtain original process basis.

Scope Changes include changes in the base scope of work or process basis.

- Changes should be included in the phase in which they were initiated. Refer to the table on pages 2 and 3 to help you decide how to classify the changes by project phase. If you cannot provide the requested change information by phase, but can provide the information for the total project please indicate the totals.
- Indicate "minus" (–) in front of cost or schedule values, if the net changes produced a reduction. If no changes were initiated during a phase, write "0" in the "Total Number" columns.
- State the cost of changes in U.S. dollars to the nearest $1000 and the schedule changes to the nearest week. You may use a "k" to indicate thousands in lieu of "...,000".

Project Phase	Total Number of Project Development Changes	Total Number of Scope Changes	Net Cost Impact of Project Development Changes ($)	Net Cost Impact of Scope Changes ($)	Net Schedule Impact of Project Development Changes (weeks)	Net Schedule Impact of Scope Changes (weeks)
Design			$	$	wks	wks
Procurement			$	$	wks	wks
Demolition/Abatement			$	$	wks	wks
Construction			$	$	wks	wks
Startup			$	$	wks	wks
Totals			$	$	wks	wks

16. Field Rework

Was there a system for tracking and evaluating field rework for this project?

_____ Yes _____ No

If yes, please complete the following table. If no, proceed to question 17.

Please indicate the Direct Cost of Field Rework, the Cost of Quality Management, and the Schedule Impact of Field Rework for each category shown in the following table. If you track field rework by a few other or additional categories, please add them in the blank spaces provided. If the system used on this project does not include any of the Sources of Field Rework listed, write "NA" (not applicable) in the Direct Cost of Field Rework space. If your system used a listed Source of Field Rework, but this project had no Field Rework attributable to it, write "0" in the Direct Cost of Field Rework space. If you cannot provide the requested field rework information by Source of Field Rework, but can provide the information for the total project, please write "UNK" (unknown) in the fields adjacent to the sources of field rework and indicate the totals.

The ***direct cost of field rework*** relates to all costs needed to perform the rework itself whereas the ***cost of quality management*** includes quality assurance or quality control costs, which may identify the need to perform field rework or prevent the need for additional field rework.

Source of Field Rework	Direct Cost of Field Rework	Cost of Quality Management	Schedule Impact of Field Rework
Owner Change	$	$	Weeks
Design Error / Omission	$	$	Weeks
Designer Change	$	$	Weeks
Vendor Error / Omission	$	$	Weeks
Vendor Change	$	$	Weeks
Constructor Error / Omission	$	$	Weeks
Constructor Change	$	$	Weeks
Transportation Error	$	$	Weeks
	$	$	Weeks
	$	$	Weeks
	$	$	Weeks
	$	$	Weeks
	$	$	Weeks
	$	$	Weeks
Totals	$	$	Weeks

17. Actual Total Cost of Major Equipment

Please record the actual total cost of major equipment procured for permanent installation in this project in the space provided below.

- Include only the invoiced cost for items of major equipment. Do not include the cost of associated services such as making vendor inquiries, analyzing vendor bids, or expediting.
- State the cost of equipment in U.S. dollars to the nearest $1000. You may use a "k" to indicate thousands in lieu of "...,000".
- Refer to the following table to help you identify major equipment expenditures.
- If the project did not include major equipment, which is typical of many infrastructure or building projects, please write "NA."

$ ______________________

General Classification	Kinds of Equipment Covered
Columns and Pressure Vessels (Code Design)	Towers, columns, reactors, unfired pressure vessels, bulk storage spheres, and unfired kilns; includes internals such as trays and packing.
Tanks (non-code design; 0-15 psig, MAW or design pressure)	Atmospheric storage tanks, bins, hoppers, and silos.
Exchangers	Heat transfer equipment: tubular exchangers, condensers, evaporators, reboilers, coolers (including fin-fan coolers and cooling towers) - excludes fired heaters.
Direct-fired Equipment	Fired heaters, furnaces, boilers, kilns, and dryers, including associated equipment such as super-heaters, air preheaters, burners, stacks, flues, draft fans and drivers, etc.
Pumps	All types of liquid pumps and drivers.
Vacuum Equipment	Mechanical vacuum pumps, ejectors, and other vacuum-producing apparatus and integral auxiliary equipment.
Turbines	
Motors	
Electricity Generation and Transmission	Major electrical items (e.g., transformers, switch gear, motor-control centers, batteries, battery chargers, and cable [15kV]).
Speed Reducers/Increasers	
Materials-Handling Equipment	Conveyers, cranes, hoists, chutes, feeders, scales and other weighing devices, packaging machines, and lift trucks.
Package Units	Integrated systems bought as a package (e.g., air dryers, refrigeration systems, ion-exchange systems, etc.).
Special Processing Equipment	Agitators, crushers, pulverizers, blenders, separators, cyclones, filters, centrifuges, mixers, dryers, extruders, and other such machinery with their drivers.

17b. Project Complexity

Place a mark anywhere on the scale below that best describes the level of complexity for this project as compared to other projects from the same industry sector. For example, if this is a heavy industrial project, how does it compare in complexity to other heavy industrial projects. Use the definitions below the scale as general guidelines.

Low Complexity — Average Complexity — High Complexity

- **Low Complexity** - Characterized by the use of no unproven technology, small number of process steps, small facility size or process capacity, previously used facility configuration or geometry, proven construction methods, etc.
- **High Complexity** - Characterized by the use of unproven technology, an unusually large number of process steps, large facility size or process capacity, new facility configuration or geometry, new construction methods, etc.

18. Workhours and Accident Data

Please record total craft workhours, the number of recordable injuries, and the number of lost workday cases separately in the spaces provided below.

- Use the U.S. Department of Labor's OSHA definitions for recordable injuries and lost workday cases among this project's craft workers. *If you do not track in accordance with these definitions,* write "UNK" in the recordable injuries and lost workday cases columns.
- Write "UNK" in any space for which the information is unavailable or incomplete.
- A consolidated project OSHA 200 log is the best source for the data.

Total Craft Workhours	OSHA Recordable Injuries	OSHA Lost Workday Cases

18a. How many of the craft workhours reported in the table above were "overtime" (or "premium time")? (Write "UNK" in the blank if you don't have this information)

_______________ hrs

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Safety Practices

Safety includes the site-specific program and efforts to create a project environment and state of consciousness which embraces the concept that all accidents are preventable and that zero accidents is an obtainable goal. If this project was accident free, check "NA" as appropriate for questions 27 through 30.

	Yes	No	
19.	___	___	This project had a written site-specific safety plan.
20.	___	___	This project had a written site-specific emergency plan.
21.	___	___	This project had a site safety supervisor.
22.	___	___	The site safety supervisor for this project was full-time.
23.	___	___	This project had a written safety incentive program for hourly craft employees.
24.	___	___	Toolbox safety meetings were required.
25.	___	___	This project required prehire substance abuse testing of contractor employees.
26.	___	___	Contractor employees were randomly screened for alcohol and drugs.

27. Substance abuse tests were conducted after an accident:
    _____Always _____Sometimes _____Seldom _____Never _____NA

28. Accidents were formally investigated:
    _____Always _____Sometimes _____Seldom _____Never _____NA

29. Near-misses were formally investigated:
    _____Always _____Sometimes _____Seldom _____Never _____NA

30. Senior management reviewed accidents:
    _____Always _____Sometimes _____Seldom _____Never _____NA

31. Safety was a high priority topic at all pre-construction and construction meetings:
    _____Always _____Sometimes _____Seldom _____Never

32. Safety records were a criterion for contractor/subcontractor selection:
    _____Always _____Sometimes _____Seldom _____Never

33. Pre-task planning for safety was conducted by contractor foremen:
    _____Always _____Sometimes _____Seldom _____Never

34. Jobsite-specific orientation was conducted for new contractor and subcontractor employees:
    _____Always _____Sometimes _____Seldom _____Never

Team Building Practices

Team Building is a process that brings together a diverse group of project participants and seeks to resolve differences, remove roadblocks and proactively build and develop the group into an aligned, focused and motivated work team that strives for a common mission and for shared goals, objectives and priorities.

36. Was a team building process used for this project? Yes _____ No _____

If yes, answer questions 36a - 36h. If no, go to question 37.

	Yes	No	
36a.	___	___	Was an independent consultant used to facilitate the team building process?
36b.	___	___	Was a team-building retreat held early in the life of the project?
36c.	___	___	Did this project have a documented team-building implementation plan?
36d.	___	___	Were objectives of the team building process documented and clearly defined?

36e. Were team building meetings held among team members throughout the project?

_____Regularly _____Sometimes _____Seldom _____Never

36f. Were follow-up sessions held to integrate new team members and reinforce concepts?

_____Regularly _____Sometimes _____Seldom _____Never

36g. Please indicate the project phases in which team building was used. (Check all that apply)

___ Pre-Project Planning
___ Design
___ Procurement
___ Construction
___ Startup

36h. Please indicate the parties involved in the team building process. (Check all that apply)

___ Owner
___ Designer(s)
___ Contractor(s)
___ Major Suppliers
___ Subcontractor(s)
___ Construction Manager
___ Other. If other, please specify ______________________________

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Constructability Practices

Constructability is the optimum use of construction knowledge and experience in planning, design, procurement, and field operations to achieve overall project objectives. Constructability is achieved through the effective and timely integration of construction input into planning and design as well as field operations.

37. Was Constructability implemented on this project? Yes_____ No_____

If yes, please respond to the following statements (37a-37l). If no, go to question 38.

37a. Which of the following best describes the constructability program designation for this project?

____ No designation
____ Part of standard construction management activities
____ Part of another program, such as Quality or only identified on a project level
____ Recognized on a corporate level, but may be part of another program
____ Stand-alone program on same level as Quality or Safety

37b. Which of the following best describes the constructability training of personnel for this project?

____ None
____ If any occurs, done as on-the-job training
____ Awareness seminar(s)
____ Part of standard orientation
____ Part of standard orientation; deeply ingrained in corporate culture

37c. Which of the following best describes the role of the constructability coordinator for this project?

____ Coordinator not identified
____ Part-time if identified; very limited responsibility
____ Informal full- or part-time position; responsibilities vary
____ Formal full- or part-time position; responsibilities vary
____ Full-time position; plays major project role

37d. Which of the following best describes the constructability program documentation for this project?

____ None; CII documents may be available
____ Limited reference in any manual; CII documents may be distributed or referenced
____ Project-level constructability documents exist; may be included in other corporate documents
____ Project constructability manual is available
____ Project constructability manual is thorough, widely distributed, and periodically updated

37e. Which of the following best describes the nature of project-level efforts and inputs concerning constructability for this project?

____ None
____ Reactive approach, constrained by review mentality, poor understanding of proactive benefit
____ Aware of major benefits, proactive approach
____ Proactive approach; routinely consult lessons learned
____ Aggressive, proactive approach from beginning of project; routinely consult lessons learned

37f. Which of the following best describes the implementation of constructability concepts on this project?

____ Very little concept implementation
____ Some concepts used periodically; often considered too late to be of use
____ Selected concepts applied regularly; full use, timeliness of input varies
____ All concepts consistently considered; timely implementation of feasible concepts
____ All concepts consistently considered, continuously evaluated, aggressively implemented

37g. Constructability ideas on this project were collected by: (Check as many as apply)

____ Suggestion Box
____ Interviews
____ Review Meetings
____ Questionnaire
____ Other Methods ____________________
____ Not Collected

37h. To what extent was a computerized constructability database utilized for this project?

____ None
____ Minimal
____ Moderate
____ Extensive

37i. Please characterize the frequency of the constructability reviews and discussions for this project.

____ Once a Week
____ Once a Month
____ Once every 3 Months
____ Once every 6 Months
____ Once a Year or Less Frequent

37j. Please indicate the time period of the first meeting that deliberately and explicitly focused on constructability. Place a check below the appropriate period.

Pre-Project Planning			Detail Design/Procurement			Construction		
Early	Middle	Late	Early	Middle	Late	Early	Middle	Late

Yes No

37k. ___ ___ Constructability was an element addressed in this project's formal written execution plan.

37l. ___ ___ Were the actual cost savings (identified cost savings less implementation cost) due to the constructability program tracked on this project?

If yes, please list? $ ______________

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Pre-Project Planning Practices

Pre-Project Planning involves the process of developing sufficient strategic information with which owners can address risk and decide to commit resources to maximize the chance for a successful project. Pre-project planning is often perceived as synonymous with front-end loading, front-end planning, feasibility analysis, and conceptual planning. Please respond to the following statements using the definition provided below the scale for guidance (Questions 38a - 38d are for Contractors only.)

38e. Place a mark on the scale below that best describes the composition of the pre-project planning team.

Excellent — Poor

- **Excellent** - Highly skilled and experienced members with authority; representation from business, project management, technical disciplines, and operations; able to respond to both business and project objectives.
- **Poor** - Members with a poor combination of skill or experience that lack authority; insufficient representation from business, project management, technical disciplines, and operations; unable to respond to both business and project objectives.

38f. Place a mark on the scale below that best describes the technology evaluation for this project.

Excellent — Poor

- **Excellent** - Thorough and detailed identification and analysis of existing and emerging technologies for feasibility and compatibility with corporate business and operations objectives. Scale-up problems and hands-on process experience were considered.
- **Poor** - Poor or no technology evaluation.

38g. Place a mark on the scale below that best describes the evaluation of alternate siting locations.

Excellent — Poor

- **Excellent** - Thorough and detailed assessment of relative strengths and weaknesses of alternate locations to meet owner requirements.
- **Poor** - Poor or no evaluation of alternate siting locations.

38h. Place a mark on the scale below that best describes the risk analysis performed for project alternatives.

Excellent — Poor

- **Excellent** - Risks associated with the selected project alternatives were identified and analyzed. These analyses included financial/business, regulatory, project, and operational risk categories in order to minimize the impacts of risks on project success.
- **Poor** - Poor or no risk analysis performed for project alternatives.

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The Project Definition Rating Index (PDRI) identifies and describes critical elements in a scope definition package and allows a project team to predict factors impacting project risk. It is intended to evaluate the completeness of project scope definition prior to consideration for authorization.

39. Was the Project Definition Rating Index (PDRI) utilized on this project? _____ yes _____ no

If yes, indicate the score received just prior to total project budget authorization. ________
Please attach a copy of the PDRI scoresheet and proceed to question 40.

If no, please complete the following matrix using the appropriate definition levels given below. Definition is provided for each of the pre-project planning elements on pages 4 through 11 of the glossary of terms. Indicate how well defined each element was prior to the total project budget authorization by placing a check below the appropriate definition level. Elements with definition levels 2 through 4 darkened should be answered as "yes/no" questions. Indicate *definition level 1* for "yes" or *definition level 5 for* "no" to indicate if the elements either existed or did not exist within the project definition package at authorization.

Definition Levels:

1 - Complete definition	3 - Some deficiencies	5 - Incomplete or poor definition
2 - Minor deficiencies	4 - Major deficiencies	N/A - Not applicable

Note: If the project on which you are reporting is a building or infrastructure project, some of the following elements may not apply to your project. Please place a check in the "N/A" column to indicate "not applicable" if any element does not apply to your project.

	Definition Level at Authorization					
	Complete ←				→ Poor	
Technical Elements	1	2	3	4	5	N/A
a. Process Flow Sheets						
b. Site Location						
c. P&ID's						
d. Heat & Material Balances						
e. Environmental Assessment						
f. Utility Sources With Supply Conditions						
g. Mechanical Equipment List						
h. Specifications - Process/Mechanical						
i. Plot Plan						
j. Equipment Status						
Business Elements						
k. Products						
l. Capacities						
m. Technology						
n. Processes						
o. Site Characteristics Available vs. Req'rd						
p. Market Strategy						
q. Project Objectives Statement						
r. Project Strategy						
s. Project Design Criteria						
t. Reliability Philosophy						
Execution Approach Elements						
u. Identify Long Lead/Critical Equip. & Matl's						
v. Project Control Requirements						
w. Engineering/Construction Plan & Approach						

Design/Information Technology Practices

Please place a check to indicate the extent to which each design/information technology application listed below was used on this project. See the legend below for definition of the "Use Levels." If you believe that an application could not have been appropriately applied on this project check "NA."

