| REPORT DOCUMENTATION PAGE | *Form Approved* *OMB No. 0704-0188* |
|---|---|



| 1. AGENCY USE ONLY *(Leave blank)* | 2. REPORT DATE | 3. REPORT TYPE AND DATES COVERED |
|---|---|---|
| | 7 August 1998 | |

| 4. TITLE AND SUBTITLE | 5. FUNDING NUMBERS |
|---|---|
| A COMPARISON OF PROJECT DELIVERY SYSTEMS ON UNITED STATES FEDERAL CONSTRUCTION PROJECTS | |
| 6. AUTHOR(S)<br>Shawn D. Moore | |
| 7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)<br>The Pennsylvania State University | 8. PERFORMING ORGANIZATION REPORT NUMBER<br>98-048 |
| 9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)<br>THE DEPARTMENT OF THE AIR FORCE<br>AFIT/CIA, BLDG 125<br>2950 P STREET<br>WPAFB OH 45433 | 10. SPONSORING/MONITORING AGENCY REPORT NUMBER |
| 11. SUPPLEMENTARY NOTES | |
| 12a. DISTRIBUTION AVAILABILITY STATEMENT<br>Unlimited distribution<br>In Accordance With 35-205/AFIT Sup 1 | 12b. DISTRIBUTION CODE |

13. ABSTRACT *(Maximum 200 words)*

| 14. SUBJECT TERMS | 15. NUMBER OF PAGES |
|---|---|
| | 119 |
| | 16. PRICE CODE |

| 17. SECURITY CLASSIFICATION OF REPORT | 18. SECURITY CLASSIFICATION OF THIS PAGE | 19. SECURITY CLASSIFICATION OF ABSTRACT | 20. LIMITATION OF ABSTRACT |
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The Pennsylvania State University
The Graduate School
College of Engineering

# A COMPARISON OF PROJECT DELIVERY SYSTEMS ON UNITED STATES FEDERAL CONSTRUCTION PROJECTS

A Thesis in
Architectural Engineering
by
Shawn D. Moore



Submitted in Partial Fulfillment
of the Requirements
for the Degree of

Master of Science

August 1998

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# ABSTRACT

Previous subjective research identified shortened project duration as the primary reason for public owners' selection of design-build for project delivery. This study presents specific comparisons of the design-bid-build and design-build delivery systems to objectively inform federal project owners of actual project performance.

The United States Federal Construction Program, deeply rooted in traditional design-bid-build project delivery, has attempted to a limited degree to deliver projects via the design-build delivery system to better meet project cost, schedule and quality goals. This research first analyzed 273 completed private, public and federal construction projects to provide direct, objective comparison of cost, schedule and quality performance between design-bid-build and design-build project delivery systems. An in-depth investigation was then conducted on the 88 federal construction projects to compare projects by delivery system based on equivalent project delivery system start at zero percent design complete.

This research collected project specific cost, schedule and quality data, as well as several variables known to impact project performance. Univariate statistical testing of 15 performance metrics identified several significant differences in delivery system performance, which were further analyzed by percent design complete prior to construction contract award. Quality performance measurements addressed the influence of time in objectively assessing completed facility quality. Multivariate linear regression modeling tested each delivery system, facility type, and more than 70 variables to explain the highest proportion of variation in project delivery speed.

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# GLOSSARY OF TERMS

**Construction Procurement Speed**: The rate at which a facility is procured for construction. It is measured by the facility's gross area in square feet divided by the number of months taken to procure the construction contract. Procurement time is the total time between the date of construction project advertisement in the Commerce Business Daily (CBD) and the subsequent notice to proceed date after contract award for either the construction or design-build effort. For design-build projects, the construction procurement time begins with either the solicitation for offer or request for proposal (whichever applies) on the date advertised in the CBD and ends on the notice to proceed date. Included in this time period are proposal development, submission, evaluation, selection, negotiation and award of the contract. Design-bid-build construction procurement time begins on the CBD construction bid invitation announcement date and ends on the notice to proceed with construction date.

**Construction Speed**: The rate at which a facility is constructed measured in square feet per month of construction time. Construction time is the total time elapsed between the contract award date and the beneficial occupancy date. Design-build construction time begins on the construction start date and ends on the beneficial occupancy date. Some design-build projects reported the construction start date on the same date as the design-build design start date.

**Cost**: The amount of money paid by an owner for the design and construction of a facility, measured in U.S. dollars. Costs exclude the value of land acquisition, extensive site work, process equipment or owner costs.

**Design-Build**: The process whereby an owner contracts with a single entity to perform both design and construction under a single design-build contract. Contractually, design-build offers the owner a single point of responsibility for design and construction services. Portions or all of the design and construction may be performed by the entity or subcontracted to other companies (either design or construction).

**Design-Bid-Build**: Traditional project delivery system in the U.S. construction industry wherein an owner contracts separately with a designer and a construction contractor. The owner normally contracts with a design company to provide complete design documents from concept (0% design) through detailed design drawings and specifications (100% design). The owner or owner's agent then solicits bids from construction contractors based on the design drawings. One contractor usually is selected and enters into a contractual agreement with the owner to construct the facility in compliance with the design drawings and specifications. The owner contracts separately with a construction contractor based on acceptable bids estimated from the design documents to execute and complete facility construction.

**Facility Delivery Process**: The activities required to provide a facility from facility programming through facility operation and maintenance.

**Facility Programming**: "The process of analyzing the owner's desires, needs, goals and objectives in order to define the essential facility requirements and present that criteria to the designer. The program must establish and maintain an information framework which can be utilized as an evaluation and decision making tool throughout the life cycle of construction" (Perkinson, 1991).

**Facility Team**: "All parties who perform activities in the facility delivery process. These may include the owner architect/engineer, constructor, design-build entity, and subcontractors" (Konchar, 1997).

**Project Delivery Speed**: The rate at which a facility is delivered from contracted concept design initiation to beneficial occupancy date at construction completion. Based on a facility's gross square footage, delivery speed is measured in square feet per month of project duration.

**Project Delivery System**: The roles, interaction, and obligations of contracted parties and the sequence of activities necessary to provide a facility project from design concept initiation through construction completion.

**Project Design Phases:** The four sequential phases of a project's design throughout the entire design process from zero percent design complete to completion of construction documents. The four phases are as follow:

**Concept Design Phase**: (0% to 15% design) The start of the facility design process initiated by the design contract award date. This phase of design includes preliminary project estimate, site analysis, and conceptual architectural drawings (AIA, 1987).

**Schematic Design Phase**: (15% to 35% design) Graphical sketches, models, and spatial relationships from the concept phase are developed into clearly defined project site layout, interior spaces and dimensions, building systems and component equipment layout, parametric estimate and engineering reports (AIA, 1987).

**Design Development Phase**: (35% to 65% design) The phase in the design process wherein a detailed construction estimate is begun, architectural plan, section and elevation relationships are finalized, structural foundation and facility frame are refined, building systems are appropriately sized, outline specifications are developed into respective sections, and material selection is well-underway (AIA, 1987).

**Contract Documents Phase**: (65% to 100% design) The phase after design development is complete wherein the construction project estimate is finalized, construction drawing details are created and completed, all materials are scheduled, building systems are fully integrated, specifications are completed, and construction bidding documents are completed (AIA, 1987).

**Quality**: The degree to which a facility meets the expected facility performance. Quality is measured by comparing the actual performance with the facility user's or owner's expectations of the referenced building.

**Schedule**: The total elapsed time taken by the facility team to design and construct a facility, measured in calendar days.

## ACKNOWLEDGMENTS

I would like to thank the Air Force Institute of Technology for this opportunity to advance my knowledge by believing and investing in my professional and technical skills through The Pennsylvania State University Construction Management graduate program.

To my mentor and coach, Dr. Victor Sanvido, I express my genuine appreciation and deepest respect for your persistant inquiry, integrity and vision. Your knowledge, perspective, and motivation served as a catalyst to drive my academic pursuits, research frustrations, and dedication to advancing the design and construction industry. Thank you for teaching me how to learn for life.

To my friends and colleagues in the Computer Integrated Construction Laboratory, I am sincerely grateful for your camaraderie, support and patience in conducting this research. I extend particular thanks to Dr. Mark Konchar whose interest, insight and expert consultation provided tremendous value to this research. Thank you all for teaching me the importance of collaboration and teamwork.

To my role models, Mom and Dad, I owe my confidence and accomplishments to your parenting. My goals and dreams would not be attainable were it not for your constant interest, encouragement, and love. Thank you for teaching me discipline, responsibility, and compassion.

Most importantly to my two beautiful ladies, my wife Michelle and daughter Katie, I owe you my eternal love, gratitude and devotion. Your sacrifice, unending belief, patience, strength and ceaseless smiles put this research effort and life itself into perspective. Thank you for teaching me the power of love and life.

# CHAPTER 1

## INTRODUCTION

As early as the 1960s, the design and construction industry recognized that the success of a project was often impacted by the project delivery system used (AIA, 1975). Owners sought alternatives to the traditional design-bid-build method to obtain professional services and guaranteed price to deliver their projects within cost, schedule and quality requirements without having to commit to complete design.

Over the past several centuries until the conclusion of World War II, the master-builder was the dominant professional responsible for project delivery (Sanvido et al., 1992). This master-builder was educated and trained to be fully knowledgeable of and responsible for both the design and the construction of their projects. However, as buildings became more specialized, master-builders were replaced by specialists in planning, design, contracting and construction, thus effectively fragmenting the design and construction process. As a result, the design-bid-build or traditional method emerged as the standard project delivery system in the United States construction marketplace.

This is especially true of the United States Federal Government which has structured its project acquisition and execution policies around the design-bid-build project delivery system. Over the past several decades the traditional design-bid-build method of sequentially planning, designing and constructing facilities has successfully met some of the demands of the cost and schedule driven federal projects. Despite these successes, this system has some shortcomings. Pocock (1996) reported an average cost growth of approximately 8% since 1988 for military projects utilizing this traditional system. With federal construction budgets becoming smaller (Ichniowski, 1998), the government is looking for more effective methods to deliver projects using increasingly scarce resources.

As a designer and project manager in the Air Force, the researcher has personally encountered and contributed to problems stemming from the "hand-off" of the design from the architect to the construction contractor. Often times, the design did not come to fruition nor did the building support the user's goals or needs. This does not suggest that all projects encounter problems associated with the use of the traditional system. In fact, there is no evidence on which to make such a claim of one system's performance over another for federal projects. An objective and quantitative comparison of projects accomplished by design-bid-build and design-build will help federal agencies decide which project delivery approach might be better suited for a project.

## 1.1 Background

The design-build concept has been gaining in project application in recent years in the general building sector of construction. Most recently it accounted for nearly 25 percent of the 286 billion dollars expended in 1996 for non-residential construction (Tarricone 1996, U.S. Dept. of Commerce, 1997). This marked a 103 percent increase in the number of design-build contracts over $5 million in value from the previous year (DBIA, 1996). As the interest in and the use of alternate project delivery mechanisms, especially design-build, grows within the private sector (Kreikemeier, 96), the United States Federal Government is likewise seeking to inject contractor expertise into the design process via design-build project delivery.

In 1967 design-build was introduced into the federal sector by order of Congress for limited use only on residential projects within the Department of Defense. This was a major milestone in challenging the policies governing both the procurement of design A/E services (Brooks Act, 40 U.S.C. SS 541) as well as competitively bid construction contracting (FAR, Part 36.103). From 1985 to 1993 the use of design-build project delivery for military construction projects was limited to 3 facilities a year, with less restrictions imposed on the frequency of its use after 1993 (Duncan, 1997). The United States Postal Service executed its first design-build project in 1989. It has steadily increased its use of design-build project delivery by approximately 5 percent each year to its current 30 percent share of USPS project delivery (Ferrari, 1997). Recently, passage of the Federal Acquisition Reform Act of 1996 formally authorized design-build project delivery for broad application by federal agencies for their facilities. This change will most likely increase the use of this project delivery system.

The Federal Bureau of Prisons (FBOP) recently changed its contracting philosophy and delivery process to design-build (Ichniowski, et al., 1998). FBOP cited design and construction collaboration as the main reason for adopting design-build. This integration of the designer and contractor is usually deemed more desirable since it allows designers and builders to interact during initial concept design, material selection, and constructability reviews (The Collaborative Process Group, 1996). This should allow FBOP to better cope with cost and time pressures to execute several new prison facilities over the next several years. A recent study of military projects using various project delivery systems identified a relationship between degree of project integration and successful project execution (Pocock et al., 1996) worth investigating further. Unfortunately, very limited literature exists that objectively and quantitatively reports the successes and lessons learned from the applications of design-build within the federal government.

## 1.2 PROBLEM STATEMENT

Very little objective and quantifiable data has been collected that shows specific cost and schedule savings or enhanced quality performance by delivery systems used on public projects (Mouritsen, 1993, Songer 1996). A comparison of project costs, schedule and quality performance of design-bid-build and design-build projects will establish a benchmark. Next, a list of guidelines to better help owners select delivery systems for U.S. Federal Construction Program projects can be developed.