Use Levels:

1 - Extensive Use	3 - Moderate Use	5 - No Use
2 - Much Use	4 - Little Use	N/A - Not applicable

40a. Was an ***integrated database*** utilized on this project? Yes ____ No ____

If yes, please indicate the extent that each of the following shared data within the integrated database. If other applications were used, please list them. If no, proceed to question 40b.

	Use Levels					
	Extensive Use ←→ No Use					
Applications	1	2	3	4	5	N/A
Facility planning						
Design / Engineering						
3D CAD model						
Procurement / Suppliers						
Material management						
Construction operations / Project controls						
Facility operations						
Administrative / Accounting						

40b. Was ***electronic data interchange (EDI)*** utilized on this project? Yes ____ No ____

If yes, please indicate the extent to which each of the following document types were transmitted using EDI. If other applications were used, please list them. If no, proceed to question 40c.

	Use Levels					
	Extensive Use ←→ No Use					
Applications	1	2	3	4	5	N/A
Purchase orders						
Material releases						
Design specifications						
Inspection reports						
Fund transfers						

40c. Was *3D CAD modeling* utilized on this project? Yes ____ No ____

If yes, please indicate the extent to which a 3D CAD model was used for each of the following applications. If other applications were used, please list them. If no, proceed to question 40d.

	Use Levels					
	Extensive Use ←				→ No Use	
Applications	1	2	3	4	5	N/A
Define / communicate project scope						
Perform plant walk-throughs (Replacing plastic models)						
Perform plant operability / maintainability analyses						
Perform constructability reviews with design team						
Use as reference during project / coordination meetings						
Work breakdown and estimating						
Plan rigging or crane operations						
Check installation clearances / access						
Plan and sequence construction activities						
Construction simulation / visualization						
Survey control and construction layout						
Material management, tracking, scheduling						
Exchange information with vendors / fabricators						
Track construction progress						
Visualize project details or design changes						
Record "As-Built" conditions						
Train construction personnel						
Safety assessment / training						
Plan temporary structures (formwork, scaffolding, etc.)						
Operation / Maintenance training						
Turn-over design documents to the project owner						
Start-up planning						

40d. Was *bar coding* utilized on this project? Yes ____ No ____

If yes, please indicate the extent to which bar coding was used for each of the following applications. If other application were used, please list them. If no, proceed to question 41.

	Use Levels					
	Extensive Use ←				→ No Use	
Applications	1	2	3	4	5	N/A
Document control						
Materials management						
Equipment maintenance						
Small tool / consumable material control						
Payroll / Timekeeping						

Project Change Management Practices

Change Management focuses on recommendations concerning the management and control of both *scope changes* and *project development changes*.

Yes No

41a. ___ ___ Was a formal documented change management process, familiar to the principal project participants used to actively manage changes on this project?

41b. ___ ___ Was a baseline project scope established early in the project and frozen with changes managed against this base?

41c. ___ ___ Were design "freezes" established and communicated once designs were complete?

41d. ___ ___ Were areas susceptible to change identified and evaluated for risk during review of the project design basis?

41e. ___ ___ Were changes on this project evaluated against the business drivers and success criteria for the project?

41f. ___ ___ Were all changes required to go through a formal change justification procedure?

41g. ___ ___ Was authorization for change mandatory before implementation?

41h. ___ ___ Was a system in place to ensure timely communication of change information to the proper disciplines and project participants?

41i. ___ ___ Did project personnel take proactive measures to promptly settle, authorize, and execute change orders on this project?

41j. ___ ___ Did the project contract address criteria for classifying change, personnel authorized to request and approve change, and the basis for adjusting the contract?

41k. ___ ___ Was a tolerance level for changes established and communicated to all project participants?

41l. ___ ___ Were all changes processed through one owner representative?

41m. ___ ___ At project close-out, was an evaluation made of changes and their impact on the project cost and schedule performance for future use as lessons learned?

41n. ___ ___ Was the project organized in a Work Breakdown Structure (WBS) format and quantities assigned to each WBS for control purposes prior to total project budget authorization?

The questionnaire is complete. Thank you for your participation.

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Glossary of Terms

Acceptance Testing. Facility capacity testing at the time a project is expected to reach design capacity. The timing in which this takes place varies by type of facility. Acceptance testing may occur shortly after start-up of a process unit, 6 to 12 months on building or mechanical trains, or 2 to 3 years for a paper mill.

Alliance Partner. A participant in a long-term association with a non-affiliated organization, used to further the common interests of the members. The continued association is based upon mutual trust and the satisfactory performance of each participant, and the alliance as a whole, rather than a pure contractual obligation.

Bar Coding. The use of automatic identification technology by labeling, identifying, and controlling items, materials, and equipment through the use of bar codes. A bar code can be defined as a self contained message with information encoded in the widths of bars and spaces in a printed pattern.

Change. A change is any event which results in a modification of the project work, schedule or cost. Owners and designers frequently initiate changes during design development to reflect changes in project scope or preferences for equipment and materials other than those originally specified. Contractors often initiate changes when interferences are encountered, when designs are found to be not constructable, or other design errors are found.

Constructability. The optimum use of construction knowledge and experience in planning, design, procurement and field operations to achieve overall project objectives. Constructability is achieved through the effective and timely integration of construction input into planning and design as well as field operations.

Contingency. All costs in contingency accounts including but not limited to normal contingency, allowances, reserves, indirect costs for schedule contingency, escalation, etc.

Cost of Land. The cost of land includes the purchase price of the land obtained for project use. It does not include the cost of preparing the land for use, such as soil remediation, demolition of existing structures, site preparation, etc.

Cost of Quality Management. The sum of those costs associated with quality deviation prevention and appraisal activities. Examples include:

- Quality System/Program Development
- Personnel Qualification Testing
- Formal Design Check/Review
- On/Off-Site Inspection

Direct Cost of Field Rework. The sum of those costs associated with actual performance of tasks involved in rework. Examples include:

- labor
- materials
- equipment
- supervisory personnel
- associated overhead cost

Electronic Data Interchange (EDI). EDI is a technology that permits the direct computer-to-computer exchange of data in a standard format. Data is transmitted in a standard industry format, checked for error, and imported directly into the receiving computer system without re-keying.

Integrated Database. An integrated database is a concept of organizing, storing, and managing all electronic data relating to a project in such a fashion that data is entered and stored once and then accessed and utilized by multiple users and applications. The users may include those involved with facility planning, design, procurement, construction, plant operations, and suppliers.

Mechanical Completion. The point in time when a plant is capable of being operated although some trim, insulation, and painting may still be needed. This occurs after completion of precommissioning. In some industries, mechanical completion may have the same general meaning as beneficial occupancy.

Pre-Project Planning. The process of developing sufficient strategic information with which owners can address risk and decide to commit resources to maximize the chance for a successful project. Pre-project planning includes putting together the project team, selecting technology, selecting project site, developing project scope, and developing project alternatives. Pre-project planning is often perceived as synonymous with front-end loading, front-end planning, feasibility analysis, programming, and conceptual planning.

Project Development Changes. Changes required to execute the original scope of work or obtain original process basis. Examples include:

- Unforeseen site conditions that require a change in design / construction methods
- Changes required due to errors and ommisions
- Acceleration
- Change in owner preferences
- Additional equipment or processes required to obtain original planned throughput
- Operability or maintainability changes

Project Change Management. Practices related to the management and control of both scope changes and project changes.

P&IDs (Piping and Instrumentation Diagrams). Schematic diagrams which show the layout and relationship of piping and instrumentation.

Scope Changes. Changes in the base scope of work or process basis. Examples include:

- Feedstock change
- Changed site location
- Changed throughput
- Addition of unrelated scope

Team Building. A project focused process that brings together key stakeholders in the project outcome, usually representatives of the project owner, designer, contractor, and/or major suppliers. It seeks to resolve differences, remove roadblocks, and build and develop trust and commitment, a common mission statement, shared goals, interdependence, accountability among team members and problem solving skill.

Total Actual Project Cost. The total actual project cost amount should include all actual project costs from pre-project planning through startup or to a "ready for use" condition, excluding the cost of land. Remediation costs and demolition costs should be included.

Total Project Budget. The total project budget amount should include all planned expenses from pre-project planning through startup or to a "ready for use" condition, excluding the cost of land. Remediation costs and demolition costs should be included. The total project budget should correspond to the estimate at the start of detail design including contingency.

3D CAD modeling. Computer aided drafting system that provides three dimensional views for checking physical interferences in addition to providing two and three dimensional drafting capabilities.

Pre-Project Planning Element Definitions

a. **Process Flow Sheets** - Drawings that provide the process description of the unit. Evaluation criteria should include:
- Major equipment items
- Flow of materials to and from the major equipment items
- Primary control loops for the major equipment items
- Sufficient information to allow sizing of all process lines

b. **Site Location** - Has the geographical location of the proposed project been defined? This involves an assessment of the relative strengths and weaknesses of alternate site locations. A site that meets owner requirements and maximizes benefits for the owner company should be selected. Evaluation of sites may address issues relative to different types of sites (i.e. global country, local, "inside the fence," or "inside the building"). This decision should consider the long term needs of the owner company (CII 1995). The selection criteria should include items such as:
- General geographic location
  - Access to the targeted market area
  - Near sources of raw materials
  - Local availability and cost of skilled labor (example construction, operation, etc.)
  - Available utilities
  - Existing facilities
- Land availability and cost
- Access (example road, rail, marine, air, etc.)
- Construction access and feasibility
- Political constraints
- Legal constraints
- Regulatory constraints
- Financing requirements
- Social issues
- Weather
- Climate

c. **P&ID's (Piping and Instrumentation Diagrams)** - These are often referred to by different companies as:
- EFD's - Engineering Flow Diagrams
- MFD's - Mechanical Flow Diagrams
- PMCD's - Process and Mechanical Control Diagrams

In general, P&ID's are considered to be a critical element within the scope definition package of an industrial project. Since incomplete information on P&ID's is frequently identified as a source of project escalation, it is important to understand their level of completeness. It often requires several iterations, or passes, to obtain all of the necessary information from each discipline specialist. During each iteration, additional information is added to the P&ID's. Thus, it is unlikely for P&ID's to be completely defined in a project's scope definition package.

It is important, however, to assess which iterations have occurred to date as well as the items that have been defined or are currently being developed.

CII Benchmarking and Metrics
Completed Project Data: Owners (Version 2.0)

The following list can be used as an aid in evaluating the current state of development of the P&ID's.

- Equipment
  - Number of items
  - Name of items
  - Type or configuration
  - Spare item requirements
  - Data on and sizing of equipment/drive mechanisms
  - Horsepower/energy consumption
  - Nozzle sizes
  - Insulation/tracing
  - Vendor data (if vendor designed)
  - Seal arrangements
  - Packaged equipment details

- Piping
  - Line sizes
  - Line specifications
  - Flow arrows and continuations
  - Secondary flows
  - Specification breaks
  - Insulation and tracing
  - Sample points
  - Reducers
  - Vent and sewer designations
  - Line numbers
  - Tie-ins designated
  - Any expansion and flexible joints shown
  - Piping design details added

- Valves
  - Process needed valves
  - Valves needed for maintenance
  - Bypasses, blocks, and bleeds
  - Drains, vents, freeze protection, etc.
  - Type of valve designated
  - Non-lined sized valves indicated
  - Control valves sized
  - Miscellaneous designated valves added
  - Valve tags added
  - Valve design details added

- Piping Specialty Items
  - Identification of items
  - Numbering of items
  - Specialty item design details

- Utilities
  - Elements, loops, and functions
  - Primary elements
  - Local panel or control house location
  - Control panel or CRT location
  - Computer inputs and outputs
  - Process steam traps
  - Hardwired interlocks
  - Motor controls
  - Type of primary elements
  - Instrument numbers
  - Uniform logic control details
  - Indicator lights
  - Instrumentation design details

- Safety Systems
  - Process Safety Management Hazard Analysis review
  - Key process relief valves
  - Remaining relief valves
  - Failure mode of control valves
  - Car sealed valves
  - Relief valve sizes (instrumentation/process check)
  - Relief system line sizes
  - System design details

- Special Notations
  - Identification of sloped lines
  - Barometric legs (seals)
  - Critical elevations and dimensions
  - Vendor or designer supplied notes
  - Critical locations (valves, etc.)
  - Notes on venting or draining
  - Vessel trim notes
  - Startup and shutdown notes
  - Design detail notes

d. Heat and Material Balances - Heat balances are tables of heat input and output for major equipment items (including all heat exchangers) within the unit. Material balances are tables of material input and output for all equipment items within the unit. The documentation of these balances should include:

- Special heat balance tables for reaction systems
- Information on the conditions (example temperature and pressure)
- Volumetric amount (GPM, ACFM, etc.)

e. Environmental Assessment - Evaluation of the site by characteristics such as:

- Location in an EPA air quality non-compliance zone
- Location in a wet lands area
- Environmental permits now in force
- Location of nearest residential area
- Ground water monitoring in place
- Containment requirements
- Existing environmental problems with the site
- Past/present use of site

f. Utility Sources with Supply Conditions - Has a list been made identifying availability/non-availability of site utilities needed to operate the unit with supply conditions of temperature, pressure, and quality? This should include items such as:

- Potable water
- Drinking water
- Cooling water
- Fire water
- Sewers
- Electricity (voltage levels)
- Instrument air
- Plant air
- Gases
- Steam
- Condensate

g. Mechanical Equipment List - The mechanical equipment list should identify all mechanical equipment by tag number, in summary format, to support the project. The list should define items such as:

- Existing sources
  - Modified
  - Relocated
  - Dismantled
  - Rerated
- New Sources
  - Purchase new
  - Purchase used
- Relative sizes
- Weights
- Location
- Capacities
- Materials
- Power requirements
- Flow diagrams
- Design temperature and pressure
- Insulation and painting requirements
- Equipment ladders and platforms

h. **Specifications - Process/Mechanical** - General specifications for the design, performance, manufacturing, material, and code requirements should include items such as:

- Classes of equipment (example pumps, exchangers, vessels, etc.)
- Process pipe heating
  - Process
  - Freeze
  - Jacketed
- Process pipe cooling
  - Jacketed
  - Traced
- Piping
- Protective coating
- Insulation
- Valves
- Bolts/gaskets

i. **Plot Plan** - The plot plan will show the location of new work in relation to adjoining units. It should include items such as:

- Plant grid system with coordinates
- Unit limits
- Gates and fences
- Off-site facilities
- Tank farms
- Roads and access ways
- Roads
- Rail facilities
- Green space
- Buildings
- Major pipe racks
- Lay down areas
- Construction/fabrication areas

j. **Equipment Status** - Has the equipment been defined, inquired, bid tabbed, or purchased? This includes all engineered equipment such as:

- Process
- Electrical
- Mechanical
- HVAC
- Instruments
- Specialty items
- Distributed control systems

Evaluation criteria should include:

- Equipment data sheets
- Number of items inquired
- Number of items with approved bid tabs
- Number of items purchased

k. **Products** - A list of products to be manufactured and their specifications. It should address items such as:

- Chemical composition
- Physical form
- Raw materials
- Allowable impurities
- By-products
- Wastes

l. **Capacities** - The design output of a given specification product from the unit. Capacities are usually defined as:

- On-stream factors
- Yield
- Design rate

m. **Technology** - The chemistry used to convert the raw materials supplied to the unit into the finished product. Proven technology involves least risk, while experimental technology has a potential for change. Technology can be evaluated as:

- Existing/proven
- Duplicate
- New
- Experimental

n. **Processes** - A particular, specific sequence of steps to change the raw materials into the finished product. Proven processes involve the least risk while experimental processes have a potential for change. Processes can be evaluated as:

- Existing/proven
- Duplicate
- New
- Experimental

o. **Site Characteristics Available vs. Required** - An assessment of the available vs. the required site characteristics. Evaluation criteria should include:

- Capacity
  - Utilities
  - Fire water
  - Flare systems

Cooling water
Storm water containment system
Power
Pipe racks
Waste treatment/disposal

- Type of buildings/structures
- Amenities
  Food service
  Change rooms
  Medical facilities
  Recreation facilities
  Ambulatory access
- Product shipping facilities
- Material receiving facilities
- Material storage facilities
- Product storage facilities
- Security

p. **Market Strategy** - Has a market strategy been developed and clearly communicated? It must identify the driving forces (other than safety) for the project and specify what is most important from the viewpoint of the business group. It should address items such as:

- Cost
- Schedule
- Quality

q. **Project Objectives Statement** - This is a mission statement that defines the project objectives and priorities for meeting business objectives. It is important to obtain total agreement from the entire project team regarding these objectives and priorities to ensure alignment.

r. **Project Strategy** - Has a project strategy been defined that supports the market strategy in relation to the following items:

- Cost
- Schedule
- Quality

s. **Project Design Criteria** - The requirements and guidelines which govern the design of the project. Evaluation criteria should include:

- Level of design detail required
- Climatic data
- Codes and standards
  National
  Local
- Utilization of engineering standards
  Owner's
  Mixed
  Contractor's

t. **Reliability Philosophy** - A list of the general design principles to be considered to achieve dependable operating performance from the unit. Evaluation criteria should include:

- Justification for spare equipment
- Control, alarm, and safety systems redundancy
- Extent of providing surge and intermediate storage capacity to permit independent shut down of portions of the plant
- Mechanical/structural integrity of components (metallurgy, seals, types of couplings, bearing selection, etc.)

u. **Identify Long Lead / Critical Equipment and Materials** - Identify engineered equipment and material items with lead times that will impact the detailed engineering for receipt of vendor information or impact the construction schedule with long delivery times.

v. **Project Control Requirements** - Has a method for measuring and reporting progress been established? Evaluation criteria should include:

Change management procedures
Cost control procedures
Schedule / percent complete control procedures
Cash flow projections
Report requirements

w. **Engineering / Construction Plan & Approach** - This is a documented plan identifying the methodology to be used in engineering and constructing the project. It should include items such as:

Responsibility matrix
Contracting strategies (e.g. lump sum, cost-plus, etc.)
Subcontracting strategy
Work week plan / schedule
Organizational structure
Work Breakdown Structure
Construction sequencing of events
Safety requirements / program
Identification of critical lifts and their potential impact on operating units
QA / QC plan

Appendix B: Best Practice Use Survey Responses

This appendix provides information regarding the responses to each of the best practice questions utilized in this study. The question numbers correspond to the survey instrument provided in Appendix A. The response to questions 38e, 38f, 38g, and 38h for pre-project planning is of a continuous nature. Distribution statistics are provided for the response to each of these questions. The statistics include the mean, median, standard deviation, and quartile values. The "high use" and "low use" designation for each of these items is based on the median value. All projects with a response value greater than the median are categorized as "high use", while those with a value equal to or less than the median value are categorized as "low use."

The response to all questions other than 38e, 38f, 38g, and 38h is of a categorical nature. The percent of responses for each category is given for each question. The criteria utilized to determine "high use" and "low use" for each of these questions is indicated by the use of shading. In all cases, the selection of response categories to represent "high use" and "low use" was based on an attempt to place, as near as possible, an equal number of observations in "high use" and "low use" categories.

Pre-Project Planning Practice Use

38e. Describe the composition of the Pre-Project Planning team.

38f. Describe the technology evaluation for this project.

38g. Describe the evaluation of alternate siting locations.

38h. Describe the risk analysis performed for project alternatives.

Poor (0) through Excellent (10)

	Items			
	38e	38f	38g	38h
100%	10.0	10.0	10.0	10.0
75%	8.5	9.0	10.0	8.0
50%	7.5	8.0	8.5	7.0
25%	6.5	7.0	6.5	5.0
0%	2.0	4.0	0.5	0.5
Mean	7.4	7.8	7.7	6.4
SD	1.9	1.4	2.5	2.1
n	55	55	55	55

	Mean/n			
Level	38e	38f	38g	38h
High	9.0 / 25	9.1 / 23	9.5 / 30	8.2 / 26
Low	6.0 / 30	6.9 / 32	5.5 / 25	4.7 / 29

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Pre-Project Planning Practice Use

	Definition Level at Authorization					
	Complete ◄──►				Poor	
Technical Elements	1	2	3	4	5	N/A
a. Process Flow Sheets	44%	21%	17%	2%	2%	14%
b. Site Location	84%				0%	16%
c. P&ID's	25%	27%	27%	4%	9%	8%
d. Heat & Material Balances	31%	23%	9%	4%	6%	27%
e. Environmental Assessment	58%	13%	17%	6%	0%	6%
f. Utility Sources With Supply Conditions	51%	26%	15%	6%	0%	2%
g. Mechanical Equipment List	40%	40%	18%	2%	0%	0%
h. Specifications - Process/Mechanical	34%	30%	21%	11%	2%	2%
i. Plot Plan	46%	33%	9%	4%	0%	8%
j. Equipment Status	25%	28%	30%	4%	4%	9%
Business Elements						
k. Products	81%	6%	4%	0%	0%	9%
l. Capacities	77%	11%	4%	0%	2%	6%
m. Technology	62%	26%	8%	0%	2%	2%
n. Processes	66%	19%	9%	0%	4%	2%
o. Site Characteristics Available vs. Req'rd	86%				8%	6%
p. Market Strategy	45%	21%	9%	0%	2%	23%
q. Project Objectives Statement	94%				4%	2%
r. Project Strategy	64%	23%	9%	2%	2%	0%
s. Project Design Criteria	45%	38%	9%	8%	0%	0%
t. Reliability Philosophy	29%	29%	31%	2%	7%	2%
Execution Approach Elements						
u. Identify Long Lead/Critical Equip. & Matl's	60%	34%	6%	0%	0%	0%
v. Project Control Requirements	30%	43%	17%	8%	2%	0%
w. Engineering/Construction Plan & Approach	42%	26%	28%	2%	0%	2%

▒ = High Use Level

Project Change Management Practice Use

Question	Yes	No
41a. Was a formal documented change management process, familiar to the principal project participants used to actively manage changes on this project?	91%	9%
41b. Was a baseline project scope established early in the project and frozen with changes managed against this base?	93%	7%
41c. Were design "freezes" established and communicated once designs were complete?	82%	18%
41d. Were areas susceptible to change identified and evaluated for risk during review of the project design basis?	64%	36%
41e. Were changes on this project evaluated against the business drivers and success criteria for the project?	84%	16%
41f. Were all changes required to go through a formal change justification procedure?	73%	27%
41g. Was authorization for change mandatory before implementation?	84%	16%
41h. Was a system in place to ensure timely communication of change information to the proper disciplines and project participants?	91%	9%
41i. Did project personnel take proactive measures to promptly settle, authorize, and execute change orders on this project?	91%	9%
41j. Did the project contract address criteria for classifying change, personnel authorized to request and approve change, and the basis for adjusting the contract?	72%	28%
41k. Was a tolerance level for changes established and communicated to all project participants?	73%	27%
41l. Were all changes processed through one owner representative?	93%	7%
41m. At project close-out, was an evaluation made of changes and their impact on the project cost and schedule performance for future use as lessons learned?	76%	24%
41n. Was the project organized in a Work Breakdown Structure (WBS) format and quantities assigned to each WBS for control purposes prior to total project budget authorization?	51%	49%

[shaded box] = Yes/High Use Level

Team Building Practice Use

Question	Yes	No
36, Was a team building process used for this project?	78%	22%
36a, Was an independent consultant used to facilitate the team building process?	29%	71%
36b, Was a team-building retreat held early in the life of the project?	44%	56%
36c, Did this project have a documented team-building implementation plan?	38%	62%
36d, Were objectives of the team building process documented and clearly defined?	56%	44%

Question	Regularly	Sometimes	Seldom	Never
36e, Were team building meetings held among team members throughout the project?	22%	38%	13%	27%
36f, Were follow-up sessions held to integrate new team members and reinforce concepts?	11%	36%	18%	35%

36g, Please indicate the project phases in which team building was used. Check all that apply. High Use ; $\Sigma 36g > 0.50$

Pre-Project Planning	Design	Procurement	Construction	Startup
62%	66%	35%	60%	33%

36h, Please indicate the parties involved in the team building process. Check all that apply. High Use: $\Sigma 36h > 0.50$

Owner	Designer	Contractors	Major Suppliers	Subcontractors	Constr. Mngr.	Other
78%	74%	67%	24%	15%	62%	16%

[shaded box] = Yes/High Use Level

Constructability Practice Use

Question	Yes	No
37. Was Constructability implemented on this project?	89%	11%

37a. Which of the following best describes the constructability program designation for this project?	
18%	No designation
69%	Part of standard construction management activities
5%	Part of another program, such as Quality or only identified on a project level
2%	Recognized on a corporate level, but may be part of another program
6%	Stand-alone program on same level as Quality or Safety

37b. Which of the following best describes the constructability training of personnel for this project?	
20%	None
40%	If any occurs, done as on-the-job training
9%	Awareness seminar(s)
22%	Part of standard orientation
9%	Part of standard orientation; deeply ingrained in corporate culture

[ ] = Yes/High Use Level

Continued next page

Constructability Practice Use (Cont.)

37c. Which of the following best describes the role of the constructability coordinator for this project?	
31%	Coordinator not identified
11%	Part-time if identified; very limited responsibility
29%	Informal full- or part-time position; responsibilities vary
16%	Formal full- or part-time position; responsibilities vary
13%	Full-time position; plays major project role

37d. Which of the following best describes the constructability program documentation for this project?	
36%	None; CII documents may be available
24%	Limited reference in any manual; CII documents may be distributed or referenced
27%	Project-level constructability documents exist; may be included in other corporate documents
9%	Project constructability manual is available
4%	Project constructability manual is thorough, widely distributed, and periodically updated

37e. Which of the following best describes the nature of project-level efforts and inputs concerning constructability for this project?	
11%	None
9%	Reactive approach, constrained by review mentality, poor understanding of proactive benefit
31%	Aware of major benefits, proactive approach
25%	Proactive approach; routinely consult lessons learned
24%	Aggressive, proactive approach from beginning of project; routinely consult lessons learned

Constructability Practice Use (Cont.)

37f. Which of the following best describes the implementation of constructability concepts on this project?	
14%	Very little concept implementation
13%	Some concepts used periodically; often considered too late to be of use
40%	Selected concepts applied regularly; full use, timeliness of input varies
22%	All concepts consistently considered; timely implementation of feasible concepts
11%	All concepts consistently considered, continuously evaluated, aggressively implemented

37g. Constructability ideas on this project were collected by: Check as many as apply. High Use: $\Sigma 37g>0.50$.	
6%	Suggestion Box
2%	Interviews
82%	Review Meetings
2%	Questionnaire
13%	Other Methods

37h. To what extent was a computerized constructability database utilized for this project?	
78%	None
13%	Minimal
7%	Moderate
2%	Extensive

[shaded box] = Yes/High Use Level

Constructability Practice Use (Cont.)

37i. Please characterize the frequency of the constructability reviews and discussions for this project.	
38%	Once a Week
40%	Once a Month
4%	Once every 3 Months
4%	Once every 6 Months
14%	Once a Year or Less Frequent

37j. Please indicate the time period of the first meeting that deliberately and explicitly focused on constructability.	
24%	Early Pre-Project Planning
27%	Middle Pre-Project Planning
9%	Late Pre-Project Planning
18%	Early Detail Design/Procurement
4%	Middle Detail Design/Procurement
5%	Late Detail Design/Procurement
2%	Early Construction
0%	Middle Construction
0%	Late Construction

[shaded box] = Yes/High Use Level

Constructability Practice Use (Cont.)

Question	Yes	No
37k. Constructability was an element addressed in this project's formal written execution plan.	51%	49%
37l. Were the actual cost savings (identified cost savings less implementation cost) due to the constructability program tracked on this project?	12%	88%

■ = Yes/High Use Level

Appendix C: Practice Use Item Assessment

Pre-Project Planning

	Use Level						
	High		Low				
Question	n	Project Cost Growth Mean	n	Project Cost Growth Mean	R^2	F	Prob > F
38e.	25	0.026	28	0.146	0.152	9.12	0.004
38f.	22	0.037	31	0.127	0.084	4.68	0.035
38g.	28	0.042	25	0.142	0.106	6.03	0.017
38h.	25	0.035	28	0.138	0.114	6.58	0.013
39a.	39	0.056	11	0.167	0.107	5.78	0.020
39b.	49	0.082	0	-	-	-	-
39c.	29	0.044	21	0.157	0.128	7.02	0.010
39d.	40	0.071	10	0.168	0.061	3.13	0.083
39e.	32	0.068	19	0.129	0.036	1.83	0.181
39f.	27	0.082	24	0.092	0.003	0.15	0.700
39g.	21	0.071	30	0.104	0.011	0.54	0.467
39h.	33	0.066	18	0.134	0.043	2.22	0.142
39i.	27	0.043	23	0.124	0.082	4.28	0.043
39j.	32	0.063	19	0.136	0.052	2.69	0.107
39k.	46	0.078	5	0.207	0.061	3.18	0.080
39l.	42	0.081	9	0.135	0.017	0.87	0.356
39m.	33	0.042	18	0.179	0.179	10.66	0.002
39n.	34	0.041	17	0.189	0.202	12.35	0.000
39o.	44	0.064	4	0.248	0.126	6.66	0.013
39p.	36	0.082	15	0.111	0.007	0.37	0.544
39q.	47	0.079	2	0.336	0.103	5.43	0.024
39r.	33	0.056	18	0.153	0.088	4.74	0.034
39s.	23	0.056	28	0.119	0.040	2.06	0.157
39t.	31	0.059	19	0.126	0.047	2.36	0.130
39u.	31	0.063	20	0.133	0.048	2.49	0.120
39v.	38	0.051	13	0.205	0.186	11.23	0.001
39w.	35	0.092	16	0.086	0.000	0.01	0.905

Project Change Management

	Use Level						
	Yes		No				
Question	n	Project Cost Growth Mean	n	Project Cost Growth Mean	R^2	F	Prob > F
41a.	48	0.082	5	0.158	0.021	1.10	0.299
41b.	50	0.079	3	0.265	0.079	4.38	0.041
41c.	44	0.086	9	0.107	0.003	0.13	0.717
41d.	35	0.066	18	0.134	0.044	2.34	0.132
41e.	45	0.083	8	0.125	0.010	0.50	0.483
41f.	40	0.046	13	0.222	0.244	16.45	0.000
41g.	45	0.074	8	0.174	0.055	2.95	0.092
41h.	50	0.096	3	-0.025	0.034	1.79	0.187
41i.	49	0.079	4	0.222	0.061	3.32	0.074
41j.	39	0.084	13	0.084	0.002	0.10	0.755
41k.	40	0.053	13	0.200	0.170	10.42	0.002
41l.	49	0.079	4	0.214	0.054	2.91	0.094
41m.	38	0.086	13	0.117	0.008	0.39	0.535
41n.	26	0.075	27	0.103	0.008	0.42	0.520

Team Building

	Use Level						
	Yes/High		No/Low				
Question	n	Project Cost Growth Mean	n	Project Cost Growth Mean	R^2	F	Prob > F
36a.	16	0.094	37	0.087	0.000	0.02	0.883
36b.	23	0.041	30	0.126	0.077	4.25	0.044
36c.	21	0.051	32	0.114	0.041	2.17	0.147
36d.	31	0.048	22	0.148	0.104	5.90	0.019
36e.	32	0.084	21	0.098	0.002	0.11	0.745
36f.	26	0.080	27	0.098	0.004	0.19	0.668
36g.	30	0.061	23	0.126	0.044	2.36	0.131
36h.	31	0.086	22	0.095	0.001	0.04	0.838