## 1.3 RESEARCH OBJECTIVES

The research had the following four objectives:

1. Compare total project costs, schedule and quality characteristics of U.S. Federal Government projects using design-build and design-bid-build delivery systems by facility type and performance metric.
2. Relate these cost, schedule and quality findings to those found in the general public and private sectors of construction.
3. Investigate objective metrics to equally measure each delivery system's performance.
4. Describe project characteristics which explain the highest proportion of variation in delivery speed performance.

### 1.3.1 SCOPE

This research focused on data collected from public sector facility projects completed inside the continental United States within the past five years. Project data collected from the General Services Administration, Department of Defense, Department of Veterans Affairs, the National Aeronautics and Space Administration, and the United States Postal Service represented federal design and construction projects. Though local and state governments also execute facility projects within the public sector of the United States, they adhere to jurisdictional regulations and restrictions which vary by municipality and state (Roberts et al., 1996). Their procedures are not necessarily in accordance with federal acquisition regulations; therefore, local and state public agency facility projects reported in this study are considered independently of the federal construction sector.

The federal acquisition regulations also served to narrow the scope of alternate project delivery systems studied. Construction management is another project delivery system used within the private sector; however, this mechanism is not currently supported in executing federal construction projects within the United States.

Project performance examined in this study is limited to the installed costs, schedule and quality measures of the projects reported. The time and costs to accomplish pre-project planning activities and programming documentation are not included in this research. These tasks occur prior to the start of the project delivery process as measured from zero percent design complete in this research. Likewise, actual cost and schedule data to complete facility start-up and operation beyond the beneficial occupancy date were not collected. Other costs and benefits, such as organizational, social and environmental, and compliance with existing ordinances and statutes of various governmental entities are not addressed in this study.

### 1.3.2 RELEVANCE

Differences exist between the organizational behavior and composition of the private sector and the public sector design and construction industry. This is based on the position of the owner and his/her agents in administering, monitoring, and paying for the project (NSPE, 1994). However, it is assumed that both delivery systems attempt to provide facilities at the least possible cost to meet the facility requirements. Certainly, the private sector is more profit driven, whereby the project delivery system serves to support the most efficient execution of the facility. In contrast, the federal government is more process driven in the procurement and execution of projects due to regulatory and budgetary constraints imposed by Congress (Mouritsen, 1993). Therefore, this research is critical in reporting accurate project performance data and measures for federal construction projects. As a result, influential project characteristics that are identified within the owner's control can help government agencies better execute their facility projects within their regulatory constraints.

## 1.4 RESEARCH METHODOLOGY

Critical success factors and criteria identified through the literature review were used to develop objective project performance measures. A structured survey distributed throughout the federal construction industry provided comprehensive project data. Statistical analysis of projects by delivery system and facility type allowed direct comparison of project performance and the identification of variables most influential in explaining project outcomes.

To achieve the research objectives, the following steps were taken.

1. Review relevant literature.

Inquiry into project delivery literature provided an understanding of the current state of project delivery specific knowledge and research. Literature review encompassed building process models, critical success factors, owner selection criteria, comparative studies of project delivery performance, and objective measurement and testing.

2. Develop and test objective performance metrics.

A data collection questionnaire was developed to objectively collect cost, schedule and quality data. The data collection instrument was designed through several trial attempts using actual project data provided by member organizations of the Construction Industry Institute (CII) Taskforce sponsoring this research. Project characteristics identified through literature and expert interview were incorporated into the data collection tool for use in clearly defining the project type as well as explaining any specific project attributes that may explain differences in performance.

3. Collect data.

Data was collected in two phases. Phase one data collection distributed a data collection tool via mail to project owners, architect/engineers, design-builders, and constructors nation-wide. Use of the survey provided random sampling of the entire construction industry. Follow-up phone calls to respondents verified the accuracy and completed the data. The quality rating input was provided by owners, thus preventing bias by constructors. This data collection effort constituted the original base study data collection sponsored by the Construction Industry Institute (CII).

Phase two used interviews with each public project owner to identify all federal projects. Collaboration with federal experts and project owners identified several key issues omitted in the original study. As a result, new cost and schedule questions were developed to support new performance measures. New performance measures compared project delivery systems by performance metric including all design effort starting at zero percent design complete. Furthermore, federal project owners, specifically project managers and facility users/ operators, reassessed the quality performance of their facilities one year after their initial quality ratings were provided in the CII study.

4. Analyze data

To objectively analyze costs and compare similar facilities by delivery system, costs were indexed and facilities were classified. Project unit costs were adjusted for time and location to baseline all projects as of December 1996. Based on the initial building type reported from each respondent, researchers analyzed each facility's systems and their complexity, team member experience, project systems used, and facility unit cost to identify any similarities. This exercise subsequently categorized each facility into one of six facility types: light industrial, multi-unit dwelling, simple office, complex office, heavy industrial, and high-technology.

Univariate comparisons were conducted on the original CII study data when sorted by private, public and federal projects for each facility type. Univariate comparisons of delivery systems for each performance metric utilized non-parametric statistical methods to test for significant inequalities in reported data. Both mean and median values were statistically tested using 2 sample t-tests and Mood's median tests to represent the central tendency of the reported cost and schedule performance data. Quality performance data collected using discrete variables required the sole use of 2 sample t-tests to compare each delivery system's mean score for significant differences. Hypothesis testing was conducted on all 85 original projects and 3 new projects by delivery system for all projects and for each facility type. Results of significant differences were provided at the 95 percent confidence level. Next using new project data, univariate comparisons of design-build and design-bid-build federal projects analyzed differences based on the new cost and schedule data inclusive of initial design efforts. Comparisons again addressed delivery system performance for all projects and for facility type.

Multiple linear regression modeling of the delivery speed metric was used to test the influence of several variables on the variation in delivery speed for all 88 projects. With all other variables present in the explanatory model, each delivery system was tested individually to measure their impact on the performance metric, and hence identify the differences between them.

## 1.5 RESEARCH FINDINGS

Based on the objectives previously noted, this research provided the following results:

1. Direct, objective comparisons identified design-build projects performed better than design-bid-build projects for private, public, and federal projects; however, results differed by performance measure and facility type for each owner.
2 Federal design-build and design-bid-build projects experienced equal delivery speed performance when measured from zero percent design start.

3 Qualitative investigation of the influence of time since project completion identified design-build projects to have less difficulty in facility start-up and lower operation/ maintenance costs than design-bid-build projects.

4 Projects contracted for construction during the concept design phase performed better than projects contracted during the construction documents phase.

5 Facility size, facility type and delivery system explained the greatest proportion of project delivery speed variation.

### 5.1 Reader's Guide

Chapter 2 defines the project delivery systems studied in this research and provides summaries of project delivery related literature. Chapter 2 includes research on project delivery process modeling and project planning, non-empirical studies of project success factors and criteria, and empirical studies of project delivery system performance. Chapter 3 provides a description of the data collection methods used in acquiring objective data from both industry-wide and federal owner specific projects. The data collection tool is accompanied by definitions of all the variables included in this instrument. Federal project owner specific questions are also explained in detail. In chapter 4, the fifteen project performance metrics are followed by the associated univariate and multivariate data analysis comparisons of project delivery systems. Chapter 5 provides the results of comparing delivery systems by performance metric for both the original CII and new federal data. Chapter 6 presents contributions and limitations of this research, future research areas and conclusions.

# CHAPTER 2

# LITERATURE REVIEW

Chapter 2 provides a summary of recent and current research to establish the framework for this thesis. This chapter first defines project delivery for design-build and design-bid-build, followed by summaries of relevant project delivery system research. These empirical and objective studies address the delivery system process, its application and selection within the private and public sector construction industry.

## 2.1 PROJECT DELIVERY SYSTEMS

Projects can be designed and constructed in a variety of different combinations in delivering a complete and useable facility. Some of the generic names assigned to delivery mechanisms used throughout the United States are construction management at risk, construction management agency, program management, multiple-prime contracting, design-build and design-bid-build. According to Ireland (1982), all the various delivery method definitions attempt to "describe the roles of participants, the relationships between them, both formal and informal, the timing of events and the practices and techniques of management that are used." Therefore as applied to this research, a project delivery system is defined as the roles, interaction, and obligations of contracted parties and the sequence of activities necessary to provide a facility project from design concept initiation through to final construction completion.

Two of the project delivery systems mentioned previously, design-build and design-bid-build, are compared in this research. Although each system can exist in various organizational forms, each system is based on different fundamental commitments to the project owner.

Figure 2.1 illustrates the basic contractual relationships for design-build project delivery where the owner holds only one contract with a design-build entity. Several design-build options include: design professional as the design-build entity; general contractor as the design-build entity; joint venture between general contractor and design professional as the design-build entity; and design-build company with both in-house design and construction capability (Sanvido et al., 1992). Another configuration identified via dashed lines in Figure 2.1 is where the owner contracts separately with an architectural engineer to accomplish a portion of design prior to the award of the design-build contract. This method, known as bridging (Kenig, 1996), is commonly used in the federal sector as a recognized and accepted form of design-build project delivery

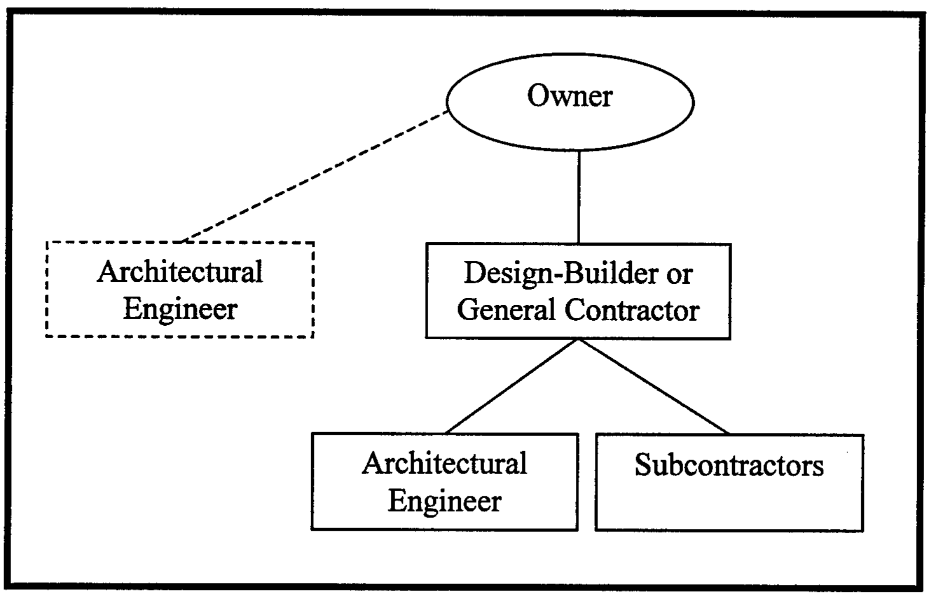


Figure 2.1: Contractual relationships for design-build projects.

Figure 2.2 illustrates the basic contractual relationships for design-bid-build projects. The owner holds separate design and construction contracts to deliver the project. Typically, there is no direct interaction between the designer and constructor prior to construction bid.

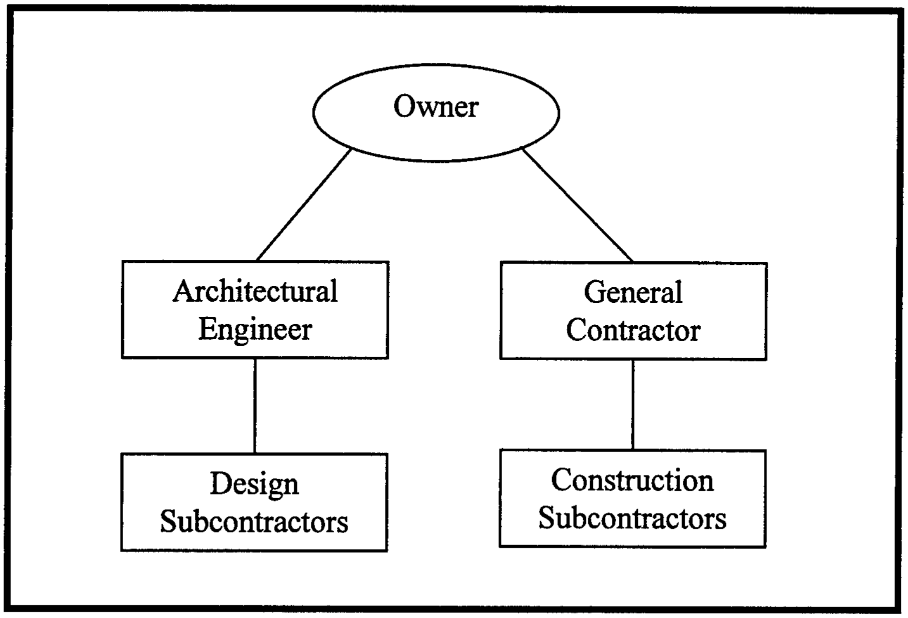


Figure 2.2: Contractual relationships for design-bid-build projects.

Besides the contractual relationships, these two delivery systems are also defined by relative sequence of activities illustrated in Figure 2.3. The design build contract typically begins after formal acceptance of the design-build entity's proposal at the conclusion of the construction procurement phase. However, partial design may be developed during the construction procurement phase to satisfy the request for proposal's design submittal criteria. Therefore, the date of project advertisement would reflect the actual start of design for the design-build project. Furthermore, the design-build bridging option may initiate an architectural engineer to start concept design in the design phase to prepare the request for design-build proposals used in the construction procurement phase.