Constructability

	Use Level						
	Yes/High		No/Low				
Question	n	Project Cost Growth Mean	n	Project Cost Growth Mean	R^2	F	Prob > F
37a.	44	0.071	9	0.181	0.073	4.05	0.049
37b.	22	0.066	31	0.106	0.016	0.86	0.358
37c.	32	0.088	21	0.091	0.000	0.01	0.944
37d.	22	0.073	31	0.101	0.008	0.44	0.510
37e.	26	0.076	27	0.102	0.007	0.38	0.539
37f.	18	0.087	35	0.090	0.000	0.00	0.949
37g.	44	0.094	9	0.066	0.005	0.24	0.627
37h.	12	0.046	41	0.102	0.023	1.21	0.276
37i.	42	0.092	11	0.078	0.001	0.07	0.788
37j.	42	0.077	5	0.122	0.009	0.43	0.514
37k.	28	0.053	25	0.130	0.063	3.46	0.069
37l.	6	0.023	46	0.100	0.026	1.34	0.251

Percent Design Complete

	Level						
	High		Low				
	n	Project Cost Growth Mean	n	Project Cost Growth Mean	R^2	F	Prob > F
Authorization	19	0.039	18	0.125	0.083	3.17	0.084

Contract Cost Incentives

	Level						
	Yes		No				
	n	Cost Growth Mean	n	Cost Growth Mean	R^2	F	Prob > F
Design	15	0.037	26	0.130	0.102	4.41	0.042
Construction	19	0.068	32	0.105	0.013	0.67	0.418

Contract Compensation Strategy

	Level						
	Cost Reimbursable		Other				
	n	Project Cost Growth Mean	n	Project Cost Growth Mean	R^2	F	Prob > F
Design	24	0.068	18	0.136	0.056	2.39	0.130
Construction	26	0.067	25	0.116	0.025	1.24	0.271

Contract Organization Strategy

	Level						
	Yes		No				
	n	Project Cost Growth Mean	n	Project Cost Growth Mean	R^2	F	Prob > F
Design/Build	9	0.027	42	0.093	0.032	1.61	0.211

Appendix D: Best Practice Use Index Formulas and Definitions

This appendix provides information regarding the item response values for each best practice question and the formulas utilized to calculate the best practice use index values. For each best practice use question, the item response value is given for each possible response category. The formula used to calculate the best practice use index is given at the end of each best practice section. The variables in the equations correspond to the appropriate question numbers. To calculate the best practice index value for a specific project simply substitute the item response values, based on the actual response for each question, in the corresponding variable in the equation and perform the calculation. Discussion regarding the development premises for the item response values and best practice use index formulas is provided in Chapter 4.

The pre-project planning practice use index equation is somewhat different than the equation for the other best practices. The equation is grouped in two parts such that the items within question 38 and the items within question 39 have equal weight. The sum of question 38 items is multiplied by 0.125 such that the total possible score for this part of the equation is 5.0. Likewise the sum of question 39 items is multiplied by the appropriate ratio such that the total possible score for that part of the equation is 5.0.

Pre-Project Planning Practice Use

Question 38	Poor (0) through Excellent (10)
38e. Describe the composition of the Pre-Project Planning team.	0 through 10
38f. Describe the technology evaluation for this project.	0 through 10
38g. Describe the evaluation of alternate siting locations.	0 through 10
38h. Describe the risk analysis performed for project alternatives	0 through 10

Question 39	Use Levels Extensive Use ◄——► No Use					
Technical Elements	1	2	3	4	5	N/A
a. Process Flow Sheets	36	26	17	8	2	36
b. Site Location	32	[redacted]			2	32
c. P&ID's	31	23	15	8	2	31
d. Heat & Material Balances	23	17	10	5	1	23
e. Environmental Assessment	21	15	10	5	2	21
f. Utility Sources With Supply Conditions	18	12	8	4	1	18
g. Mechanical Equipment List	18	13	9	4	1	18
h. Specifications - Process/Mechanical	17	12	8	4	1	17
i. Plot Plan	17	13	8	4	1	17
j. Equipment Status	16	12	8	4	1	16

Continued next page

Pre-Project Planning Practice Use (Cont.)

Business Elements						
k, Products	56	33	22	11	1	56
l, Capacities	55	33	21	11	2	55
m, Technology	54	39	21	10	2	54
n, Processes	40	28	17	8	2	40
o, Site Characteristics Available vs. Req'rd	29	[redacted]			2	29
p, Market Strategy	26	16	10	5	2	26
q, Project Objectives Statement	25	[redacted]			2	25
r, Project Strategy	23	14	9	5	1	23
s, Project Design Criteria	22	16	11	6	3	22
t, Reliability Philosophy	20	14	9	5	1	20
Execution Approach Elements						
u, Identify Long Lead/Critical Equip. & Matl's	8	6	4	2	1	8
v, Project Control Requirements	8	6	4	2	0	8
w, Engineering/Construction Plan & Approach	11	8	5	3	1	11

Pre-Project Planning Practice Use Index = (q_38e+ q_38f+ q_38g+ q_38h)*0.125+(q_39a+ q_39b + q_39c+ q_39d+ q_39e+ q_39f+ q_39g+ q_39h+ q_39i+ q_39j+ q_39k+ q_39l+ q_39m+ q_39n+ q_39o + q_39p+ q_39q+ q_39r+ q_39s+ q_39t+ q_39u+ q_39v+ q_39w)*0.5/60.6

Project Change Management Practice Use

Question	Yes	No
41a. Was a formal documented change management process, familiar to the principal project participants used to actively manage changes on this project?	1.00	0.00
41b. Was a baseline project scope established early in the project and frozen with changes managed against this base?	1.00	0.00
41c. Were design "freezes" established and communicated once designs were complete?	1.00	0.00
41d. Were areas susceptible to change identified and evaluated for risk during review of the project design basis?	1.00	0.00
41e. Were changes on this project evaluated against the business drivers and success criteria for the project?	1.00	0.00
41f. Were all changes required to go through a formal change justification procedure?	1.00	0.00
41g. Was authorization for change mandatory before implementation?	1.00	0.00
41h. Was a system in place to ensure timely communication of change information to the proper disciplines and project participants?	1.00	0.00
41i. Did project personnel take proactive measures to promptly settle, authorize, and execute change orders on this project?	1.00	0.00
41j. Did the project contract address criteria for classifying change, personnel authorized to request and approve change, and the basis for adjusting the contract?	1.00	0.00
41k. Was a tolerance level for changes established and communicated to all project participants?	1.00	0.00
41l. Were all changes processed through one owner representative?	1.00	0.00
41m. At project close-out, was an evaluation made of changes and their impact on the project cost and schedule performance for future use as lessons learned?	1.00	0.00
41n. Was the project organized in a Work Breakdown Structure (WBS) format and quantities assigned to each WBS for control purposes prior to total project budget authorization?	1.00	0.00

Project Change Management Practice Use
Index=0.50*q_41a+0.75*q_41b+0.50*q_41c+0.75*q_41d+0.50*q_41e+1.75*q_41f+1.00*q_41g+ 0.00*q_41h+0.75*q_41i+0.50*q_41j+1.25*q_41k+0.75*q_41l+0.50*q_41m+0.50*q_41n

Team Building Practice Use

Question	Yes	No
36. Was a team building process used for this project?	-	-
36a. Was an independent consultant used to facilitate the team building process?	1.00	0.00
36b. Was a team-building retreat held early in the life of the project?	1.00	0.00
36c. Did this project have a documented team-building implementation plan?	1.00	0.00
36d. Were objectives of the team building process documented and clearly defined?	1.00	0.00

Question	Regularly	Sometimes	Seldom	Never
36e. Were team building meetings held among team members throughout the project?	1.00	0.67	0.33	0.00
36f. Were follow-up sessions held to integrate new team members and reinforce concepts?	1.00	0.67	0.33	0.00

36g. Please indicate the project phases in which team building was used. Check as many as apply.				
Pre-Project Planning	Design	Procurement	Construction	Startup
0.25	0.25	0.15	0.25	0.10

36h. Please indicate the parties involved in the team building process. Check as many as apply.						
Owner	Designer	Contractors	Major Suppliers	Subcontractors	Constr. Mngr.	Other
-	0.25	0.25	0.15	0.10	0.25	-

Team Building Practice Use Index = 0.50*q_36a+2.50*q_36b+1.50*q_36c+2.50*q_36d+0.50*q_36e+0.50*q_36f+1.50*q_36g+ 0.50*q_36h

Constructability Practice Use

Question	Yes	No
37. Was Constructability implemented on this project?	-	-

Question	
37a. Which of the following best describes the constructability program designation for this project?	
0.00	No designation
0.25	Part of standard construction management activities
0.50	Part of another program, such as Quality or only identified on a project level
0.75	Recognized on a corporate level, but may be part of another program
1.00	Stand-alone program on same level as Quality or Safety

37b. Which of the following best describes the constructability training of personnel for this project?	
0.00	None
0.25	If any occurs, done as on-the-job training
0.50	Awareness seminar(s)
0.75	Part of standard orientation
1.00	Part of standard orientation; deeply ingrained in corporate culture

Continued next page

Constructability Practice Use (Cont.)

37c. Which of the following best describes the role of the constructability coordinator for this project?	
0.00	Coordinator not identified
0.25	Part-time if identified; very limited responsibility
0.50	Informal full- or part-time position; responsibilities vary
0.75	Formal full- or part-time position; responsibilities vary
1.00	Full-time position; plays major project role

37d. Which of the following best describes the constructability program documentation for this project?	
0.00	None; CII documents may be available
0.25	Limited reference in any manual; CII documents may be distributed or referenced
0.50	Project-level constructability documents exist; may be included in other corporate documents
0.75	Project constructability manual is available
1.00	Project constructability manual is thorough, widely distributed, and periodically updated

37e. Which of the following best describes the nature of project-level efforts and inputs concerning constructability for this project?	
0.00	None
0.25	Reactive approach, constrained by review mentality, poor understanding of proactive benefit
0.50	Aware of major benefits, proactive approach
0.75	Proactive approach; routinely consult lessons learned
1.00	Aggressive, proactive approach from beginning of project; routinely consult lessons learned

Continued next page

Constructability Practice Use (Cont.)

37f. Which of the following best describes the implementation of constructability concepts on this project?	
0.00	Very little concept implementation
0.25	Some concepts used periodically; often considered too late to be of use
0.50	Selected concepts applied regularly; full use, timeliness of input varies
0.75	All concepts consistently considered; timely implementation of feasible concepts
1.00	All concepts consistently considered, continuously evaluated, aggressively implemented

37g. Constructability ideas on this project were collected by: (Check as many as applicable)	
0.10	Suggestion Box
0.25	Interviews
0.50	Review Meetings
0.10	Questionnaire
0.05	Other Methods

37h. To what extent was a computerized constructability database utilized for this project?	
0.00	None
0.33	Minimal
0.67	Moderate
1.00	Extensive

Continued next page

Constructability Practice Use (Cont.)

37i. Please characterize the frequency of the constructability reviews and discussions for this project.	
1,00	Once a Week
0,75	Once a Month
0,50	Once every 3 Months
0,25	Once every 6 Months
0,00	Once a Year or Less Frequent

37j. Please indicate the time period of the first meeting that deliberately and explicitly focused on constructability.	
1,00	Early Pre-Project Planning
0,95	Middle Pre-Project Planning
0,90	Late Pre-Project Planning
0,85	Early Detail Design/Procurement
0.80	Middle Detail Design/Procurement
0.75	Late Detail Design/Procurement
0,50	Early Construction
0,25	Middle Construction
0,10	Late Construction

Continued next page

Constructability Practice Use (Cont.)

Question	Yes	No
37k. Constructability was an element addressed in this project's formal written execution plan.	1.00	0.00
37l. Were the actual cost savings (identified cost savings less implementation cost) due to the constructability program tracked on this project?	1.00	0.00

Constructability Practice Use Index = (0.5*q_37a+1.5*q_37b+0.5*q_37c+0.5*q_37d+0.5*q_37e+0.5*q_37f+0.0*q_37g+1.5*q_37h+0.5*q_37i+3.00*q_37k+1.0*q_37l)*q_37j

Appendix E: Best Practice Index Cronbach Coefficient Alpha

Pre-Project Planning Index		
Cronbach Coefficient Alpha = 0.868768		
Deleted Variable	Correlation with Total	Alpha
Q_38E	0.493682	0.866332
Q_38F	0.313798	0.868353
Q_38G	0.310487	0.867610
Q_38H	0.562381	0.865395
Q_39A	0.543839	0.860408
Q_39B	.	0.870055
Q_39C	0.500895	0.862393
Q_39D	0.346704	0.866883
Q_39E	0.505764	0.862308
Q_39F	0.520060	0.862553
Q_39G	0.527383	0.863426
Q_39H	0.537728	0.862049
Q_39I	0.501750	0.864053
Q_39J	0.594142	0.861601
Q_39K	0.438474	0.864235
Q_39L	0.452823	0.867457
Q_39M	0.519602	0.864652
Q_39N	0.601498	0.858423
Q_39O	0.426206	0.864162
Q_39P	0.280271	0.868148
Q_39Q	0.202725	0.868961
Q_39R	0.661693	0.857577
Q_39S	0.647053	0.859341
Q_39T	0.531709	0.861348
Q_39U	0.519918	0.867508
Q_39V	0.558283	0.865808
Q_39W	0.485043	0.865438

Project Change Management Index		
Cronbach Coefficient Alpha = 0.695213		
Deleted Variable	Correlation with Total	Alpha
Q_41A	0.335817	0.678035
Q_41B	0.205866	0.690420
Q_41C	0.363948	0.671968
Q_41D	0.409572	0.663994
Q_41E	0.253735	0.686125
Q_41F	0.540577	0.643244
Q_41G	0.419961	0.665103
Q_41H	0.393575	0.672376
Q_41I	0.364594	0.675225
Q_41J	0.263415	0.686629
Q_41K	0.457065	0.656792
Q_41L	0.115086	0.698075
Q_41M	0.161028	0.700166
Q_41N	0.131593	0.710566

Team Building Index		
Cronbach Coefficient Alpha = 0.876991		
Deleted Variable	Correlation with Total	Alpha
Q_36A	0.576941	0.868773
Q_36B	0.571653	0.871093
Q_36C	0.510565	0.877662
Q_36D	0.677430	0.858203
Q_36E	0.665265	0.859963
Q_36F	0.683446	0.859172
Q_36G	0.816060	0.846797
Q_36H	0.754906	0.853145

Constructability Index		
Cronbach Coefficient Alpha = 0.878217		
Deleted Variable	Correlation with Total	Alpha
Q_37A	0.448705	0.875178
Q_37B	0.642719	0.864145
Q_37C	0.723744	0.858449
Q_37D	0.605906	0.866746
Q_37E	0.773031	0.855997
Q_37F	0.743921	0.858568
Q_37G	0.571299	0.870927
Q_37H	0.464755	0.874426
Q_37I	0.514253	0.872931
Q_37J	0.624397	0.875174
Q_37K	0.671266	0.868572
Q_37L	0.410890	0.878163

Appendix F: Additional ANOVA Analysis

Project Cost Growth by Project Environment

Project Cost Level						
High		Low				
n	Project Cost Growth Mean	n	Project Cost Growth Mean	R^2	F	Prob > F
25	0.090	28	0.089	0.000	0.00	0.976

Project Duration Level						
High		Low				
n	Project Cost Growth Mean	n	Project Cost Growth Mean	R^2	F	Prob > F
22	0.068	25	0.097	0.009	0.41	0.525

Project Cost Rate Level						
High		Low				
n	Project Cost Growth Mean	n	Project Cost Growth Mean	R^2	F	Prob > F
23	0.061	24	0.105	0.020	0.95	0.336

Equipment Cost Factor Level						
High		Low				
n	Project Cost Growth Mean	n	Project Cost Growth Mean	R^2	F	Prob > F
25	0.070	24	0.092	0.006	0.27	0.605

Project Complexity Level						
High		Low				
n	Project Cost Growth Mean	n	Project Cost Growth Mean	R^2	F	Prob > F
25	0.101	28	0.079	0.005	0.24	0.623

Best Practice Use by Project Environment

Pre-Project Planning

Project Nature Level								
Addition		Grass Roots		Modernization				
n	PPP Index Mean	n	PPP Index Mean	n	PPP Index Mean	R^2	F	Prob > F
20	7.8	12	7.6	22	8.4	0.073	2.02	0.143

	Project Environment Level						
	High		Low				
Project Environment	n	Pre-Project Planning Index Mean	n	Pre-Project Planning Index Mean	R^2	F	Prob > F
Cost	26	7.8	28	8.2	0.030	1.60	0.211
Duration	23	7.7	25	8.1	0.035	1.68	0.202
Cost Rate	24	7.8	24	8.0	0.007	0.35	0.558
Craft Wrkhrs.	23	7.9	26	8.2	0.020	0.97	0.328
Equip. Cost Fct.	26	8.3	24	7.8	0.055	2.82	0.099
Complexity	26	7.9	28	8.0	0.002	0.13	0.720

Project Change Management

Project Nature Level								
Addition		Grass Roots		Modernization				
n	Project Change Mngmnt Index Mean	n	Project Change Mngmnt Index Mean	n	Project Change Mngmnt Index Mean	R^2	F	Prob > F
20	7.6	12	7.8	23	8.0	0.009	0.23	0.800

	Project Environment Level						
	High		Low				
Project Environment	n	Project Change Mngmnt. Index Mean	n	Project Change Mngmnt. Index Mean	R^2	F	Prob > F
Cost	27	7.4	28	8.2	0.042	2.31	0.134
Duration	23	7.6	25	8.4	0.044	2.14	0.150
Cost Rate	24	7.9	24	8.1	0.003	0.13	0.716
Craft Wrkhrs.	23	7.9	26	8.2	0.010	0.46	0.498
Equip. Cost Fct.	26	8.1	25	7.7	0.009	0.43	0.514
Complexity	27	7.4	28	8.3	0.054	3.00	0.089

Team Building

Project Nature Level								
Addition		Grass Roots		Modernization				
n	Team Building Index Mean	n	Team Building Index Mean	n	Team Building Index Mean	R^2	F	Prob > F
20	3.6	12	7.2	23	4.6	0.149	4.56	0.014

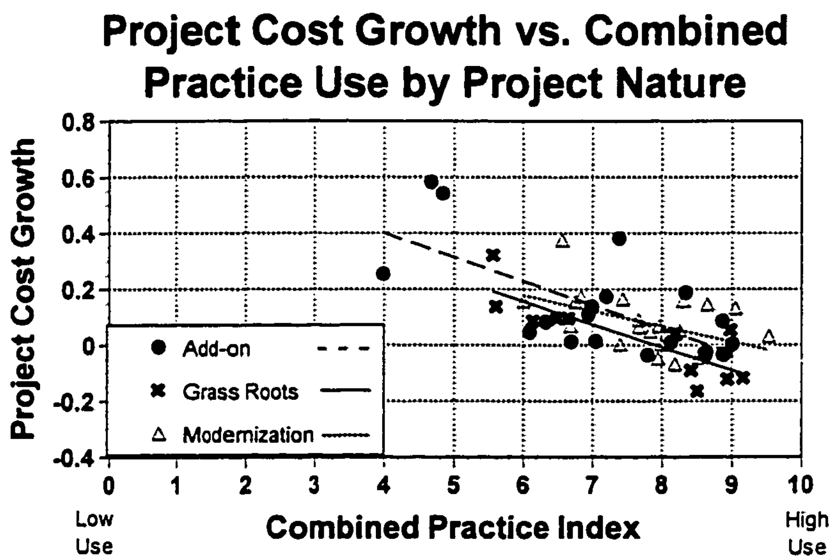
	Project Environment Level						
	High		Low				
Project Environment	n	Team Building Index Mean	n	Team Building Index Mean	R^2	F	Prob > F
Cost	27	5.4	28	4.2	0.029	1.57	0.216
Duration	23	4.8	25	4.7	0.000	0.01	0.933
Cost Rate	24	5.6	24	3.9	0.050	2.40	0.127
Craft Wrkhrs.	23	5.8	26	4.3	0.040	1.99	0.165
Equip. Cost Fct.	26	4.7	25	5.1	0.005	0.25	0.617
Complexity	27	5.0	28	4.6	0.002	0.13	0.724

Constructability

Project Nature Level								
Addition		Grass Roots		Modernization				
n	Cnstblty Index Mean	n	Cnstblty Index Mean	n	Cnstblty Index Mean	R^2	F	Prob > F
20	3.0	12	3.4	23	4.0	0.034	0.91	0.407

	Project Environment Level						
	High		Low				
Project Environment	n	Cnstblty Index Mean	n	Cnstblty Index Mean	R^2	F	Prob > F
Cost	27	2.9	28	4.1	0.059	3.34	0.073
Duration	23	3.2	25	3.9	0.020	0.93	0.339
Cost Rate	24	3.5	24	3.6	0.000	0.02	0.901
Craft Wrkhrs.	23	3.0	26	4.4	0.071	3.59	0.064
Equip. Cost Fct.	26	4.1	25	3.1	0.041	2.10	0.153
Complexity	27	3.8	28	3.2	0.015	0.80	0.375

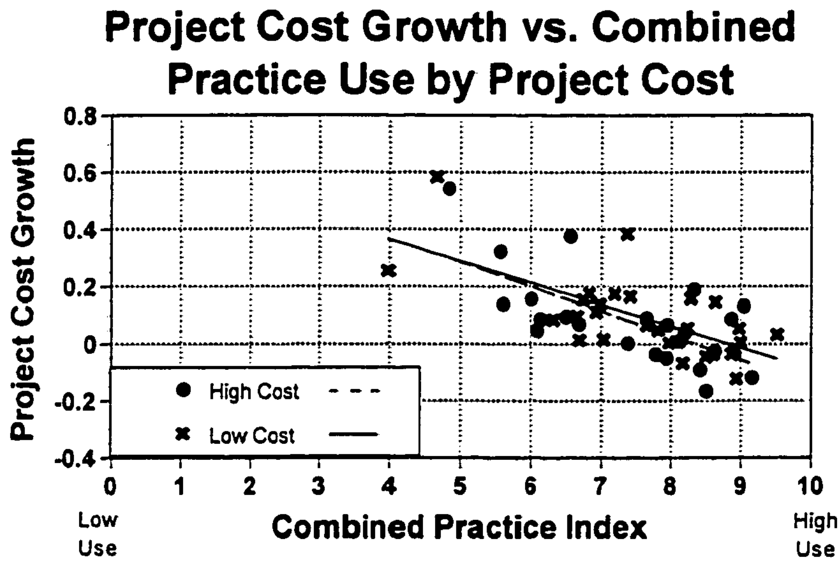
Appendix G: Additional Regression Analysis



Model Equation
Project Cost Growth = 0.513 – 0.056 x Combined Practice Index + 0.230 x Nature (Add.) + 0.135 x Nature (Gr. Rts.) – 0.03 x Nature (Add.) x Combined Practice Index – 0.027 x Nature (Gr. Rts.) x Combined Practice Index

Regression Fit				
Degrees of Freedom	R-Square	Adj R-Square	F Stat	Prob > F
46	0.5042	0.4503	9.36	0.0000

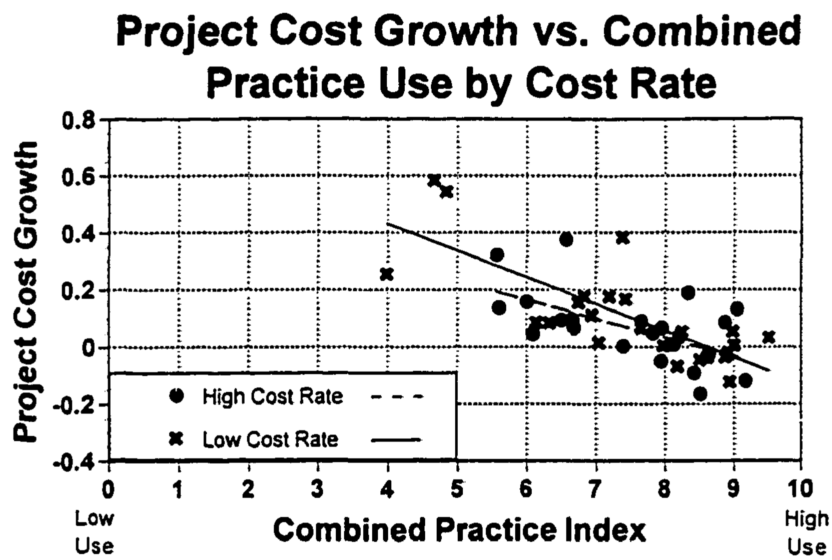
Parameter Estimates				
Variable	Estimate	Std. Error	T Stat	Prob > T
Intercept	0.513	0.2170	2.36	0.0224
Combined Practice Index	-0.056	0.0277	-2.01	0.0497
Nature (Add.)	0.230	0.2520	0.91	0.3666
Nature (Gr. Rts.)	0.135	0.2850	0.47	0.6392
Nature (Mod.)	0.000	.	.	.
Nature (Add.) x Combined Practice Index	-0.030	0.0327	-0.92	0.3642
Nature (Gr. Rts.) x Combined Practice	-0.027	0.0366	-0.73	0.4702
Nature (Mod.) x Combined Practice Index	0.000	.	.	.



Model Equation
Project Cost Growth = 0.663 – 0.076 x Combined Practice Index + 0.051 x Cost (High) – 0.010 x Cost (High) x Combined Practice Index

Regression Fit				
Degrees of Freedom	R-Square	Adj R-Square	F Stat	Prob > F
48	0.4608	0.4271	13.68	0.0000

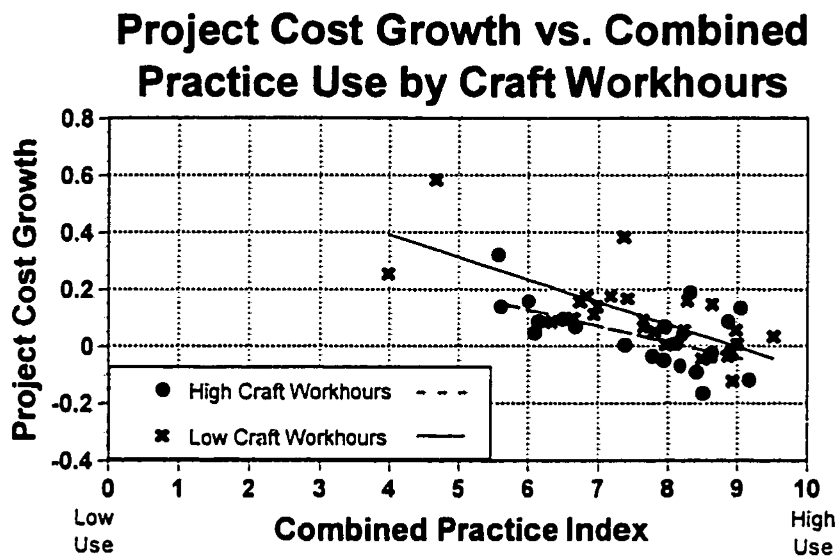
Parameter Estimates				
Variable	Estimate	Std. Error	T Stat	Prob > T
Intercept	0.663	0.1300	5.09	0.0000
Combined Practice Index	-0.076	0.0169	-4.47	0.0000
Cost (High)	0.051	0.1920	0.27	0.7899
Cost (Low)	0.000	.	.	.
Cost (High) x Combined Practice Index	-0.010	0.0252	-0.40	0.6885
Cost (Low) x Combined Practice Index	0.000	.	.	.



Model Equation
Project Cost Growth = 0.800 – 0.093 x Combined Practice Index – 0.242 x Cost Rate (High) + 0.028 x Cost Rate (High) x Combined Practice Index

Regression Fit				
Degrees of Freedom	R-Square	Adj R-Square	F Stat	Prob > F
43	0.5249	0.4917	15.83	0.0000

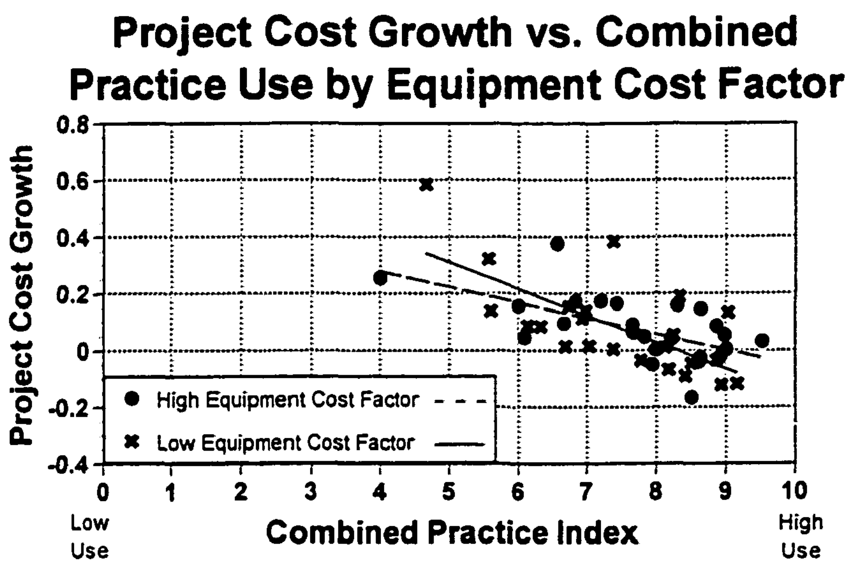
Parameter Estimates				
Variable	Estimate	Std. Error	T Stat	Prob > T
Intercept	0.800	0.1180	6.76	0.0000
Combined Practice Index	-0.093	0.0156	-5.98	0.0000
Cost Rate (High)	-0.242	0.1990	-1.22	0.2297
Cost Rate (Low)	0.000	.	.	.
Cost Rate (High) x Combined Practice	0.028	0.0260	1.06	0.2941
Cost Rate (Low) x Combined Practice	0.000	.	.	.



Model Equation
Project Cost Growth = 0.705 – 0.079 x Combined Practice Index - 0.242 x Craft Wkhrs. (High) + 0.023 x Craft Wkhrs. (High) x Comb. Practice Index

Regression Fit				
Degrees of Freedom	R-Square	Adj R-Square	F Stat	Prob > F
44	0.4949	0.4605	14.37	0.0000

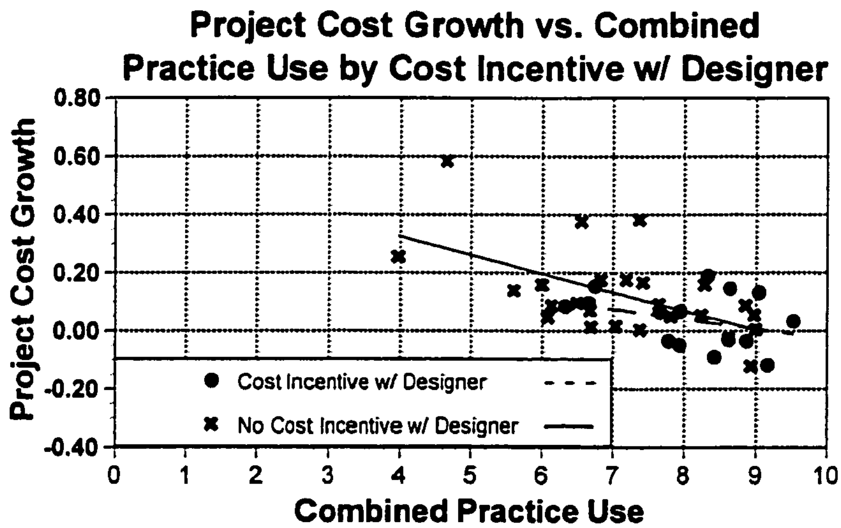
Parameter Estimates				
Variable	Estimate	Std. Error	T Stat	Prob > T
Intercept	0.705	0.1150	6.13	0.0000
Combined Practice Index	-0.079	0.0148	-5.32	0.0000
Craft Wkhrs. (High)	-0.242	0.1820	-1.33	0.1888
Craft Wkhrs. (Low)	0.000	.	.	.
Craft Wkhrs. (High) x Comb. Practice	0.023	0.0235	0.98	0.3331
Craft Wkhrs. (Low) x Comb. Practice	0.000	.	.	.