The design-bid-build delivery system sequence begins with the start of conceptual design. Typically, once design is completed through the contract documents, the project is advertised for bid. This begins the construction procurement phase. During the construction procurement phase, general contractors formulate their bids based on the contract documents and submit them usually in open competition. The construction notice to proceed date identifies the start of the construction phase.

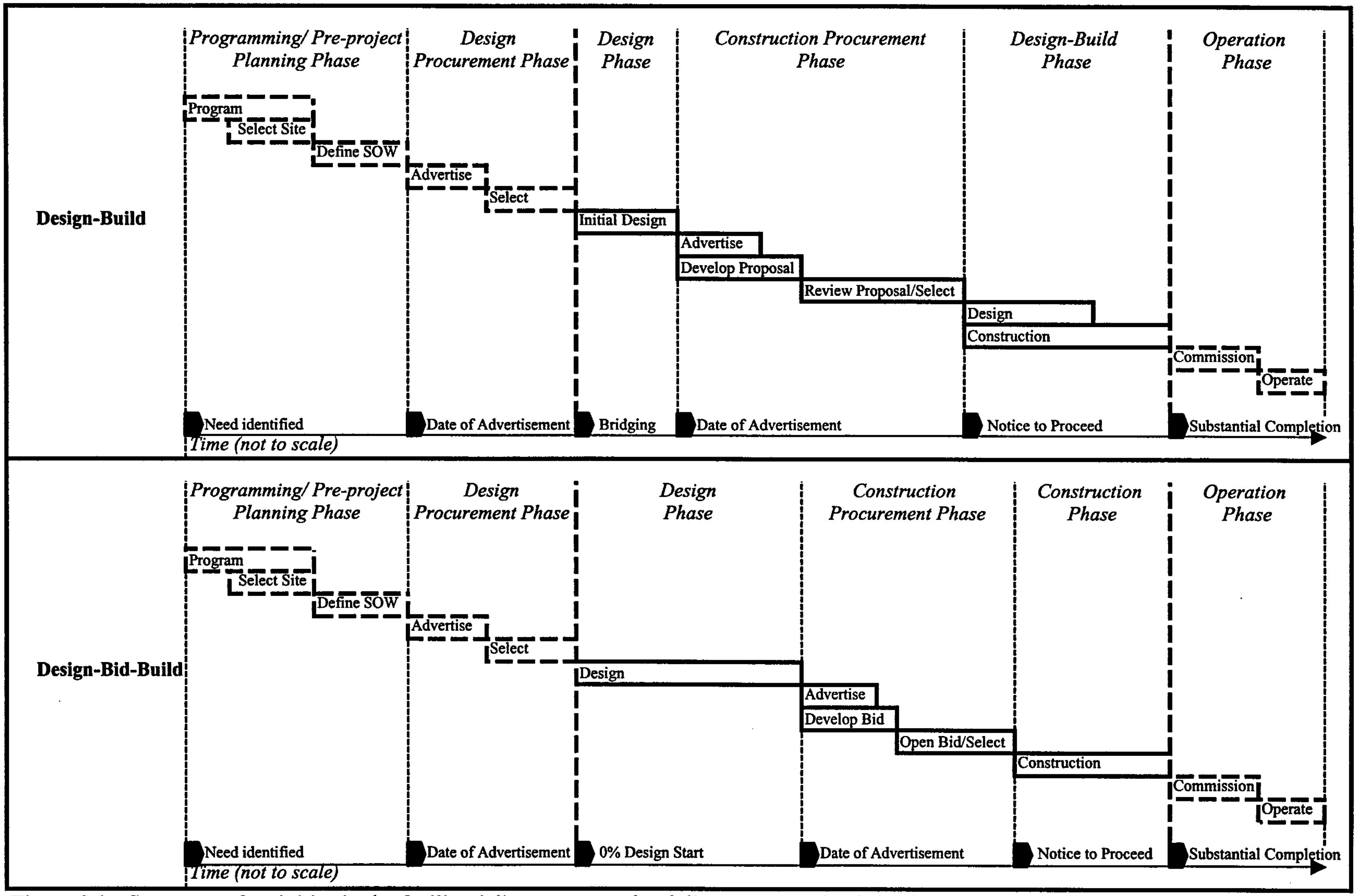


Figure 2.3: Sequence of activities in the facility delivery process by delivery system for federal projects.

The activities illustrated by dashed lines (see Figure 2.3) prior to the start of the design phase and after substantial completion of the construction and design-build phases are not included in the project delivery process as measured by this study. All programming documentation, site selection, and definition of project scope of work as well as selection of the designer is accomplished prior to the start of design for both delivery systems. Likewise, building commissioning or start-up and subsequent facility operation is conducted after substantial completion of the construction or design-build contract. Therefore, the costs and time to operate a facility were not formally measured in this study.

Based upon the contractual arrangements and sequence of activities previously discussed, this thesis uses the following definitions to describe each of these delivery systems. *Design-Build* is a project delivery system in which an owner contracts with a single entity to perform both design and construction under a single design-build contract. Contractually, design-build offers the owner a single point of responsibility for design and construction services; however, a portion of the design may be accomplished prior to the award of the design-build contract. After contract award, the entire design or portions of the design and construction may be performed by the entity or subcontracted to other companies (either design or construction).

*Design-Bid-Build* is a project delivery system in which an owner contracts separately with a designer and a construction contractor. The owner normally contracts with a designer to provide complete design documents from concept (0% design) through detailed design drawings and specifications (100% design). The owner or owner's agent then solicits bids from construction contractors based on the design drawings. One contractor usually is selected and enters into a contractual agreement with the owner to construct the facility in compliance with the design drawings and specifications. The owner contracts separately with a construction contractor based on acceptable bids estimated from the design documents to execute and complete facility construction. The construction entity may perform all of the required construction work or subcontract all or portions of the construction.

## 2.2 RELEVANT RESEARCH

In the 1980s, very few if any public agencies were executing projects via design-build project delivery; therefore, historical project databases tracked and recorded only traditional design-bid-build project delivery. Increased use of design-build has prompted many federal and professional organizations to critically address the project delivery process, identify success criteria for delivery system selection, and subsequently measure project performance. In response to this need for design-build information, Songer (1996) created a comprehensive bibliography of design-build studies and articles. This literature review provided the researcher with a good historical understanding of the design-build mechanism and the overall lack of empirical research on the subject. It represented project owner and construction industry experiences with design-build.

Within the federal sector, several agency specific case studies, such as the United States Postal Service (USPS) General Services Administration (GSA), and Naval Facilities Engineering Command have attempted to investigate project performance (Fraga, 1996, General Services Administration, 1997, Emmons, 1996). Extensive case study investigation of design-build projects and their administration provided several recommendations to improve the internal effectiveness of the USPS's use of design-build project execution (Fraga, 1996). A recent GSA benchmarking study compared several GSA projects within four building types by geographic region across the US in terms of design time, procurement time, and construction time. However, these two studies either focused too specifically on individual project delivery performance or not at all, therefore not providing direct evidence of better or worse project delivery system performance. Furthermore, no project attributes were used to explain any variation in delivery performance.

Several subjective opinion polls within both public and private industry established a foundation for comparison of project delivery systems based on owner experiences and attitudes towards their selection and use (Federal Construction Council, 1993, Molenaar, 1995, Songer, 1996). Many of the success criteria and project characteristics identified in these studies spawned further survey research of actual project data employing both empirical and objective measurement (Mouritsen, 1993, Pocock, 1996, Bennett et al., 1996, Konchar, 1997). Though some advancements have been made in knowledge of comparative project delivery system performance, more specific inquiry is needed to explore owner specific differences between delivery systems.

### 2.2.1 Delivery Process Modeling And Planning

Many activities and decisions occur in the process of construction that can influence the success or failure of a project's outcome (Sanvido et al., 1992). Several models have been developed that identify the tasks and variables as well as their relative interactions that form the process of project delivery and the resultant facility product.

Wheeler's (1978) project life-cycle model provided a project activity breakdown structure representative of the entire building construction process developed through research within the facility design industry. His model identified nine separate phases in the process of building from concept master plan through to building operation. He recognized the complexity of design and construction, building systems integration and construction cost controls as requiring a collaborative team effort among project managers, architects, engineers, and constructors in all phases of the building process.

Sanvido's Integrated Building Process Model, IBPM (1990) identified 5 primary activities required to provide and maintain a facility throughout its lifecycle: manage, plan, design, construct, and operate. Created from an owner's viewpoint, this model decomposes the facility delivery process by hierarchy of tasks, participants, and information flow. Interrelationships and required decisions between the 5 major activities and sub-activities are identified irrespective of project delivery system. When applied to specific delivery systems, this model identifies those decisions and information that may become internal to the entity performing more than one major activity.

Perkinson (1991) created an information framework for organizing and implementing facility programming throughout the life-cycle of a building, inclusive of the five distinct phases identified by Sanvido (1990). The facility design and the subsequent satisfactory completion and performance of the constructed project is directly influenced by the clarity and definition of the facility program (the result of the planning phase). Well defined requirements and budgeted programs based on the delivery system to be used positively impacted the design and construction effort by improving communication of specific facility needs. Though closely linked, programming is accomplished by the owner prior to and completely separate from the design (Pena, 1987).

Another study (Songer, 1992) focused on modeling the decision process of public sector owners in planning design-build projects. Developed via survey responses and personal interviews with public sector owners, this research modeled pivotal owner decisions in the initial planning, analysis and execution of design-build programs and their subsequent projects. He noted a paradigm shift was necessary for owners to identify and provide functional design and construction requirements for design-build projects rather than prescriptive drawings and specifications used for design-bid-build projects.

Lynch (1996) developed a transaction cost framework for evaluating construction project organizations in making objective comparisons between project delivery systems. Based on the owner's perspective, this study identified five levels of cost analysis within a construction project organization: individual, group, firm, inter-firm, and project. Lynch defined project delivery systems in terms of contract integration whereby high contract integration represents design-build, and low contract integration represents design-build. Interrelationships of the following five separate project activities based on the level of project contract integration were tested at the project level:

- Project procurement
- Contract administration
- Information communication
- Firm interaction
- Production

Empirical model testing gained through case study application identified several positive and negative relationships between contract integration and project variables. For example, as the level of contract integration increased so did contractual reliance on functional requirements which in turn decreased the complexity of the contractual agreement. In contrast, higher contract integration decreased competition or the available pool of contractors/design-builders which increased owner's efforts and costs to negotiate the contract. For contract administration, higher levels of contract integration improved team experience and continuity of information flow. This subsequently reduced the likelihood of "developing a design beyond the point which would become necessary to communicate the design intent." (Lynch, 1996). Tests validated the interrelationships identified in the model; however, no conclusive or statistically significant results between delivery systems were provided.

### 2.2.2 Empirical Project Delivery Research

The research findings that follow consist of subjective owner and construction industry opinions and assessments that attempted to quantify aspects of project delivery systems. Resultant rankings of characteristics, success factors, and project delivery performance identified several common criteria for using one system over another.

A 1993 survey conducted by the Federal Construction Council Consulting Committee on Cost Engineering investigated the experiences of nine federal agencies with the design-build project delivery method based on 27 medium complexity projects. Respondents provided their reasons for selecting design/build, and their opinion of the relative performance of design/build projects compared to previous experience executing similar projects via design-bid-build. Reasons for using design-build were to gain time savings, lower cost, and to test the use of design-build. Increased quality and the size of project were listed as less important reasons.

Respondents next rated their respective design-build project as "much worse, somewhat worse, about the same, somewhat better, or much better" than a similar project procured through design-bid-build. Comparisons addressed the following 17 evaluation factors:

- Functionality
- User satisfaction
- Quality
  - Quality of design
  - Quality of materials
  - Quality of workmanship
  - Overall quality
- Cost
  - Cost of planning and programming
  - Cost of agency contract administration
  - Cost of design
  - Cost of construction
  - Overall costs
- Number of change orders
- Extent of other contract problems
- Time
  - Time required for planning and programming
  - Time required for design
  - Time required for construction
  - Time required overall

Average scores for each factor indicated design-build compared favorably with design-bid-build in all respects. However, detailed inspection of cost and time for design and construction yielded varying levels of satisfaction based on the percent design complete prior to hiring the design-build entity. Design-build projects awarded during the schematic design phase achieved better cost and time scores than other design-build and traditional design-bid-build projects. Interestingly, the study noted difficulty in accurately measuring design time for the design-build projects because this time was not tracked separately on the construction schedule.

Through a subjective survey of public sector owners, Molenaar (1995) reported 88 respondents' rankings of critical project characteristics, critical success criteria, and critical selection factors regarding public sector design-build. Respondents provided rankings of pre-selected variables presented in the survey. Of the fifteen critical project characteristics identified on the survey, the following 6 received the highest mean scores. These are the most influential for a successful design-build project:

- Well defined scope
- Shared understanding of scope
- Adequate owner staffing
- Owner's construction sophistication
- Established budget
- Established completion schedule

Six project success criteria were also ranked. The three primary criteria in order of importance were: on budget, conformance to owner expectations, and on schedule. Of the seven critical selection factors provided in the survey for owners to rank, mean scores strongly supported shortened project duration as the primary advantage of design-build procurement. This study concluded that though shortened project duration was identified as the most important selection factor for using design-build, owners relied more on cost performance than schedule performance to indicate project success. This study recognized that differentiation between various forms of design-build regarding percent design complete before design-builder selection and the selection method would have benefited this research.

### 2.2.3 Objective Project Delivery Research

The following sources reported statistically tested research findings based on actual, unbiased project data drawn from a representative sample of like-industry or like-owner projects. Each of the following studies provides various measures directly comparing project delivery system performance.

Mouritsen (1993) conducted a survey of 36 projects executed by the Naval Facilities Engineering Command (NAVFAC) using design-bid-build and two distinct forms of design-build project delivery. These were source selection, and the "Newport" or bridging method. Solicited in response to a request for proposal, source selection competitively negotiates with contractors based on best and final offers which does not limit award to the low cost proposer. The Newport or bridging method is based on competitive low bid on 30 percent design complete drawings.

Project delivery specific comparisons of child care center, water tank, and training range projects based on 9 measures resulted in statistically tested cost and schedule savings favoring the overall use of design-build. Results were based on a relatively small sample of 13 design-build projects and 23 design-bid-build projects. No explanation of variance supported by project attribute data between project delivery system performance was provided.

Pocock (1996) analyzed 209 military projects executed using design-build, design-bid-build, partnered, or combinations of these project delivery approaches to identify any significant differences between their performance. Mean measures of cost growth and schedule growth for projects executed in each category indicated that combination projects (projects incorporating beneficial aspects of partnering and design-build teamwork) out performed both design-build and design-bid-build individually. Impacts on cost and schedule were reported in terms of number of contract modifications and design deficiencies. No significant correlation could be statistically identified among the alternate project delivery systems. Building upon this research, Pocock (1996) conducted univariate statistical tests to measure the impact of project integration on project performance. Consistent with Lynch's modeling of level of contract integration, Pocock's results indicated higher degrees of team interaction among each of the alternative delivery systems.

A recent study conducted by the University of Reading's Design and Build Forum provided the first comprehensive industry-wide survey of project performance for several delivery systems (Bennett et al., 1996). The Reading study included univariate cost, schedule and quality results and multivariate cost and schedule project performance comparisons. Data was drawn from 332 private sector projects. Project attribute data identified project location, size, construction type, building functions, and project management organization. These were used as explanatory variables in constructing multivariate regression models of cost and schedule metrics.

The delivery systems consisted of design-bid-build, design and manage, and three variations of design-build: traditional UK design-build, develop and construct, and consultant novation. Using traditional design-build, an owner solicits contractor assistance in performing initial design and then later negotiates to have full design and construction accomplished by that contractor. With design and manage, an owner hires a construction management specialist to coordinate the procurement of both design and construction. Results of this delivery method's performance were not included in this study for two reasons: the construction management specialist did not hold any risk in managing the process, and this method was not adequately represented. Develop and construct varies only slightly from the traditional design-build approach based on the extent of design developed prior to engaging the design-build entity. With consultant novation, owners independently contract to have design accomplished until the point at which the construction entity contractually joins the project team. Once the constructor is engaged, the designer is contractually assigned to the constructor to complete the remainder of the design.

Though individual results identified consultant novation as providing the worst outcome in meeting clients' quality expectations, collectively the design-build projects provided better results than the comparative use of design-bid-build. Of greatest significance were: faster construction and delivery speeds with a greater likelihood of timely completion; lower unit costs with a greater likelihood of completion within five percent of budget; and a higher likelihood of meeting desired quality.

Multivariate regression analysis was used to further explain construction speed, delivery speed and unit cost of projects. Results showed that project attribute variables other than delivery system exerted more influence on the performance of these projects. Thus, delivery system alone does not ensure better project performance.

Konchar (1997), in collaboration with the researcher, conducted a similar study of U.S. project delivery systems. Three hundred and fifty one completed projects delivered via construction management at risk, design-build, or design-bid-build were analyzed and compared. Specific cost, schedule and quality data were collected for seven project performance measures. Based on the project delivery framework he developed, a data collection tool (described in section 3.1.1) was used to objectively record cost, schedule and quality performance data. Variables known to impact project performance, such as team communication and facility systems, were included. Cost performance was measured by two metrics; unit cost and cost growth. Four schedule performance measures used were schedule growth, delivery speed, construction speed, and intensity. Seven items were used to present 3 quality performance measures representing building turnover, building systems, and process equipment.

Univariate and multivariate statistical tests of project data showed significant differences between these delivery systems. Univariate differences between delivery systems identified all design-build projects to perform better than traditional design-bid-build projects for six of the nine performance measures overall. Differences by facility type were noted in favor of design-build delivery for five of the six facility types; however, each for a different performance measure.

Several limitations were noted as a result of this research:

1. Project performance measures only considered the design and construction process which prevented identification of impacts resulting from other phases of a project.
2. Change order and claim data was not collected; therefore, not addressing the impact of both owner initiated changes and design deficiencies on project performance.
3. The age of the facilities may have misrepresented the perception of quality at the time survey response data was requested.
4. Project delivery timelines vary based on the time necessary to procure design-build and construction services, making it difficult to equate the actual start for all projects.

## 2.3 SUMMARY OF LITERATURE REVIEW

Though projects are often viewed as unique endeavors, this literature survey provides evidence that several project variables have the potential, either independently or in combination, to explain differences in project performance at various stages in a project's delivery. Interestingly, Sanvido's (1990) four critical project success factors were repeatedly found as beneficial project attributes in this literature review. These were teamwork, contracts that act as catalysts to unite the team, specific facility type experience, and early constructability input. Other common criteria in the literature that impact desired outcome included: definition of project scope, user input, prioritized goals, qualification of designer and constructor, existence and implementation of project controls, and assessment of risk.

# CHAPTER 3

# DATA COLLECTION METHODS

Chapter 3 outlines the methods used to objectively collect and record project cost, schedule and quality performance data used to compare design-build and design-bid-build projects within the federal sector. This research uses quantitative and qualitative project specific data collected via a structured survey. This research method is based on previous empirical research methods (Pocock, 1996, Bennett et al., 1996, Mouritsen, 1993). Project performance data was based on factual records maintained by federal project owners and construction entities. It did not rely on their opinions. Follow-up survey interviews expanded upon the initial data collection effort and provided two new sets of data. These were cost and schedule data for design which was accomplished prior to design-build or construction contract, and quality data measuring the effects of time on quality assessments. The following sections describe the variables collected and the methods used to collect and record project data.

## 3.1 PHASE ONE DATA COLLECTION

As part of a collaborative research effort, this study collected and utilized 85 federal projects provided via a recent industry-wide project delivery system survey (Konchar, 1997). Three hundred and fifty one project survey responses collected in January 1997 provided a large representative sample of the design and construction industry. It had a broad geographic distribution of both private and public projects. Public project responses represented local, state and federal project owners. Of these 351 projects, 273 were executed using either design-build or design-bid-build project delivery. Inclusion of a non-response study validated the sample as representative of the industry.

### 3.1.1 Data Collection Tool

Based on the project delivery framework established in recent research (Konchar, 1997), a survey was developed to organize and capture objective project data known to impact project performance. Refer to Appendix A for the data collection tool. This data collection tool was divided into nine information categories: project characteristics, project delivery system, project schedule performance, project cost performance, project quality performance, project team characteristics, project data, project success criteria, and lessons learned. Descriptions of each section and their associated variables are presented next. Variables known to affect project performance are expressed in italics.

#### 3.1.1.1 Project Characteristics

Projects were first identified by name, *location*, survey respondent, company name, company type, *project facility type*, *building gross square footage*, *number of floors*, and *percentage of renovation and new construction*. This information established whether the project owner, design-builder, architect/designer, or contractor provided the project data. Additionally, project location allowed for geographic identification of survey responses as well as geographic project cost references for labor, materials, and historic location indices.

This section provided initial physical facility characteristics, such as building gross square footage and number of floors, to more accurately classify the facility. The size and number of floors of a project can influence the sequencing of construction activities and hence the schedule performance (Riley, 1994). Percentage of renovation and new construction of the project identified the nature of the design and construction. Renovation projects may have cost or schedule impacts caused by hidden or unforeseen work on a project.

#### 3.1.1.2 PROJECT DELIVERY SYSTEM

Respondents were asked to select the appropriate *delivery system* which best suited the project delivery mechanism used on their project. The systems were construction management at risk, design-build, and design-bid-build. These were defined on the data collection tool.

Respondents also identified the *commercial terms* used for the design-builder or designer and constructor based on their contracts with the owner. These terms define the incentives and motivations of project team members (Kenig, 1996, Sweets, 1994). Lump sum, cost plus a fixed or percentage fee and guaranteed maximum price (GMP) were considered. Lump sum and GMP contracts both restrict the maximum contract price. GMPs also allow for possible shared cost savings to the project team or owner. Cost plus contracts reimburse the actual cost of work completed. The owner must monitor and verify all payments.

#### 3.1.1.3 PROJECT SCHEDULE PERFORMANCE

Respondents were asked to provide *project schedule* dates. These were the *project advertisement date*, *design start date* (notice to proceed), *construction start date* (notice to proceed), and the *construction end date* (substantial project completion). Dates were provided for the *as-planned* or budgeted schedule and the *as-built* or actual schedule. Durations between events were calculated in calendar days. All dates were based on the project schedules maintained by the project respondents.

#### 3.1.1.4 PROJECT COST PERFORMANCE

*Project costs* were defined as the amount of money invested by the owner to accomplish the respective design and construction of the facility for the base building. Property costs, owner costs, costs of installed process or manufacturing equipment, furnishings, fittings and equipment, or other items not a cost of the base building were omitted. Three itemized costs were requested: budget, contract amount, and final cost. Each actual cost figure was asked for the design, construction and total costs. However, if actual costs were not provided, respondents were asked to note that costs were estimated. These were later verified via follow-up interviews with the survey respondent and independently with the project owner.

The cost of *site work*, reported as a percentage of final construction cost for work done outside the footprint of the building, identified the cost of developing the project site. This was useful in comparing level of site work effort to both building gross square footage and number of floors with respect to construction and total project costs.

#### 3.1.1.5 PROJECT QUALITY PERFORMANCE

This section was completed by project owners, specifically project managers or facility users/ maintainers. Project respondents other than the owner could bias facility quality assessments. Responses provided by those who were not owners identified the project owner's point of contact and phone number. Quality input from owners was provided via telephone interviews or facsimile transmittals. To prevent bias due to initial facility turnover at time of substantial completion, quality assessments were provided by owners at least six months after the substantial completion date.

Project quality performance ratings were based on seven quality assessments. Owners rated the difficulty of the building turnover process as low, medium, or high for each of the first three measures. These were *start-up*, *operation and maintenance cost*, and *number and magnitude of call-backs*. The highest possible rating was represented by low difficulty. Owners next rated four facility systems' performance: *envelope, roof, structure, foundation; interior space and layout; environmental systems* (heating, ventilation, air-conditioning, and lighting); and *process equipment and layout*. Owners evaluated whether each system's quality met, did not meet or exceeded performance expectations. In these instances, exceeded expectations was the highest possible rating.

#### 3.1.1.6 PROJECT TEAM CHARACTERISTICS

Nineteen variables describing and evaluating project team characteristics quantify the individual and collective experience and the composition of the team and its action. *Project team selection* identified the method used to procure the design-build and construction entity contracts. Open bidding represented construction entity selection based on open competition with selection decided by lowest responsive bid. Open bidding in conjunction with contract documents identified that the construction bid was based in full upon complete design drawings provided by the owner. Prequalified bidding indicated whether source selection was used to narrow the list of qualified contractors for either open bidding or negotiated contract. Qualification of project teams based on quantitative scoring criteria evaluates a company's capabilities and its project proposal (Potter et al., 1995).

Owners and constructors are both impacted by their *ability to restrain the contractor pool* as this limits their competitive choices which is further impacted by the existence of a *pool of qualified contractors*. The *percent design complete when the construction entity joined the project team* provides significant impact to the successful execution of a project based on early input of construction expertise in the design process (Sanvido, et al., 1992). However, inexperienced constructors and subcontractors unfamiliar with the project delivery system or facility type may be the only project bidders or proposal respondents providing input. This situation might directly and negatively impact project performance. Therefore, *the individual experience of project team members with similar facilities* and with *the project delivery system used on the project* can impact project performance. Respondents rated their applicable project team members' experience as excellent, limited or none.

Beyond individual team member experience, the collective *prior experience of the project team as a unit* presents many benefits to the owner in the satisfactory completion of a project. Companies consistently bidding and constructing federal facilities become familiar with the owner and their procedures as well as repeat subcontracts that can improve *project team communication and team chemistry.* Specifically regarding the *owner-project team relationship*, a first time project between these parties may lack the same trust as a partnered effort or repeat relationship (Kenig, 1996).

The project owner maintains a key role in the team based on their *ability to make decisions, define the project scope* and their *capability* to perform necessary project oversight throughout the delivery process. As identified by Molenaar's study (1995), public project performance is primarily judged on success criteria within the control of the project owners. Each respondent was asked to rate the owner's representative for each of these areas as excellent, adequate, or poor.