Model Equation
Project Cost Growth = 0.775 – 0.094 x Combined Practice Index - 0.277 x Eq. Cst. Fct. (High) + 0.039 x Eq. Cst. Fct. (High) x Combined Practice Index

Regression Fit				
Degrees of Freedom	R-Square	Adj R-Square	F Stat	Prob > F
44	0.4392	0.4010	11.49	0.0000

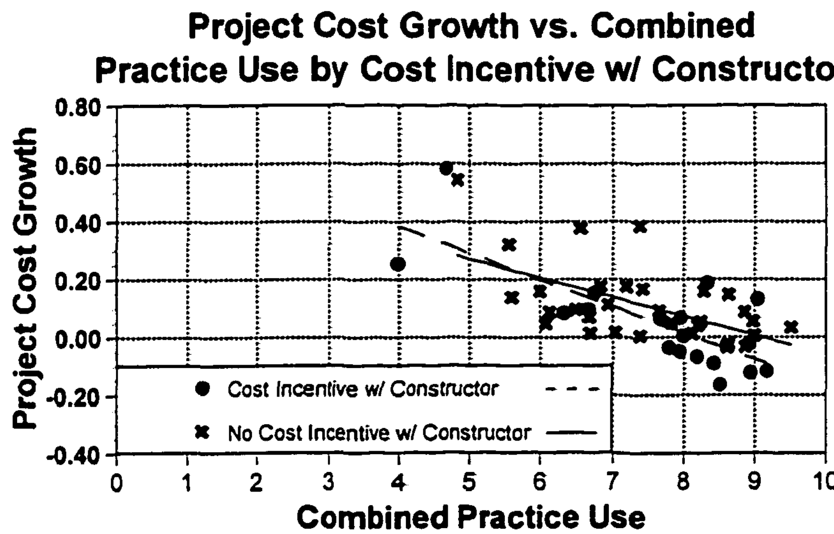
Parameter Estimates				
Variable	Estimate	Std. Error	T Stat	Prob > T
Intercept	0.775	0.1410	5.491	0.0000
Combined Practice Index	-0.094	0.0187	-4.99	0.0000
Eq. Cst Fct. (High)	-0.277	0.1990	-1.39	0.1723
Eq. Cst Fct. (Low)	0.000	.	.	.
Eq. Cst. Fct. (High) x Combined Practice	0.039	0.0259	1.49	0.1434
Eq. Cst. Fct. (Low) x Combined Practice	0.000	.	.	.



Model Equation
Project Cost Growth = 0.311 – 0.034 x Comb. Prct. Index + 0.268 x Des. Cst. Inc. (No) - 0.030 x Des. Cst. Inc. (No) x Comb. Prct. Index

Regression Fit				
Degrees of Freedom	R-Square	Adj R-Square	F Stat	Prob > F
36	0.3473	0.2929	6.38	0.0014

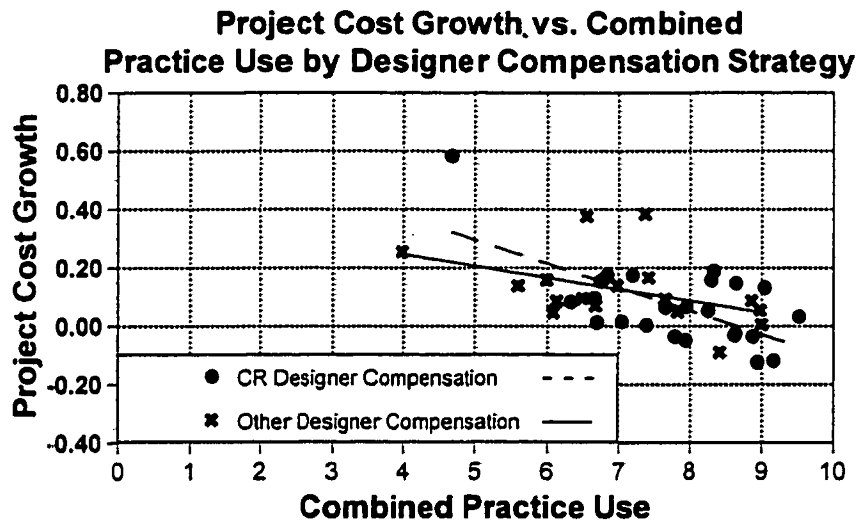
Parameter Estimates				
Variable	Estimate	Std. Error	T Stat	Prob > T
Intercept	0.311	0.2620	1.18	0.2437
Comb. Prct. Index	-0.034	0.0322	-1.05	0.3005
Des. Cst. Inc. (No)	0.268	0.2920	0.92	0.3652
Des. Cst. Inc. (Yes)	.	.	.	.
Des. Cst. Inc. (No) x Comb. Prct. Index	-0.030	0.0367	-0.83	0.4117
Des. Cst. Inc. (Yes) x Comb. Prct. Index	.	.	.	.



Model Equation
Project Cost Growth = 0.751 – 0.092 x Comb. Prct. Index - 0.151 x Con. Cst. Inc. (No) + 0.0258 x Con. Cst. Inc. (No) x Comb. Prct. Index

Regression Fit				
Degrees of Freedom	R-Square	Adj R-Square	F Stat	Prob > F
46	0.4757	0.4416	13.91	0.000

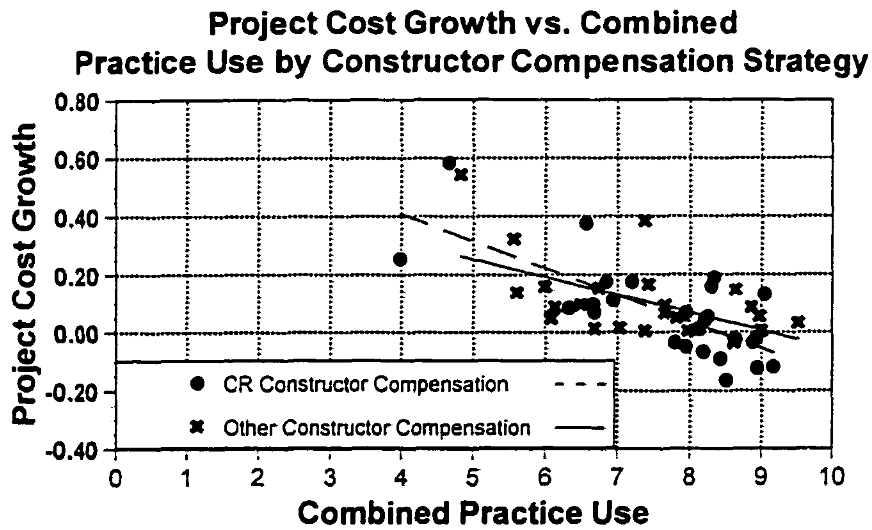
Parameter Estimates				
Variable	Estimate	Std. Error	T Stat	Prob > T
Intercept	0.751	0.1460	5.13	0.0000
Comb. Prct. Index	-0.092	0.0189	-4.87	0.0000
Con. Cst. Inc. (No)	-0.151	0.1950	-0.78	0.4408
Con. Cst. Inc. (Yes)	.	.	.	.
Con. Cst. Inc. (No) x Comb. Prct. Index	0.0258	0.0254	1.01	0.3156
Con. Cst. Inc. (Yes) x Comb. Prct. Index	.	.	.	.



Model Equation
Project Cost Growth = 0.400 – 0.040 x Comb. Prct. Index + 0.299 x Dsn Comp. (CR) - 0.041 x Dsn Comp. (CR) x Comb. Prct. Index

Regression Fit				
Degrees of Freedom	R-Square	Adj R-Square	F Stat	Prob > F
37	0.3627	0.3111	7.021	0.0007

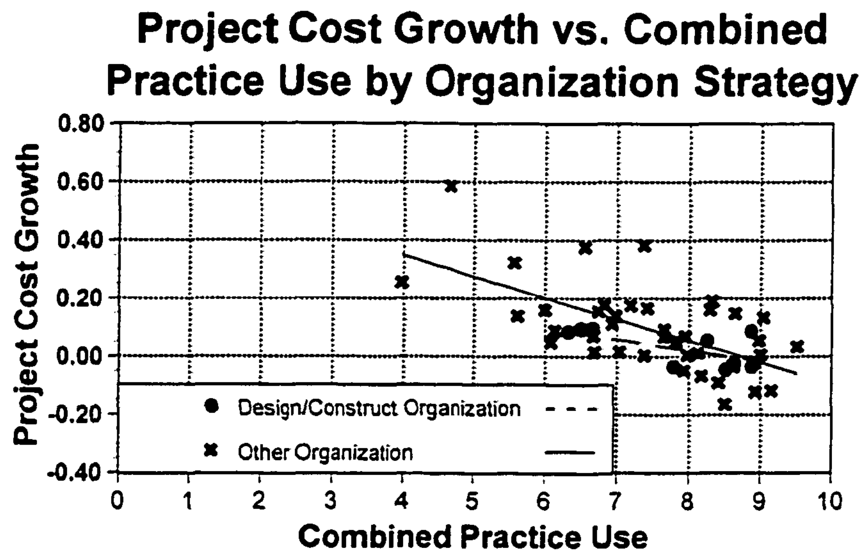
Parameter Estimates				
Variable	Estimate	Std. Error	T Stat	Prob > T
Intercept	0.400	0.1490	2.68	0.0110
Comb. Prct. Index	-0.040	0.0208	-1.90	0.0648
Dsn Comp. (CR)	0.299	0.2210	1.36	0.1835
Dsn. Comp. (Other)	.	.	.	.
Dsn. Comp. (CR) x Comb. Prct. Index	-0.041	0.0293	-1.41	0.1673
Dsn. Comp. (Other) x Comb. Prct. Index	.	.	.	.



Model Equation
Project Cost Growth = 0.558 – 0.062 x Comb. Prct. Index + 0.219 x Cnst. Comp. (CR) - 0.031 x Cnst. Comp. (CR) x Comb. Prct. Index

Regression Fit				
Degrees of Freedom	R-Square	Adj R-Square	F Stat	Prob > F
46	0.4637	0.4287	13.26	0.0000

Parameter Estimates				
Variable	Estimate	Std. Error	T Stat	Prob > T
Intercept	0.558	0.1400	3.99	0.0002
Comb. Prct. Index	-0.062	0.0187	-3.29	0.0019
Cnst. Comp. (CR)	0.219	0.1960	1.12	0.2687
Cnst. Comp. (Other)	.	.	.	.
Cnst. Comp. (CR) x Comb. Prct. Index	-0.031	0.0257	-1.20	0.2349
Cnst. Comp. (Other) x Comb. Prct. Index	.	.	.	.

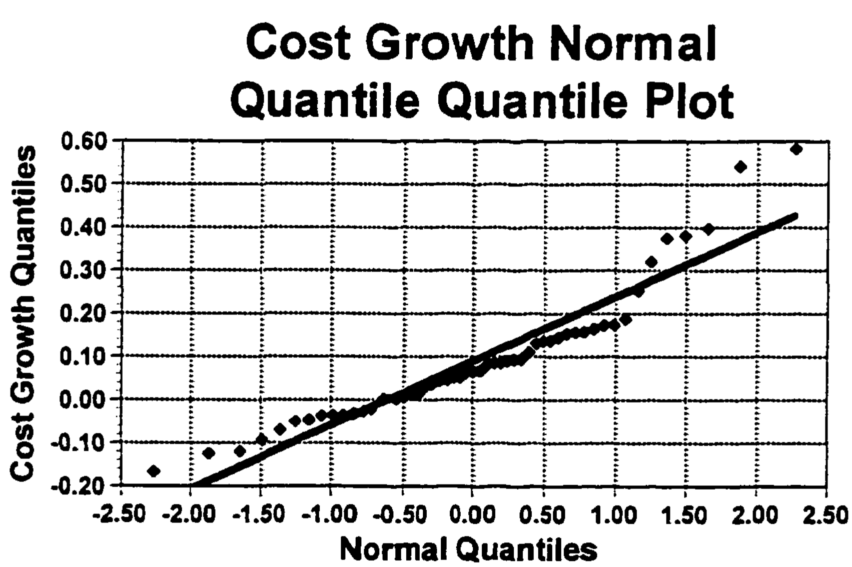


Model Equation
Project Cost Growth = 0.326 – 0.038 x Comb. Prct. Index + 0.314 x Org. Strategy (Other) – 0.035. x Org. Strategy (Other) x Comb. Prct. Index

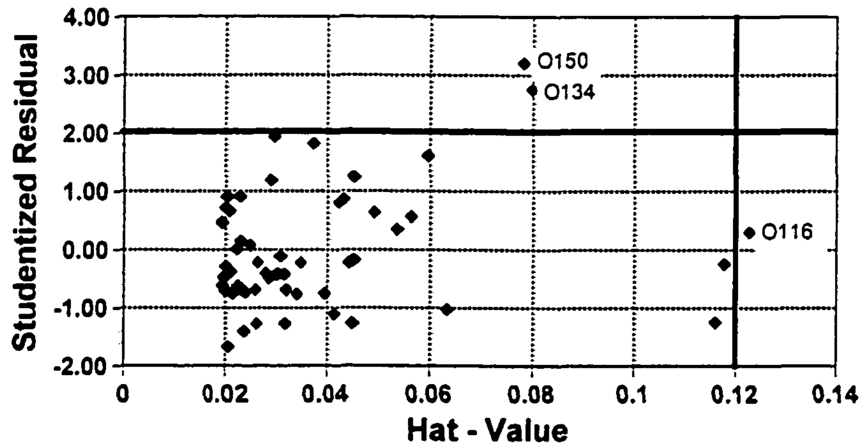
Regression Fit				
Degrees of Freedom	R-Square	Adj R-Square	F Stat	Prob > F
46	0.4183	0.3804	11.03	0.0000

Parameter Estimates				
Variable	Estimate	Std. Error	T Stat	Prob > T
Intercept	0.326	0.2870	1.13	0.2626
Comb. Prct. Index	-0.038	0.0364	-1.05	0.2999
Org. Strategy (Other)	0.314	0.3050	1.03	0.3089
Org. Strategy (D/C)	.	.	.	.
Org. Strategy (Other) x Comb. Prct. Index	-0.035	0.0389	-0.91	0.3662
Org. Strategy (D/C) x Comb. Prct. Index	.	.	.	.