Often the manner in which an owner selects the project team depends on the *complexity of the project.* High complexity projects may require specialty design and construction knowledge that may benefit from early construction input. In contrast, low complexity projects such as pre-fabricated metal buildings may not require detailed design input from the owner.

Outside of the project team's control, *regulatory and legal constraints* may limit the procurement methods available for selecting the team. Respondents were asked to rate the relative number of such constraints as many, few or none. Similarly, *onerous contract clauses* imposed by the owner to offset risk (measured as numerous, several, or none) can constrain the effectiveness of the project team. Constraints may be posed by public laws regarding use of disadvantaged businesses or minority/women owned subcontractor organizations which may not have experience with the delivery system, or facility type. These imposed organizational and operational restrictions may hinder communications and development of a shared team culture in executing the project.

#### 3.1.1.7 PROJECT DATA

As identified by previous research (Bennett et al., 1996), cost, schedule, and quality performance of a project delivery system can be influenced by the facility systems and their components. This section categorizes the physical attributes of facilities into nine primary systems. These are *foundation, structure, architectural interior finishes, exterior enclosure, roofing, environment (heating/cooling), electric service and use, controls, and site*. Each system is described by specific sub-systems or items that allow respondents to identify all applicable systems on their project with provisions to identify other systems or components not listed. It is quite possible that more than one sub-system was used in a project thus possibly increasing the complexity of the project. For example, a project located in an urban area requiring mass excavation for slurry wall foundation is much more constrained than a suburban or rural project utilizing a mat foundation. All of these physical project attributes served to accurately define facility types by similar systems.

#### 3.1.1.8 PROJECT SUCCESS CRITERIA

In this section respondents were asked to provide in rank order of importance five criteria that they use to judge project success. Additionally, respondents evaluated each success factor as it applied to the performance of the project on a scale of excellent, average, or poor. Based on their overall impression of the project performance, respondents were provided the opportunity to rate the overall success of the project as excellent, average, or poor.

#### 3.1.1.9 LESSONS LEARNED

This section allowed respondents to provide their own observations and experiences resulting from the delivery of the project. Five questions addressed the existence of possible biases or related experiences regarding the use of the delivery system for the project. Respondents were to provide any reasons, examples, circumstances, or unique project features that may have impacted project performance. Additionally, solicited comments provided valuable information used to clarify and expand upon project characteristics and performance not otherwise captured by the variables on the data collection tool. For example, project delays caused by environmental impacts or hidden conditions found in renovation projects are helpful in explaining schedule variations between what was planned and what was accomplished.

### 3.1.2 DATA STANDARDIZATION

Cost adjustments for projects were based on year completed and location. This allowed direct comparison of project costs. Historical data indices (Means, 1995) were used to equate all reported projects as required to directly compare project performance based on unit cost.

Projects were categorized by respondents into four primary types: general building, light industrial, high-technology, and civil structures (i.e. parking garages). Each had several sub-classifications. The 14 possible facility choices distributed the projects into small sample sizes which contained wide ranges of costs indicating poor classification. To better compare delivery systems by similar facility, a facility classification system was developed. Researchers investigated each survey response regarding building systems used in the project, team member experience, project complexity, unique features identified in the lessons learned, and project unit cost to identify similarities. Projects were re-categorized into one of the following six facility types.

*Light industrial* facilities consisted of primarily large, open structures with minimal electrical or mechanical loads with relatively low project complexity. Associated office space within industrial plants and warehouses is included. Warehouses, storage facilities, military commissaries, postal facilities, and military aircraft hangars were included.

*Multi-unit dwelling* facilities consisted of low-rise residential structures characterized by repetitive living units. These are low complexity projects with general lighting and simple mechanical loads. Federal projects in this category included veteran retirement/nursing homes, and military family housing such as town-houses, bachelors' enlisted quarters and dormitories.

*Simple office* facilities were identified as simple structures of less than five stories in height with primarily concrete masonry unit exterior finishes. Interior spaces were mostly open to accommodate systems furniture, training classrooms, or assembly spaces. General computer and lighting conditions required general office and assembly mechanical loads. For federal projects, this category included training buildings, youth centers, fitness centers, and basic office buildings.

Typically greater than five stories in height, *complex office* facilities consisted of higher complexity projects using mixed structural systems with monumental exterior finishes. Most of these facilities reported intensive computer use coupled with large central mechanical plants to support their operation. This facility type included complex offices, data processing facilities, out-patient medical clinics, courthouses, libraries, and military officers' clubs.

*Heavy industrial* facilities consisted of large projects of average and high complexity that relied heavily on environmental conditions, controls, and electrical systems. Structural systems utilized either structural steel frames or cast in place concrete with panelized exterior enclosures. Food processing facilities and industrial research and development test facilities were included in this category.

*High technology* facilities consisted of high complexity, intensive electrical and mechanical support and high unit costs. Included in this category were hospitals and micro-electronic facilities requiring clean room environments with strict environmental tolerances.

### 3.1.3 DATA VERIFICATION

Follow-up telephone interviews with survey respondents verified project data, clarified survey variables, and collected missing or omitted information (Dillman, 1978, Ott, 1993). As noted previously in the description of project quality performance, contact with owners or owner's representatives was required to accurately collect quality ratings. When owners were contacted to provide their quality input, the researchers used that opportunity to verify project cost and schedule data provided by design-builders, architects/designers and constructors.

## 3.2 PHASE TWO DATA COLLECTION

The initial 85 projects complemented by 3 new federal projects added as of July 1997 created the new federal data set of 88 projects. Preliminary investigation of the original CII data set during data verification noted inconsistencies in survey cost, schedule and quality reporting. Direct comparisons of delivery systems rely upon accurate, timely, and unbiased representations of cost, schedule and quality. In the phase one data collection, cost and schedule data was provided from several sources other than the owner. In this phase of the research, all new cost, schedule, and quality data was provided by the owner (project manager and facility users/ maintainers) via telephone interviews. Telephone interviews based on pre-prepared questions allows direct and immediate responses otherwise not achieved through survey distribution (Ott, 1993).

Both researchers and industry experts responding to the initial survey identified several issues requiring further investigation. Based upon the literature review, expert federal agency consultation, and lessons learned from the initial broad survey data collection, eight questions were developed. These questions solicited new project data to more precisely compare both delivery systems from an equal starting point of zero percent design complete. Each of the questions are presented and explained as follows:

- *Would you classify your public organization as belonging at the local, state, or federal level of authority?*

First, the researcher established whether a project response reported as a public project was applicable to local, state, or federal agency jurisdiction and therefore to federal acquisition regulations in the procurement and execution of the project. As the original data collection tool did not specifically allow for federal owner identification, all public projects required clarification on this point before proceeding further.

- *Was the project originally programmed as a design-build or design-bid-build project?*

Development of project requirements for funding approval is accomplished separately from the design process (Perkinson, 1991) for federal projects. The facility program establishes either the means and methods or resultant goal of providing for a completed facility. For example, a design-bid-build project's program might identify specific architectural materials, interior space relationships, and design-review procedures to aid the designer in solving the facility problem through detailed drawings and specifications. Applying the original design-bid-build facility program instead to design-build project execution requires different description of the facility problem in terms of required performance and outcome rather than detailed specification.

- *What was the design start date for design commencement (0 percent design complete)?*

This question identified whether the reported schedule dates presented in the initial data collection reflect all of the design effort which directly supported the design-build contract award or the design-bid-build award. The actual start date of design was necessary in calculating accurate schedule performance for design-build versus design-bid-build. The data collection tool only captured the design start date for design-build projects at the design-build notice to proceed date. For example, design could be advanced via a separate design contractor prior to design-build award. This allows the owner to establish the architectural theme or concept for the candidate design-builders. Another example is development of a more detailed proposal and cost estimate used to evaluate the design-builders' proposals. The design-builder might in fact accomplish design non-contractually as part of the proposal submittal requirements during the advertisement and procurement phase.

- *What commercial terms were used for this design concept initiation effort?*

The method of compensation for the design concept identifies the motives and incentives of the owner. In some cases no commercial terms may exist at the start of design. For example, designers may not receive a stipend for developing their competitive proposals for a project. This lack of compensation could influence the availability of designers and constructors wishing to pursue the project.

- *What were the costs for this design concept initiation effort at contract award and final completion?*

The total cost of design must incorporate all design effort accomplished in direct support of a project's delivery to allow for direct comparison of like costs between delivery systems. Though the design cost for design-build is contained within the overall project purchase price, the relative cost of initial design development in relation to the design-build contract price provides a true reflection of the actual project design costs. Any increases in design costs for the initial design effort indicate possible changes or modifications that might also correspond to any changes in the design-build costs (NSPE, 1994).

- *Do costs include in-house project management or owner's agent costs?*

Military construction projects managed through the US Army Corps of Engineers impose a standard income and overhead fee of approximately 6.5 percent of the construction contract price. For large projects, this fee can significantly impact the actual cost of the base building, and subsequently its cost per unit area. Confirmation that these costs were not included in the reported costs was critical.

- *What percentage of design was complete at time of construction contract award? (0-15, 15-35, 35-65, 65-100)*

This question was similar to the percent design complete when the construction entity joined the team. It requested the relative percentage of design completed prior to the design-build contract award date. The level of design development prior to design-build contract award and the project team selection mechanism is useful in identifying the actual form of design-build used (Molenaar, 1995).

- *As of this date how would you rate the seven quality performance measures of your project?*

Individually re-assessing the original seven quality measures one year after the original quality ratings were collected allowed the researcher to cross-check scores against the owners' original ratings. This questioning procedure was important for two reasons. Firstly, inconsistent ratings of projects solicited from the original quality performance respondent would invalidate the objectivity of the rating scale. Secondly, significant changes in score or scoring trends in relation to the facility's age identify the influence and impact of time in accurately measuring quality both in the early phases of a project's life and throughout its lifecycle (National Research Council, 1991).

## 3.3 SUMMARY

Surveys and telephone interviews were used as the two means of collecting objective project data from owners, design professionals, design-builders and constructors throughout the United States. Survey questions were designed to accurately record project costs, schedule, and quality data to support empirical measurement of project performance. Other factors known to affect project performance were also included in the survey to provide possible explanation of variation in performance in subsequent data analysis. Additionally, project unit costs and facility types were standardized to allow direct comparison of similar facilities as of a baseline of December 1996. Phase two data collection clarified the original cost, schedule, and quality data to account for all project costs and schedule inclusive of the entire design effort from zero percent design complete. Phase two data collection relied solely on owner provided cost, schedule, and quality data.

# CHAPTER 4

# PERFORMANCE MEASUREMENT AND DATA ANALYSIS METHODS

Chapter 4 provides definitions and descriptions of the 15 performance measures used to compare projects and the subsequent statistical analysis methods employed to test differences between project delivery systems and other key variables. Project performance measures were calculated using the objective cost, schedule and quality data collected via the original survey and new telephone interviews previously discussed in chapter 3. Performance measures were used to objectively and quantitatively compare delivery systems through univariate and multivariate statistical testing. Univariate comparisons between design-build and design-bid-build were based on results of statistical hypothesis testing of mean and median performance values. These results provided only direct comparison of delivery systems for each performance metric without the presence of any other explanatory variable. Therefore, multivariate comparisons of delivery system performance inclusive of other explanatory variables were based on statistical modeling of the delivery speed performance metric.

## 4.1 PROJECT PERFORMANCE MEASURES

Interviews conducted with federal agency owners identified available cost, schedule and quality records used to record and track performance of federal projects. Quality measures were based on evaluation criteria measured through post-occupancy-surveys conducted by some federal agencies after project completion. Information gathered through these interviews was used to develop and test metrics that accurately capture and report the cost, schedule and quality performance of projects for comparison. Fifteen project performance measures were created from this information. These fifteen performance measures were used as the dependent or response variable in analyzing project data to compare delivery systems. These measures are presented by cost, schedule, and quality categories.

### 4.1.1 Cost Performance Measures

For this research, cost was defined as the amount of money paid by an owner for the design and construction of a facility, as measured in U.S. dollars. Costs excluded the value of land acquisition, extensive site work, process equipment or owner costs. Four cost performance measures were: unit cost, total cost growth, design cost growth, and construction cost growth.