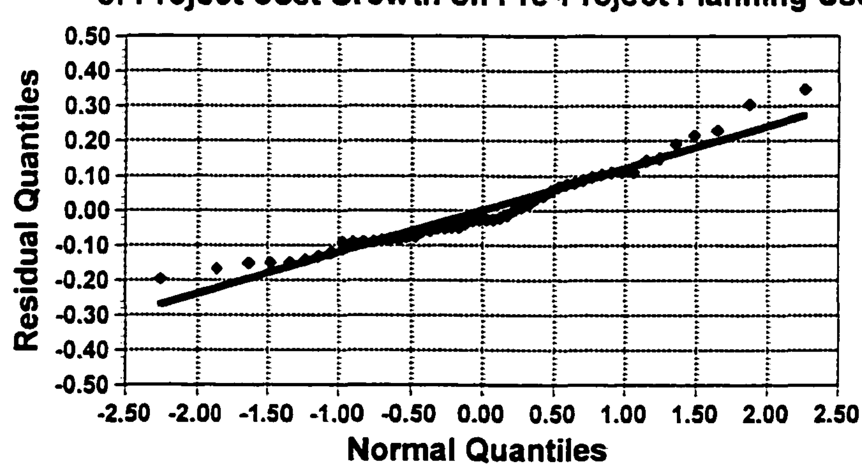
Appendix H Statistical Method Diagnostics



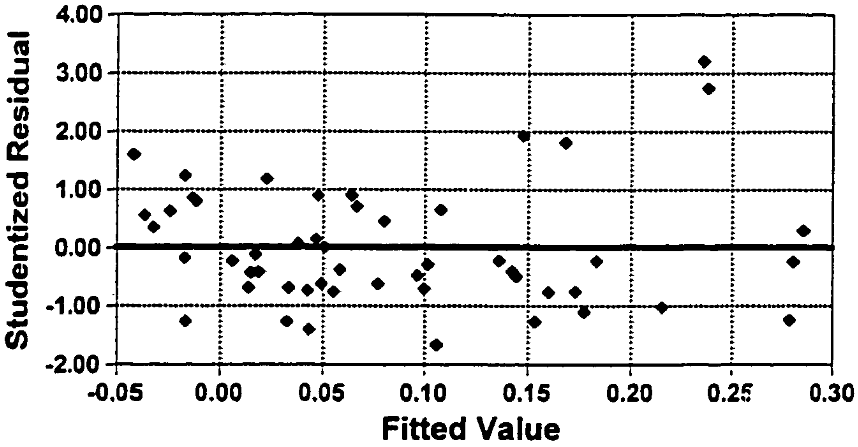
Studentized Residual vs. Hat-Value for Regression of Project Cost Growth on Pre-Project Planning Use

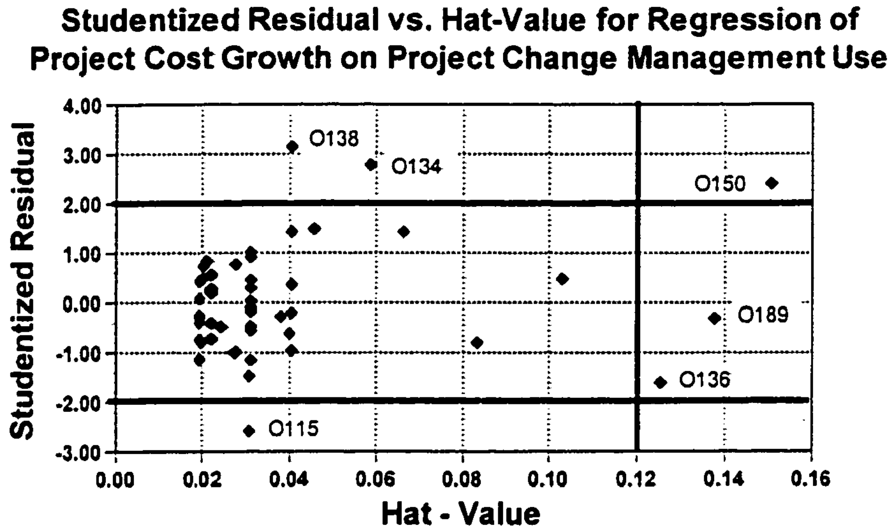


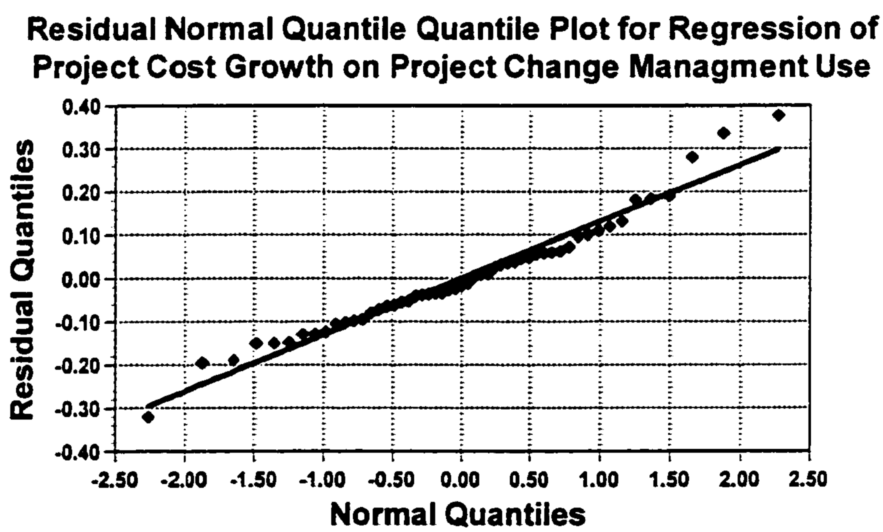
Residual Normal Quantile Quantile Plot for Regression of Project Cost Growth on Pre-Project Planning Use



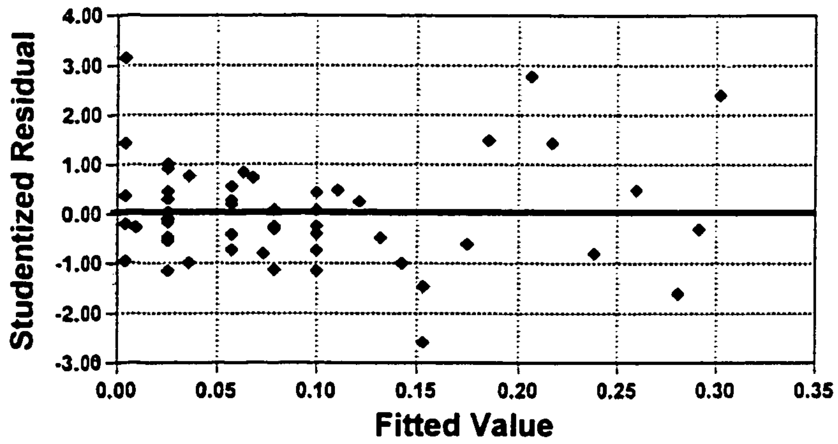
Studentized Residual vs Fitted Value for Regression of Project Cost Growth on Pre-Project Planning Use

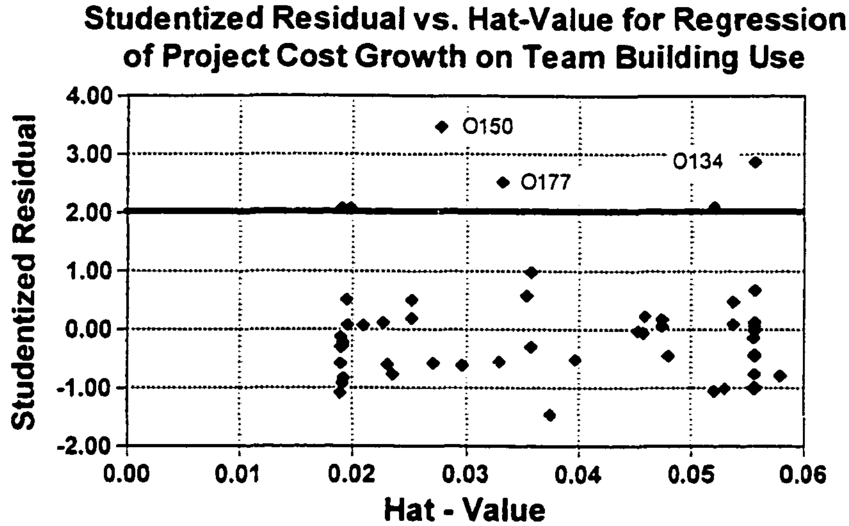


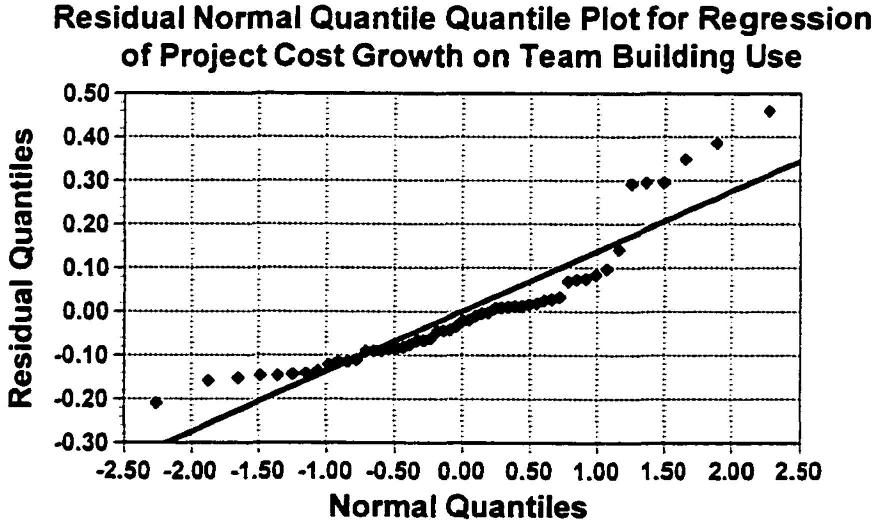

Studentized Residual vs. Hat-Value for Regression of Project Cost Growth on Project Change Management Use
Studentized Residual
4.00
3.00
2.00
1.00
0.00
-1.00
-2.00
-3.00
O138
O134
O150
O189
O136
O115
0.00
0.02
0.04
0.06
0.08
0.10
0.12
0.14
0.16
Hat - Value

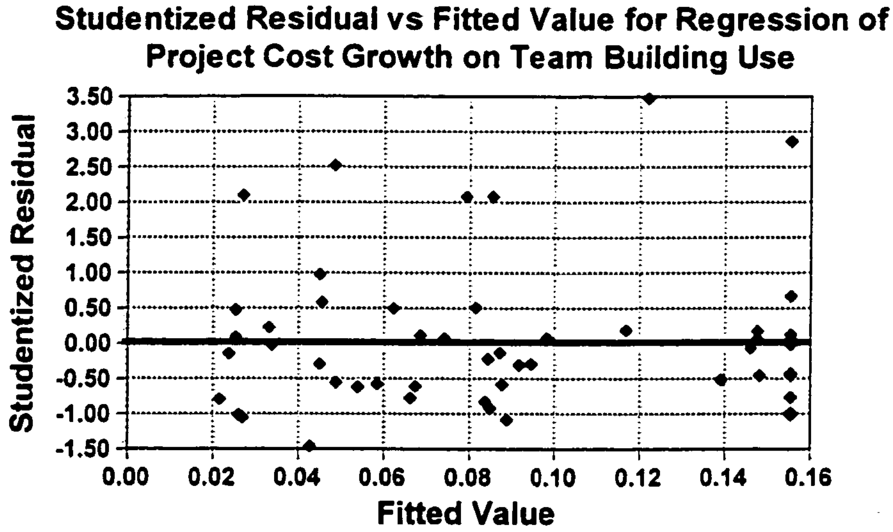

Residual Normal Quantile Quantile Plot for Regression of Project Cost Growth on Project Change Managment Use
Residual Quantiles
0.40
0.30
0.20
0.10
0.00
-0.10
-0.20
-0.30
-0.40
-2.50
-2.00
-1.50
-1.00
-0.50
0.00
0.50
1.00
1.50
2.00
2.50
Normal Quantiles

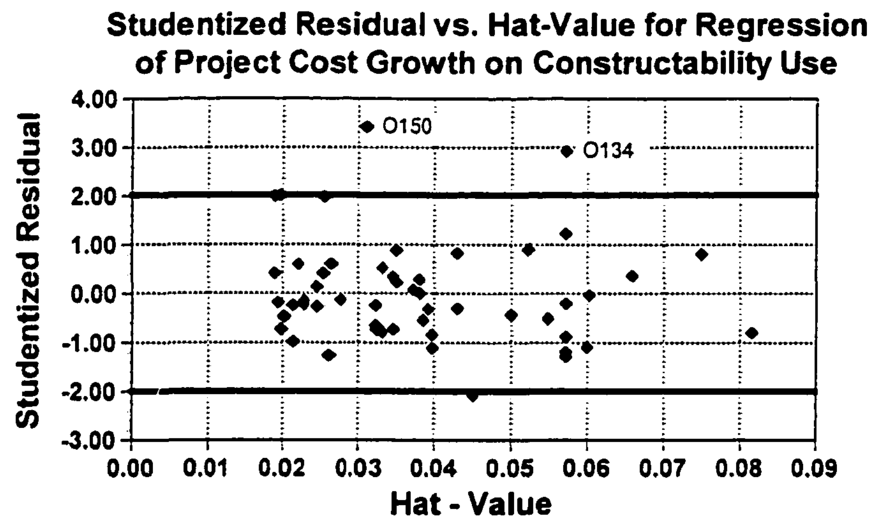
Studentized Residual vs Fitted Value for Regression of Project Cost Growth on Project Change Managment Use

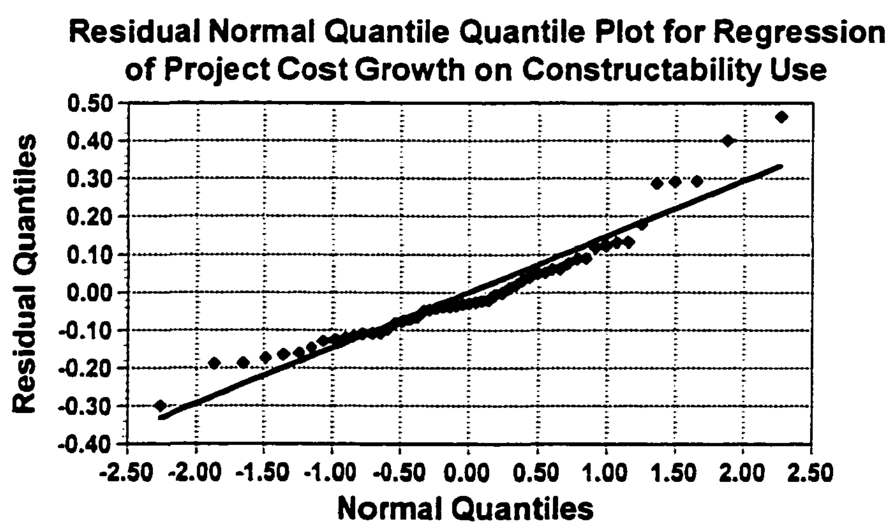



Studentized Residual vs. Hat-Value for Regression of Project Cost Growth on Team Building Use
Studentized Residual
Hat - Value
O150
O177
O134
4.00
3.00
2.00
1.00
0.00
-1.00
-2.00
0.00
0.01
0.02
0.03
0.04
0.05
0.06

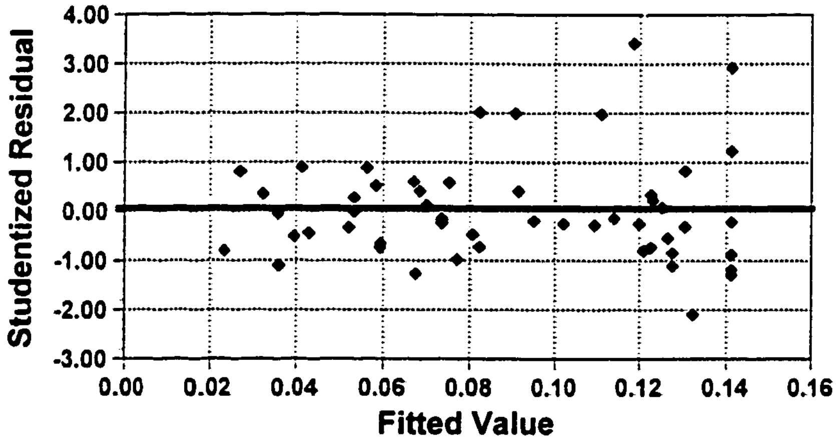

Residual Normal Quantile Quantile Plot for Regression of Project Cost Growth on Team Building Use
Residual Quantiles
Normal Quantiles
0.50
0.40
0.30
0.20
0.10
0.00
-0.10
-0.20
-0.30
-2.50
-2.00
-1.50
-1.00
-0.50
0.00
0.50
1.00
1.50
2.00
2.50