The *unit cost* measure represents the relative cost per unit area of a facility. It is used as an historical cost reference in programming federal facility projects for funding approval. This first cost metric was adjusted for time and location using Means (1995) historical cost indices. This allows direct and equitable comparison of projects constructed across the United States over the past five years. The following formula was used to measure unit cost:

$$\text{Unit cost (\$/S.F.)} = ((\text{Final Design Cost} + \text{Final Construction Cost})/\text{Area})/\text{Index} \quad (1)$$

*Cost growth* provided the resultant percentage of growth of project cost throughout a project's combined design and construction phases. Final versus contracted costs for design and construction were used to calculate the cost growth measure. Cost growth was measured as follows:

$$\text{Cost growth (\%)} = [(\text{Final Project Cost} - \text{Contract Project Cost})/\text{Contract Project Cost}] * 100 \quad (2)$$

*Design cost growth* measured the final cost of design resulting from the entire period of design relative to the contracted design costs. Any applicable costs for design accomplished prior to the design-build contract award was added to the design-builder's itemized design costs. The design cost growth measure was defined by the following formula:

*Design Cost Growth (%) = [(Final Design Cost – Contract Design Cost)/ Contract Design Cost] *100* (3)

The final cost performance measure, *construction cost growth*, focused on the difference between the final and contract costs for completing the construction phase of each project. Construction cost growth was measured in terms of percentage growth as follows:

*Construction Cost Growth (%) = [(Final Construction Cost – Contract Construction Cost)/ Contract Construction Cost]*100* (4)

### 4.1.2 SCHEDULE PERFORMANCE MEASURES

Schedule was defined as the total time taken by the facility team to design and construct a facility beginning at zero percent design complete. Four schedule metrics were created to analyze and compare project performance by delivery system: schedule growth, delivery speed, construction speed, and procurement speed. Similar to the cost measurements, the schedule growth and delivery speed measures included any time taken to accomplish design prior to the design-build contract award date.

The first measure, *schedule growth*, calculated the percent by which the overall design and construction schedule grew over the course of delivering the project. This measure calculated the difference between the as-built and as-planned schedule duration for design and construction, inclusive of design time starting from zero percent complete. The formula used for schedule growth was:

*Schedule Growth (%) = [(Total As-Built Time – Total As-Planed Time)/ Total As Planned Time]*100* (5)

*Delivery speed* was defined as the rate at which a facility' gross square footage is designed and constructed per month. It measured from the design start date at contracted concept design initiation through to substantial construction completion based on the as-built time to deliver the facility. Delivery speed measured each project using the following formula:

*Delivery Speed (S.F./Month) = [Area/(Total As-Built Time/30)]* (6)

*Construction speed* was the rate at which the construction entity constructed the facility beginning with the notice to proceed date. The following formula was used to define construction speed:

*Construction Speed (S.F./Month) = [Area/(Total As-Built Construction Time/30)]* (7)

The final schedule performance metric, *procurement speed*, was measured independently of design and construction time. This measure was defined as the rate at which a project is procured for either the construction or design-build contract as follows:

*Procurement Speed (S.F./Month) = [Area/(Total As Built Procurement Time/30)]* (8)

### 4.1.3 Quality Performance Measures

Quality was defined as the degree to which the facility met the expected facility requirements as assessed by the project owner or project user (Konchar, 1997). Seven quality measures were created that measured actual versus expected performance of the completed facility. The following seven quality performance measures were used in this research:

1. Difficulty of facility start-up
2. Number and magnitude of call-backs
3. Operation and maintenance costs
4. Quality of envelope, roof, structure, and foundation
5. Quality of interior space and layout
6. Quality of environmental systems
7. Quality of process equipment and layout

Owners (specifically owner project managers and facility users/ maintainers) measured each individual quality metric against a fixed quality rating scale of 1, 2 or 3. For the first three measures, 1 represented high difficulty, number of incidents or costs, 2 represented medium difficulty, and 3 represented low difficulty. For the final four measures regarding systems quality, a score of 1 represented expected quality was not met, 2 represented expectations were met, and 3 reflected that expectations were exceeded.

## 4.2 DATA ANALYSIS METHODS

This research relied upon various statistical tests to identify the existence of any significant relationships between delivery systems for each performance measure. Data analysis primarily utilized univariate statistical comparisons of delivery systems by performance metric to identify individual significance based on the central tendencies of the sample means and medians. This research identified specific benchmark performance measures for each delivery system based on statistical hypothesis testing of both mean and median values. Median values were reported as representative of the central tendency of the data for direct comparison. Additionally, multiple linear regression models were constructed for the delivery speed metric to identify variables which explained the highest proportion of variation in the model in the presence of each other. This model allowed for direct comparison of delivery system impact on the performance metric when holding all other variables constant.

### 4.2.1 UNIVARIATE COMPARISONS

This research relied strongly on the accurate representation of sample population behavior for each performance measure. Preliminary descriptive statistics of the projects identified several extreme outlying projects that influenced the sample mean for each performance metric. Therefore, non-parametric statistics were used because these tests do not rely upon the normal distribution of the sample population to identify significant differences between variables (Daniel, 1978). In particular, the Mood's median test is highly robust against outliers and errors in data for preliminary data analysis to identify the central tendency of the sample data (Minitab®, 1995).

For the most accurate representation of differences, analysis used both 2 sample t-tests for sample means and Mood's median tests for sample medians for each sample. For 2 sample t-tests, the null hypothesis represented that one system was either less than or equal to, or greater than or equal to the other delivery system depending on the performance metric. The alternative hypothesis represented the opposite assumption from the null hypothesis with a test-statistic greater than the critical value supporting the null hypothesis. The Mood's median test null hypothesis represented that the sample medians were all equal versus the alternative hypothesis that the medians were not equal. A chi-squared value greater than the critical value indicated that the null hypothesis was false. This redundancy ensured that only those samples supporting both the mean null hypotheses and the median alternative hypothesis were significantly and consistently different at the 95 percent confidence level. However, Mood's median tests using fewer than six observations have confidence less than 95 percent. These tests provided for univariate comparison of delivery systems for each performance metric unadjusted for the presence or influence of any other variables in explaining the differences.

The original CII project delivery survey response data was first resorted by private, public and federal projects to identify project performance by owner type. Projects for each owner type were tested using mean and median values to establish the central tendencies of their collective projects by delivery system. Sample medians were used to directly compare each delivery system's performance. The same two testing procedures were applied to the new federal project data for the cost and schedule performance measures. The quality performance metrics were based on discrete variables that required the use of 2-sample t-tests to compare each delivery system's mean score for significant differences. For example, with individual quality scores reported as either 1, 2 or 3, the median value will likely be an even integer of 2 for both delivery systems which does not allow a wide enough range for effective application of the Mood's median test.

### 4.2.2 Multivariate Comparisons

The univariate results provided singular, direct comparisons of delivery system and design complete percentages on certain project performance measures. However, univariate comparisons do not permit analysis of the relative importance or influence of project delivery systems, facility type or percent design complete in explaining resultant project performance. Multiple linear regression analysis allows further statistical investigation of the impact of delivery system on project performance measurement in relation to other possible explanatory variables (Neter, 1996). Therefore, multiple linear regression analysis was used to construct a model explaining direct relationships between measured project variables and project performance metric within one single model. This method allowed direct, quantifiable measurement of project delivery system performance for delivery speed by holding all other explanatory variables constant in the model.

Using Minitab® (1995) statistical software, each of the 70 variables collected via the data collection tool and interviews were individually included in preliminary best subset regression models. Best subset regression analysis identified various possible combinations of variables and their associated level of influence in explaining the performance metric's outcome. Minitab's statistical software permitted only 20 variables at a time to be included in each best subset regression model. The variables consistently providing the highest proportion of variation and lowest Mallow's C-p value in each of the best subset regression models were then collectively entered into one regression model. Each variable was provided the opportunity to be placed first in the model to identify its singular contribution to explaining the response variable with all other variables present.

Residual model diagnostics were performed on the multivariate regression model to check four linear regression assumptions: normality, interdependence, random distribution, and non-constant variance. Several unusual observations were noted as a result of these diagnostic plots and tests. These included non-linear relationships between variables requiring transformation, and outlying projects that might inaccurately define a linear relationship in explaining the response variable. Investigation of outlying observations used Cook's Distance (Minitab, 1995) to graphically test for leverage, and Hi tests (Minitab, 1995) to test the relative influence of the outlying observations' on the model's fit. Any unusual observation exhibiting both significant leverage and strong influence on the response variable's fitted values was closely examined to explain any unique circumstances impacting the project's outcome. Projects providing unexplained or highly unusual observations were removed from the model to better calculate the multivariate regression model fits. A new final regression model was then calculated based on the reduced number of projects to identify any changes in explanation. Again residual diagnostics, Cook's Distance and Hi tests were conducted to examine any extreme values. This procedure of reconstructing the model and examining residual diagnostics was repeated until no improvement in the level of explained variation was achieved. This level of explained variation in the model was checked against acceptable p-values for each independent variable in the model and the collective t-value of all variables acting together.

Project delivery and facility type were intentionally included in each model. This allowed direct, quantitative measurement of differences between delivery systems in the final explanatory model of delivery speed performance. Including these variables within the best subset regression models prevented any extreme interactions or insignificant relationships from being identified in the final model.

### 4.3 SUMMARY

Fifteen project performance measures were created to objectively measure project performance based on specific project cost, schedule and quality data collected from the survey and interviews. Four cost, four schedule and seven quality metrics were used to objectively measure project performance. Univariate analysis of project cost and schedule performance metrics focused on measuring and comparing projects based on equal project start dates at zero percent design complete. Analysis of seven identical quality performance measures between the new and original data investigated the consistency of reported quality over time. Multivariate analysis of project delivery speed constructed a model identifying variables that explained the highest proportion of variation in resultant project delivery. This delivery speed model was adjusted for the influence of outlying observations to accurately construct a linear relationship in explaining delivery speed. The final explanatory model achieved a high level of explained variation based on the significance level of each independent variable and the variables collectively.

# CHAPTER 5

# RESULTS

Results of the statistical analysis are presented first for private, public, and federal owners, then specifically for federal projects. The first part of this chapter presents the relative distribution of projects among owner types and facility types to identify univariate differences among each of the original private, public, and federal projects. These preliminary comparisons identify basic relationships between delivery systems by facility type and metric. Unadjusted for the many other variables that may influence and impact project performance, these univariate results substantiate further specific investigation into owner specific federal project performance.

The second part of this chapter reports solely on the expanded statistical analysis results of federal projects. This part first presents the distribution of federal project data by facility type, project size and project cost. Second, univariate results for each metric are reported. Further, univariate results describing the relationship between design complete at design-build or construction contract award and project performance metrics are then presented independent of any other variables. Finally, multivariate regression results provide statistically supported conclusions for federal project delivery speed performance.

## 5.1 DELIVERY SYSTEM PERFORMANCE BY PRIVATE, PUBLIC AND FEDERAL OWNERS

Of the original 351 projects reported in the CII study (Konchar, 1997), 273 projects were executed using either design-build or design-bid-build project delivery systems. These 273 projects comprised 134 private, 54 public, and 85 federal projects. Figure 5.1 illustrates the distribution of the 273 projects by owner type and facility type. Projects were originally categorized into six facility types: light industrial, multi-story dwelling, simple office, complex office, heavy industrial, and high technology. In this research, the heavy industrial and high-technology facilities were combined to form the "other" facility category. Of these five facility types, light industrial had the highest representation with 89 total projects among the three owner types. This category is dominated by 52 private projects composed of 41 design-build and 11 design-bid-build projects. Private projects also comprised 67% of the total 55 projects reported for the "other" category with no design-build projects reported from the federal sector. In contrast, the multi-story dwelling facility type was least represented with 22 total projects reported, 15 of which were federal.

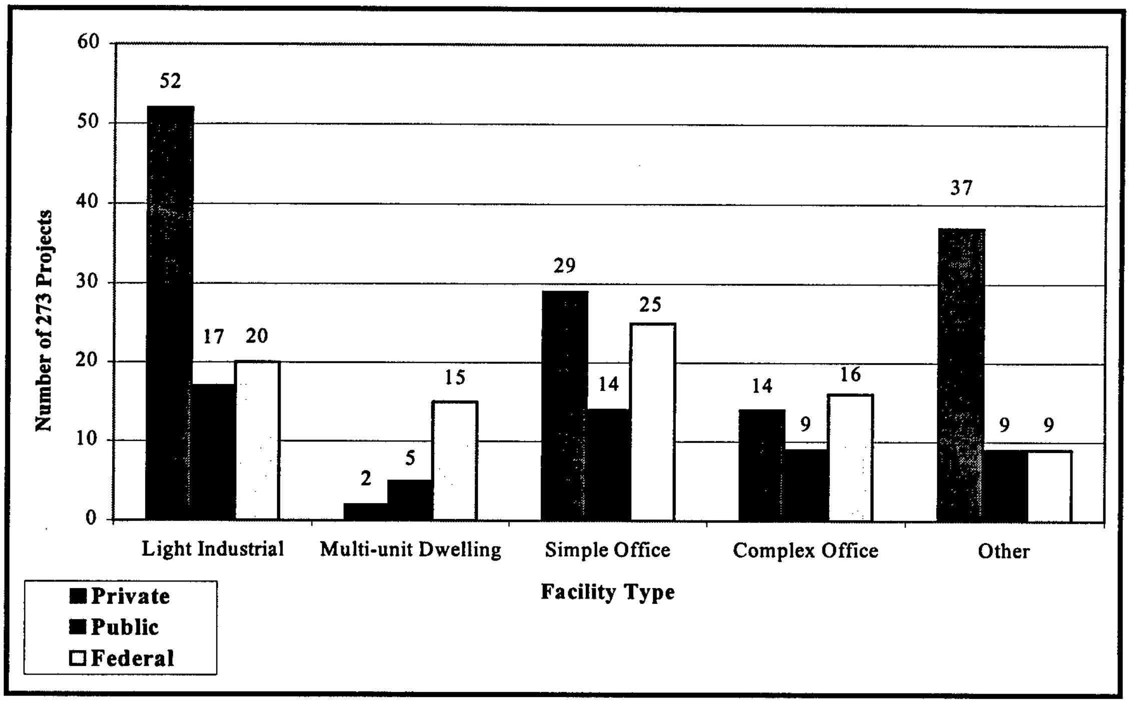


Figure 5.1: Distribution of original 273 project sample by owner and facility type.

### 5.1.1 UNIVARIATE RESULTS BY OWNER TYPE

The aforementioned 273 design-build and design-bid-build projects were sorted by owner type for specific univariate comparisons of delivery system performance by facility type and metric. The mean and median values for each metric by delivery system and facility type were tested for significance at the 95% confidence level. Only those sample means and medians with test statistics satisfying 95% confidence level t-values and Chi-squared values as well as p-values less than or equal to 0.05 are reported. Appendix B provides summary statistics for the following univariate comparisons. In the figures discussed next, significant differences are represented by darkened ovals with the corresponding relationship between delivery systems identified as greater than or less than (< or >). Open or unshaded ovals indicate no significant differences between delivery systems.

Figure 5.2 presents the results of significance testing of delivery system performance by facility type and metric for the 134 private projects. Three of the five facility types show significant performance differences between design-build and design-bid-build projects. The light industrial design-bid-build projects have a significantly higher unit cost than similar design-build projects. Simple office facilities show lower cost growth for design-build projects than design-bid-build projects. Complex offices have less schedule growth with design-build than design-bid-build delivery systems. The combined private projects identified design-build to have both less cost growth and schedule growth and significantly faster construction speed and delivery speed than design-build projects. Design-build provided significantly better system quality.

Figure 5.3 presents the results of significance testing within each facility type by delivery system for the 54 public projects. Of all the performance metrics only unit cost identified differences between delivery systems by facility type. Light industrial facilities delivered via design-bid-build had higher unit costs than design-build projects. In contrast, multi-story dwelling facilities identified design-build high security prison projects to have higher unit costs than low-income housing design-bid-build projects. Overall, only design-build was identified as faster than design-bid-build in terms of delivery speed for the combined sample of all 54 public projects. Additionally, only turnover quality provided significant differences between the two delivery systems with design-build achieving a higher turnover quality score than design-bid-build projects.

| Metric / Facility Type | Unit Cost | Cost Growth | Schedule Growth | Construction Speed | Delivery Speed | Turnover Quality | Systems Quality | Process Equipment |
|---|---|---|---|---|---|---|---|---|
| Light Industrial | ● DB<DBB | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| Multi-story dwelling | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| Simple Office | ○ | ● DB<DBB | ○ | ○ | ○ | ○ | ○ | ○ |
| Complex Office | ○ | ○ | ● DB<DBB | ○ | ○ | ○ | ○ | ○ |
| Other | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| Overall Combined | ○ | ● DB<DBB | ● DB<DBB | ● DB>DBB | ● DB>DBB | ○ | ● DB>DBB | ○ |

**Legend**

Significant differences between systems ●
No significant differences between systems ○
Significant differences called out < or >

Figure 5.2: Matrix of significant project delivery system performance for private projects by facility type and metric.

| Facility Type \ Metric | Unit Cost | Cost Growth | Schedule Growth | Construction Speed | Delivery Speed | Turnover Quality | Systems Quality | Process Equipment |
|---|---|---|---|---|---|---|---|---|
| Light Industrial | ● DB<DBB | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| Multi-story dwelling | ● DB>DBB | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| Simple Office | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| Complex Office | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| Other | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| Overall Combined | ○ | ○ | ○ | ○ | ● DB>DBB | ● DB>DBB | ○ | ○ |

**Legend**

| | |
|---|---|
| Significant differences between systems | ● |
| No significant differences between systems | ○ |
| Significant differences called out | < or > |

Figure 5.3: Matrix of significant project delivery system performance for public projects by facility type and metric.

Figure 5.4 illustrates the significant findings for project delivery system performance for 85 federal projects by facility type and metric. Of the five facility types, only simple office projects yielded statistically significant differences between design-build and design-bid-build in measures. Design-build projects performed better than design-bid-build with lower schedule growth and faster delivery speed results. No significant differences were noted between the two delivery systems for each of the quality measures within each of the five facility types. Regardless of facility type, the overall combined performance of all 85 reported federal projects again significantly supported design-build as better than design-bid-build for schedule growth and delivery speed. Regarding quality, the combined overall performance of the federal projects proved no significant differences between the two delivery systems for turnover, systems or process equipment quality.

### 5.1.2 SUMMARY OF UNIVARIATE RESULTS BY OWNER TYPE

The original result comparisons shown in Figures 5.2, 5.3, and 5.4 revealed that the design-build projects proved to be better than the design-bid-build projects in nearly every instance where significance was noted. The only exception provided within public sector multi-story dwelling facilities where design-build projects were greater than design-bid-build projects regarding unit cost. However, these significant differences among delivery systems occurred within different facility types for each owner type. The quality measures identified no significant differences between the delivery systems for each facility type by owner. However, design-build had significantly better quality, although for different measures, than design-bid-build when combining all projects within each owner. The only metric in which design-build out performed design-bid-build for each of the three owners was delivery speed without considering facility type.

Though design-build was identified as significantly better than design-bid-build in many aspects, these preliminary univariate results indicated that each of the three owner types' projects performed differently from each other based on the original data.

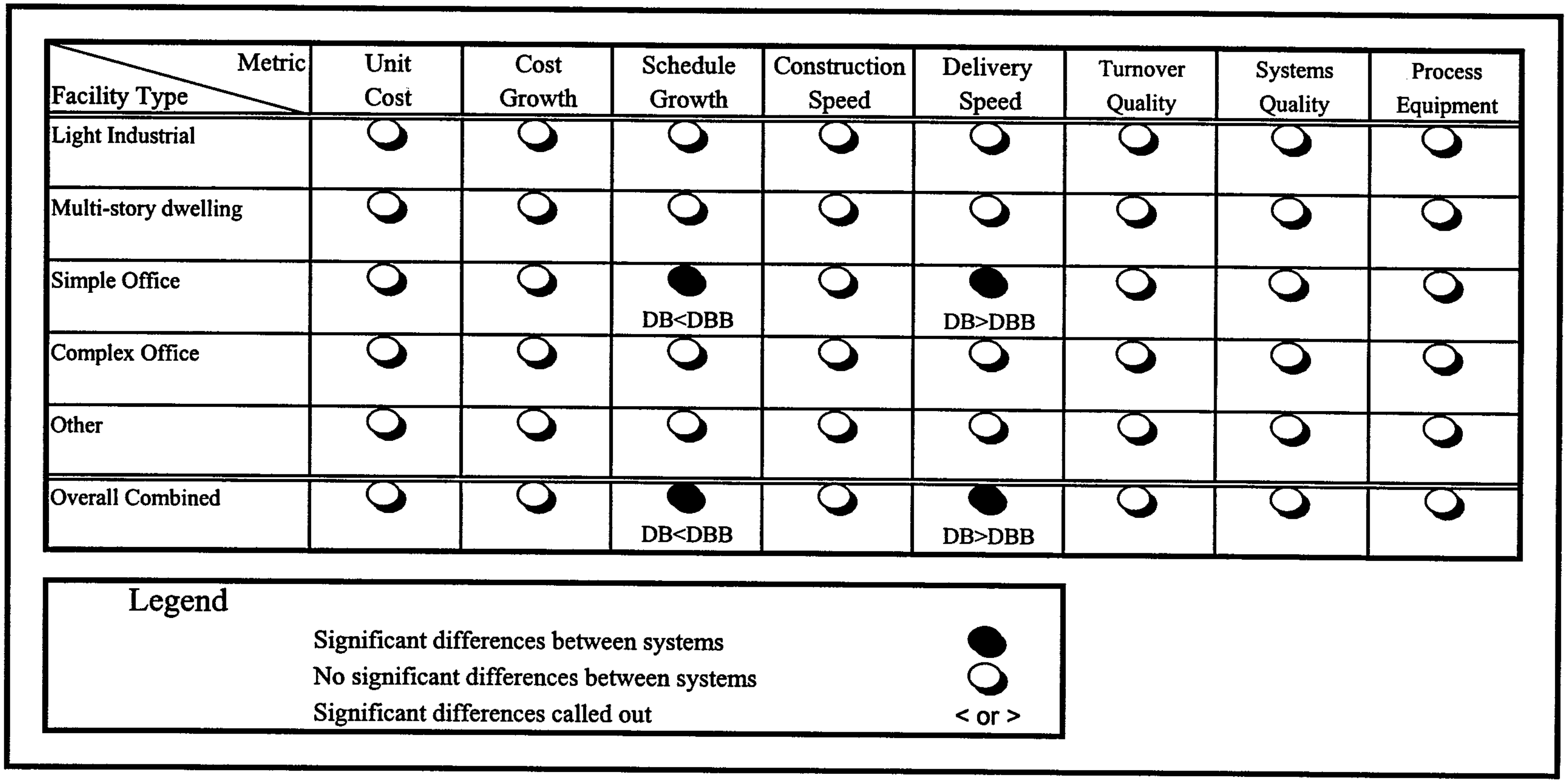


Figure 5.4: Matrix of significant project delivery system performance for federal projects by facility type and metric.

However, limitations of the original CII study identified the original data did not capture the cost or schedule data to objectively and directly measure the performance of design-build versus design-bid-build in every instance (Konchar 1997).

In specific regard to federal projects, interviews conducted with federal owners identified several shortcomings of the original CII study in reporting total cost and schedule data. For example, one design-build project reported its design start date for the design-build contract at 35 percent design already complete prior to the award date. Therefore, the cost and schedule data did not accurately account for the cost or time to accomplish the start of design from zero percent complete. In addition to cost and schedule information, some federal owners indicated that quality performance assessments were solicited too early in their project's lifecycle to accurately measure facility performance. More detailed investigations of federal projects are presented in the following section that address the impact of new design cost and schedule data as well as quality differences reported since the original CII study was conducted in 1997. The original CII study (Konchar, 1997) recognized that different project timelines for delivery systems allowed possible unequal comparisons from other than a zero percent design starting point.

## 5.2 FEDERAL PROJECT DATA

This section describes the composition of the 88 federal projects. Three projects not provided in time for inclusion in the original CII study were added to the original 85 projects. New data collected on these 88 projects focused on cost and schedule data inclusive of the design start date at zero percent design complete. Also, new quality assessments were provided for comparison to the original quality ratings.

Federal project responses were collected from several industry sources involved in the design and construction of federal facilities throughout the United States. Projects were provided by managers in companies drawn from CII, Design-Build Institute of

America (DBIA), Association of General Contractors (AGC), Partnership for Achieving Construction Excellence (PACE), and several Penn State alumni. Eighty eight projects were owned by 13 federal agencies in 22 states. Of the 88 federal projects, 69 percent were provided by federal agencies acting as project owners with the remaining 31 percent provided by construction entities that had constructed federal facilities. However, only project owners provided new cost, schedule and quality data via telephone interviews. Federal project owners included the Department of Veterans Affairs, Departments of the Army, Navy and Air Force, Federal Aviation Administration, Healthcare Finance Administration, Office of the Comptroller of the Currency, Internal Revenue Service, Justice Department, Federal Bureau of Investigations, Jet Propulsion Laboratory, National Aeronautics and Space Administration, and United States Postal Service.

Forty of the 88 projects used design-build (45 percent of the total sample size) while 48 used design-bid-build (55% of the total sample size). Figure 5.5 presents the distribution of federal sector projects among each of the facility types by delivery system. Projects were classified into the same five facility types as previously presented for the original private, public and federal owner types in Section 4.1: light industrial, multi-unit dwelling, simple office, complex office, and "other" facilities.

The simple office facility category had the highest representation with 30% of the project responses. The "other" facilities category had the lowest, representing only 10% of the reported project total. This category accounted for a total of 9 design-bid-build projects reported as heavy industrial or high technology projects. Except for the "other" facilities category, each facility type was equitably represented among the two delivery systems. Though most project sample sizes for each facility type were less than twenty, combined use of parametric and non-parametric statistical tests allowed the researcher to reach supportive conclusions about four of the five facility types.