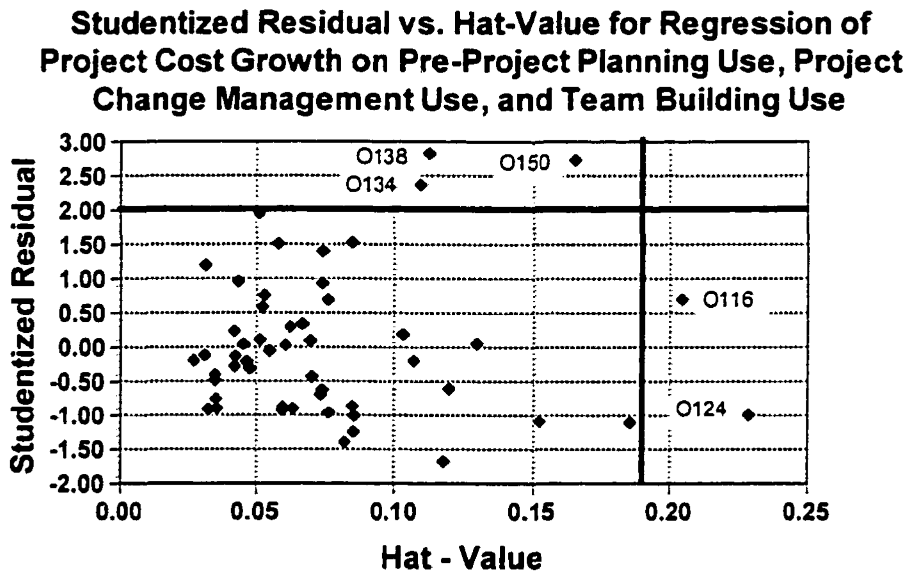

Studentized Residual vs Fitted Value for Regression of Project Cost Growth on Team Building Use
Studentized Residual
3.50
3.00
2.50
2.00
1.50
1.00
0.50
0.00
-0.50
-1.00
-1.50
0.00
0.02
0.04
0.06
0.08
0.10
0.12
0.14
0.16
Fitted Value

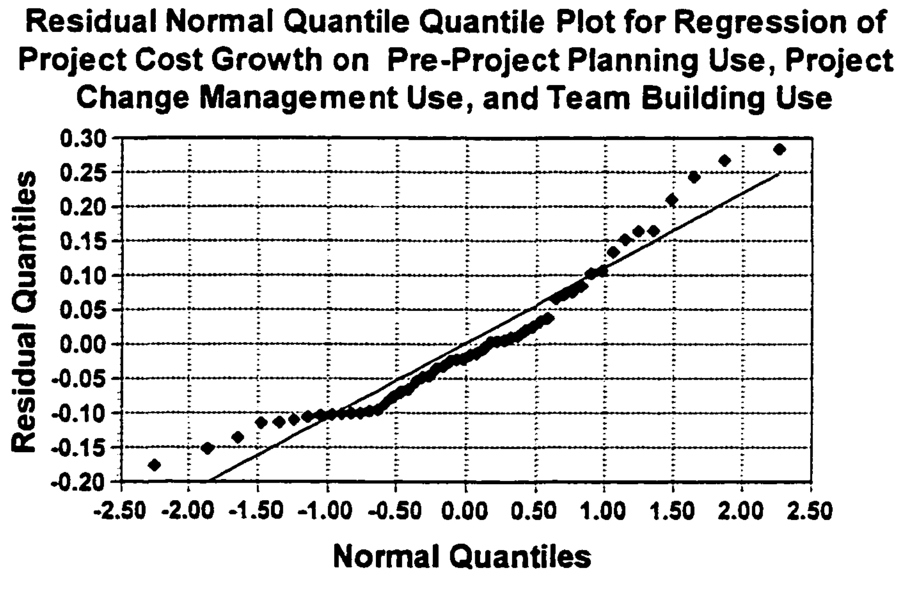

Studentized Residual vs. Hat-Value for Regression of Project Cost Growth on Constructability Use
Studentized Residual
4.00
3.00
2.00
1.00
0.00
-1.00
-2.00
-3.00
O150
O134
0.00
0.01
0.02
0.03
0.04
0.05
0.06
0.07
0.08
0.09
Hat - Value


Residual Normal Quantile Quantile Plot for Regression of Project Cost Growth on Constructability Use
Residual Quantiles
0.50
0.40
0.30
0.20
0.10
0.00
-0.10
-0.20
-0.30
-0.40
-2.50
-2.00
-1.50
-1.00
-0.50
0.00
0.50
1.00
1.50
2.00
2.50
Normal Quantiles

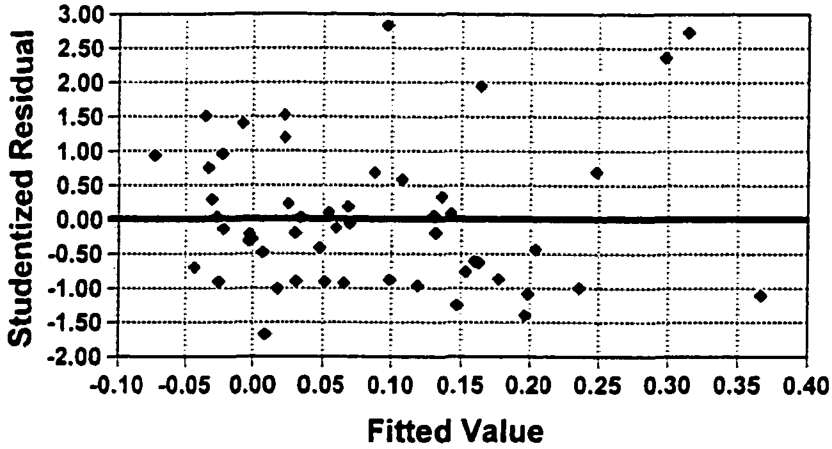
Studentized Residual vs Fitted Value for Regression of Project Cost Growth on Constructability Use



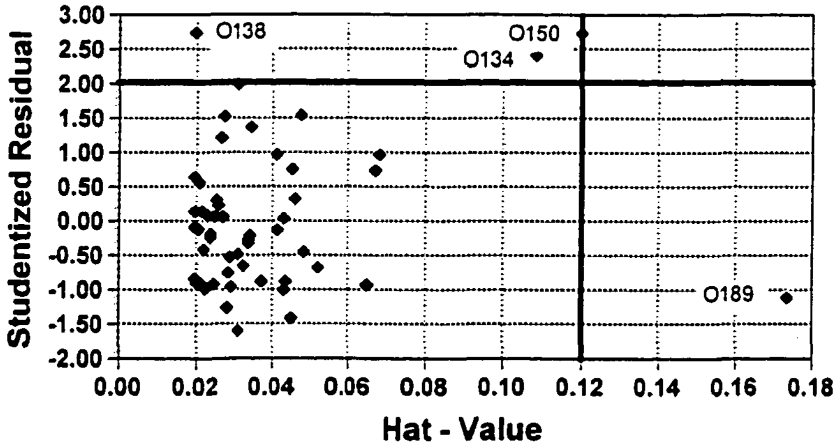

Studentized Residual vs. Hat-Value for Regression of Project Cost Growth on Pre-Project Planning Use, Project Change Management Use, and Team Building Use
Studentized Residual
Hat - Value
O138
O150
O134
O116
O124
3.00
2.50
2.00
1.50
1.00
0.50
0.00
-0.50
-1.00
-1.50
-2.00
0.00
0.05
0.10
0.15
0.20
0.25


Residual Normal Quantile Quantile Plot for Regression of Project Cost Growth on Pre-Project Planning Use, Project Change Management Use, and Team Building Use
Residual Quantiles
Normal Quantiles
0.30
0.25
0.20
0.15
0.10
0.05
0.00
-0.05
-0.10
-0.15
-0.20
-2.50 -2.00 -1.50 -1.00 -0.50 0.00 0.50 1.00 1.50 2.00 2.50

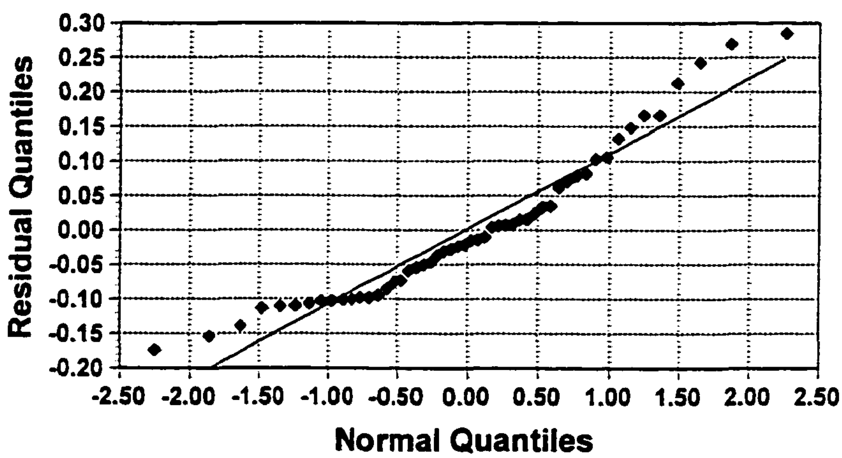
Studentized Residual vs Fitted Value for Regression of Project Cost Growth on Pre-Project Planning Use, Project Change Management Use, and Team Building Use



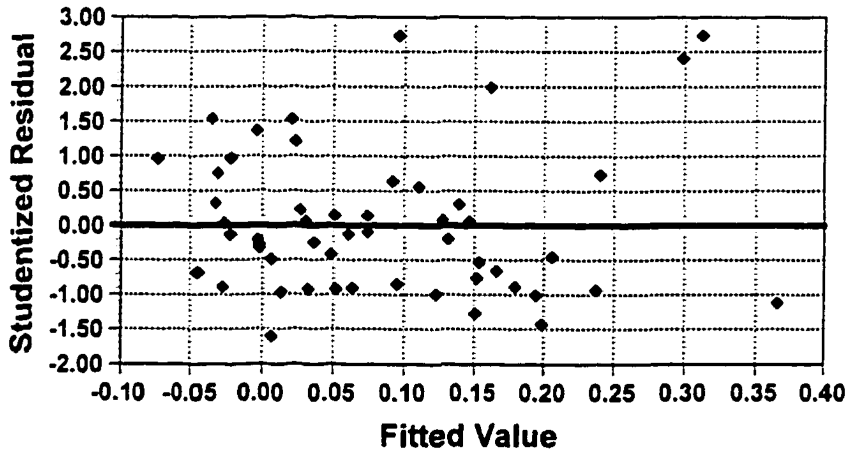
Studentized Residual vs. Hat-Value for Regression of Project Cost Growth on Combined Practice Use



Residual Normal Quantile Quantile Plot for Regression of Project Cost Growth on Combined Practice Use



Studentized Residual vs Fitted Value for Regression of Project Cost Growth on Combined Practice Use



Appendix I Benchmarking and Metrics Committee Membership

Charles Broadhead, M.W. Kellogg	Jerry Hayman, Celanese
Myra Burgess, Commonwealth Edison	John Johnson, Champion
Roger Catlett, U.S.A.C.O.E.	Kirk Morrow, CII
Robert Chapman, NIST	Marvin Oey, CII
Tom Ditmars, CITGO Petroleum	John Rose, M.W. Kellogg
Stretch Dunn, BE&K Inc.	Marv Rosen, Exxon
Ned Givens, CII	Stephen Rotondi, Rust
Paul Goodine, Shell Oil	Chatt Smith, Amoco
Deb Grubbe, DuPont	Ralph Spillinger, NASA
Paul Gunn, BMW Contractors	Richard Tucker, CII
Chip Harper, M.A. Mortenson	David Tweedie, Watkins

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Vita

Tommy Kirk Morrow was born on February 1, 1965 in Yellville, Arkansas. He grew up in Yellville with his parents Tommy and Betty, and brother Randy. He studied Civil Engineering at the University of Arkansas, Fayetteville and received a Bachelor of Science degree in May of 1988.

He accepted employment with the Federal Highway Administration soon after graduation. After serving as a bridge engineer for the Federal Highway Administration for three years he enrolled at North Carolina State University to pursue graduate studies in Civil Engineering with a specialization in Construction Engineering and Project Management. After graduating with a M.S. degree in Civil Engineering from North Carolina State University, Kirk accepted employment with J.A. Jones Construction Company within the Heavy Civil Division. He served as an office engineer and later as a concrete production superintendent for J.A. Jones on a navigation dam project in Western Pennsylvania for approximately two years.

Kirk enrolled at the University of Texas at Austin in January of 1995 in pursuit of a Ph.D. in Civil Engineering with a specialization in Construction Engineering and Project Management. During this period at the University of Texas, Kirk worked with the Construction Industry Institute Electronic Documents Research Team and the Benchmarking and Metrics Committee. The dissertation presented here is a result of research performed while working with the Benchmarking and Metrics Committee.

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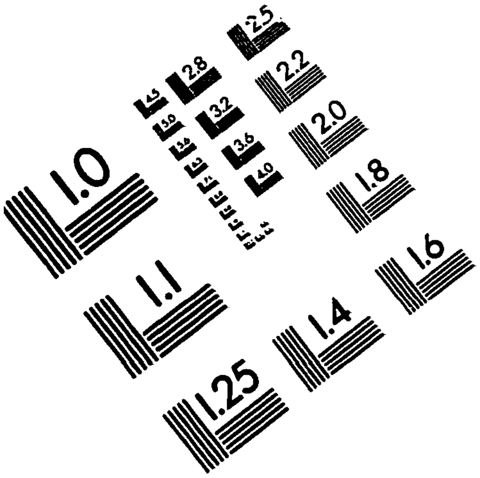
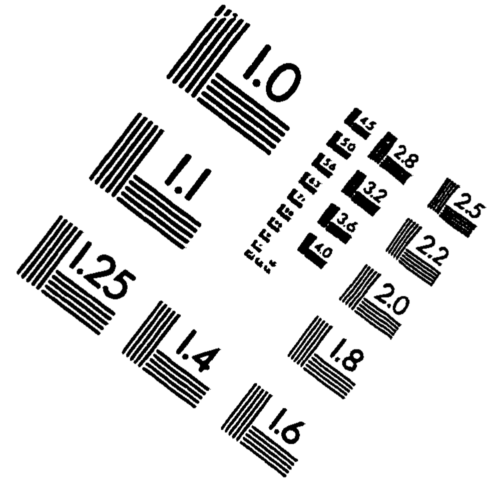
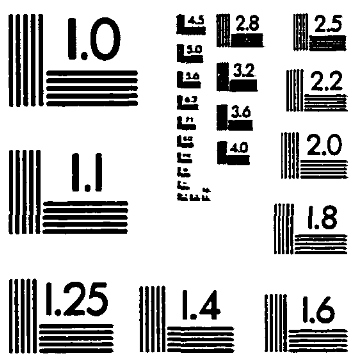
The author typed this dissertation.

IMAGE EVALUATION TEST TARGET (QA-3)

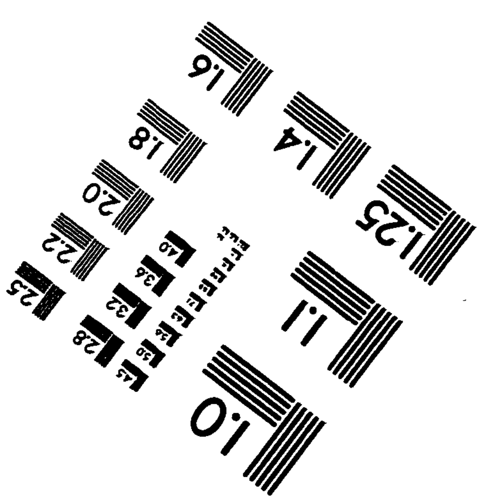






150mm

6"



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