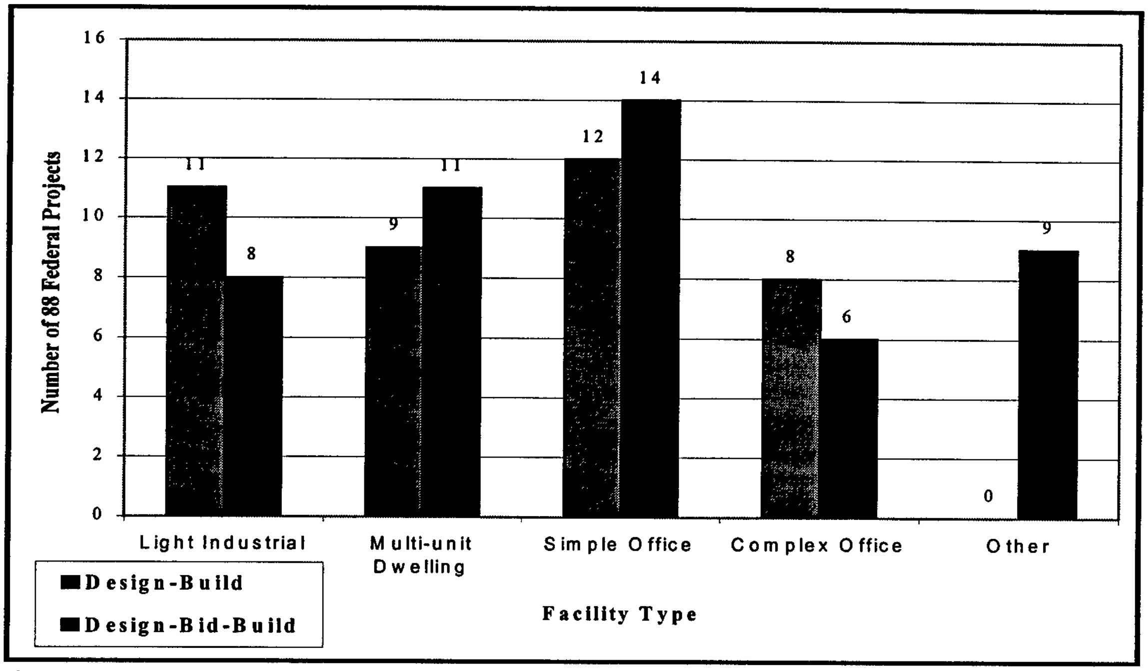


Figure 5.5: Distribution of projects by facility type and delivery system.

Figure 5.6 illustrates the distribution of projects by facility size in increments of 50,000 square feet. Gross square footage for the 88 reported projects ranged in size from a low of 3,000 square feet reported for a simple office project to 2.5 million square feet reported for a project within the other facilities category. Nearly a third of all projects were less than 50,000, with 29 percent of projects within the broad range of 100,000 to 400,000 square feet.

Figure 5.7 graphs the distribution of projects by reported total project costs in 10 unequal increments. The first six increments account for 86 percent of projects based on 5 million dollar project cost ranges up to 30 million dollars. 95 percent of light industrial and multi-unit dwelling projects had project costs within these first six ranges. Unit costs ranged from a low of 25 dollars per square foot to a high of 508 dollars per square foot.

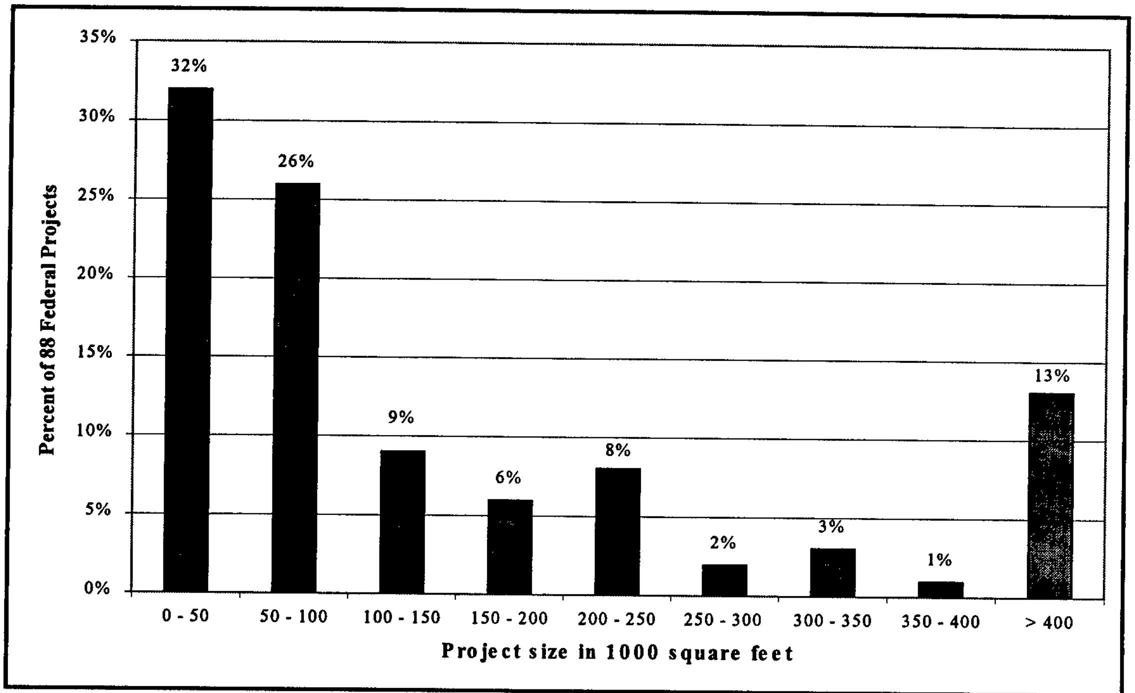


Figure 5.6: Distribution of project size in square feet.

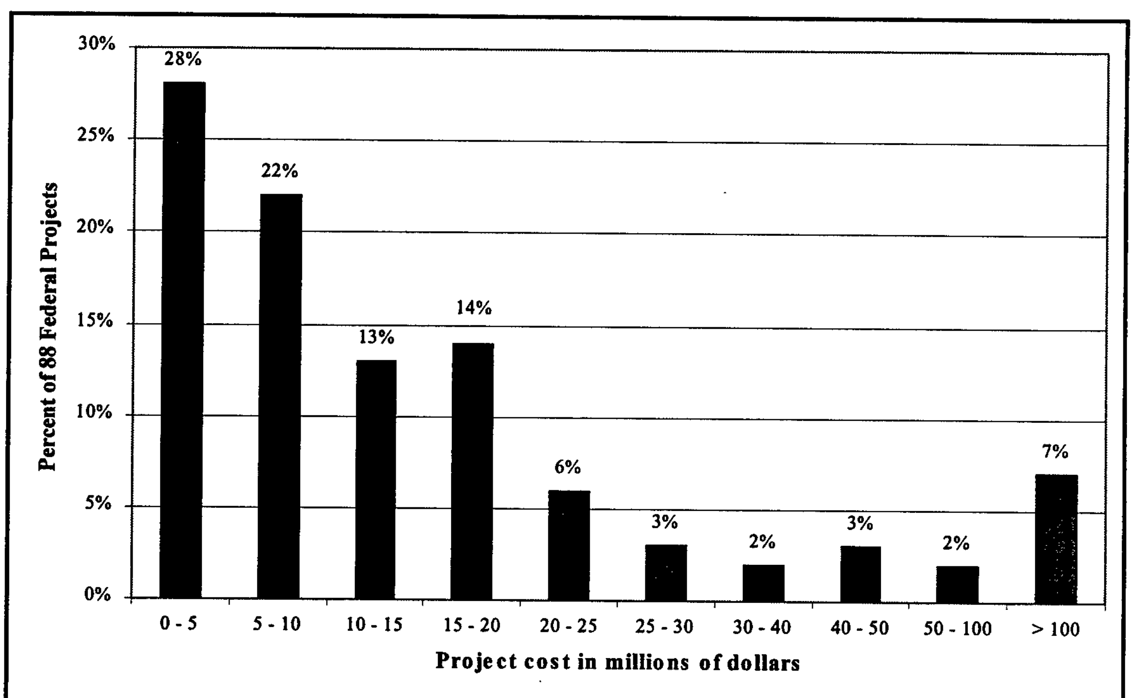


Figure 5.7: Distribution of total project cost.

Figure 5.8 illustrates the distribution of project unit costs in intervals of 25 dollars per square foot. The light industrial projects had the lowest mean and median unit costs of all the facility types at 117 and 113 dollars per square foot respectively. Interestingly, individual unit costs within this facility type ranged from a low of 62 dollars per square foot to a high of 200 dollars per foot. In contrast, the other facilities type had the highest mean and median unit costs of 192 and 162 dollars per square foot respectively, with all 9 projects having unit costs greater than 100 dollars per square foot.

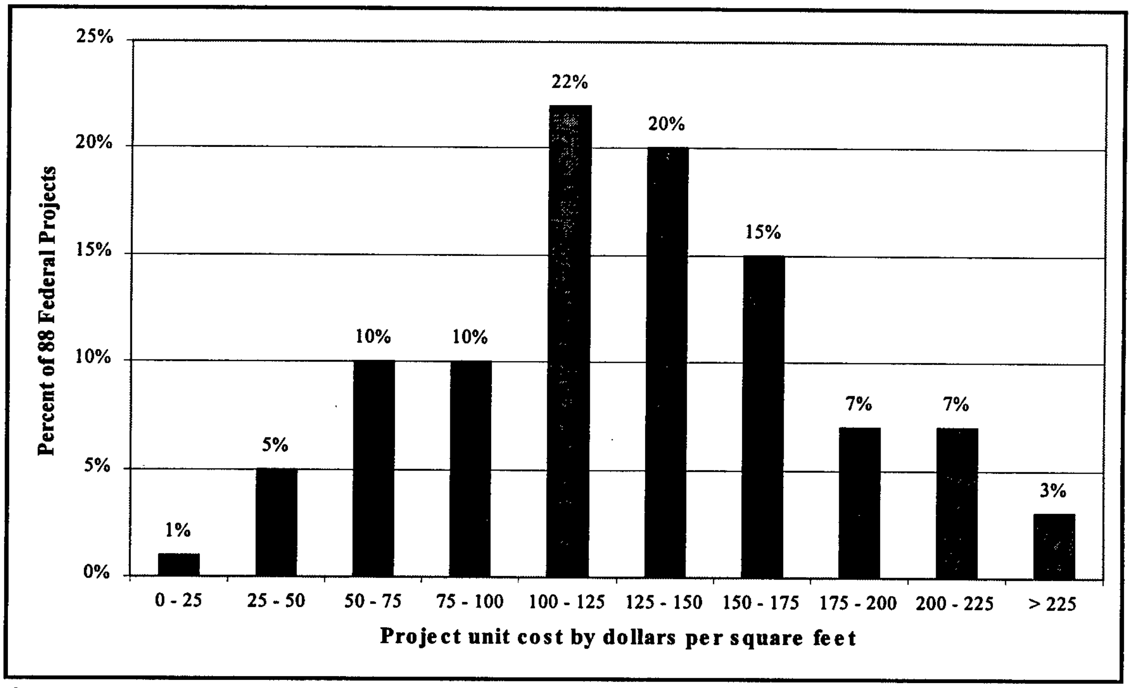


Figure 5.8: Distribution of project unit cost in dollars per square feet.

## 5.3 FEDERAL PROJECT UNIVARIATE RESULTS

Discussion of each cost, schedule and quality performance measure is presented on a univariate basis in the following section. All 88 projects are collectively analyzed against each indicator metric in comparing the performance of the two delivery systems. Statistical significance is provided only for those sample mean and median values that satisfy testing at the 95 percent confidence level with p-values less than 0.05. Significant differences between delivery systems are discussed for only those cost and schedule metrics with both median and mean p-values less than 0.05. The discrete variables used to score quality require mean values with associated p-value less than 0.05 to identify significant differences between delivery systems. Refer to Appendix C for summary statistics regarding phase two federal project data.

### 5.3.1 UNIVARIATE COST RESULTS

Four metrics were used to analyze project performance by delivery system: unit cost, cost growth, design cost growth, and construction cost growth. Results of statistical testing for each cost metric are provided in Table 5.1 by delivery system.

| Metric | Delivery System | N | Median | p-value | Mean | p-value | St.Dev | Significance |
|---|---|---|---|---|---|---|---|---|
| Unit Cost | DB | 40 | 124.00 | 0.39 | 124.00 | 0.18 | 50.80 | No |
| | DBB | 48 | 134.00 | | 141.00 | | 71.30 | |
| Cost Growth | DB | 40 | 4.01 | 0.39 | 5.72 | 0.12 | 7.16 | No |
| | DBB | 48 | 5.19 | | 9.00 | | 12.10 | |
| Design Cost Growth | DB | 40 | 0.00 | 0.39 | 5.30 | 0.21 | 21.50 | No |
| | DBB | 48 | 0.00 | | 6.10 | | 11.80 | |
| Construction Cost Growth | DB | 40 | 3.67 | 0.09 | 5.75 | 0.11 | 7.40 | No |
| | DBB | 48 | 5.56 | | 9.30 | | 12.60 | |

Table 5.1: Sample statistics for cost performance measures by delivery system.

Median values were used to represent the central tendencies of the project cost data. New data collected since the original CII study included the cost of design work performed prior to design-build contract award. No significance was noted between the delivery systems for any of the four cost measures. Measures of *design cost growth* alone resulted in median values of 0 percent for both delivery systems. There was no significant difference between the two. Nearly 70 percent of both design-build and design-bid-build projects reported design cost growth of 0 percent. Strong outlying design cost growth values made these results insignificant. The maximum standard error was plus or minus 3.4 percent. *Construction cost growth* percentages had a maximum standard error of 1.8 percent. No direct or significant correlations were found to exist between project's design cost growth and overall cost growth, or construction cost growth. Likewise either high design and construction cost growth or high cost growth and low construction cost growth.

Figure 5.9 addresses the cost growth metric with respect to occurrence of completion below, within 5 percent above, or greater than 5 percent above the contracted project cost. Here, design-build projects were two times more likely to achieve completion on or below the contracted project cost than the design-bid-build projects.

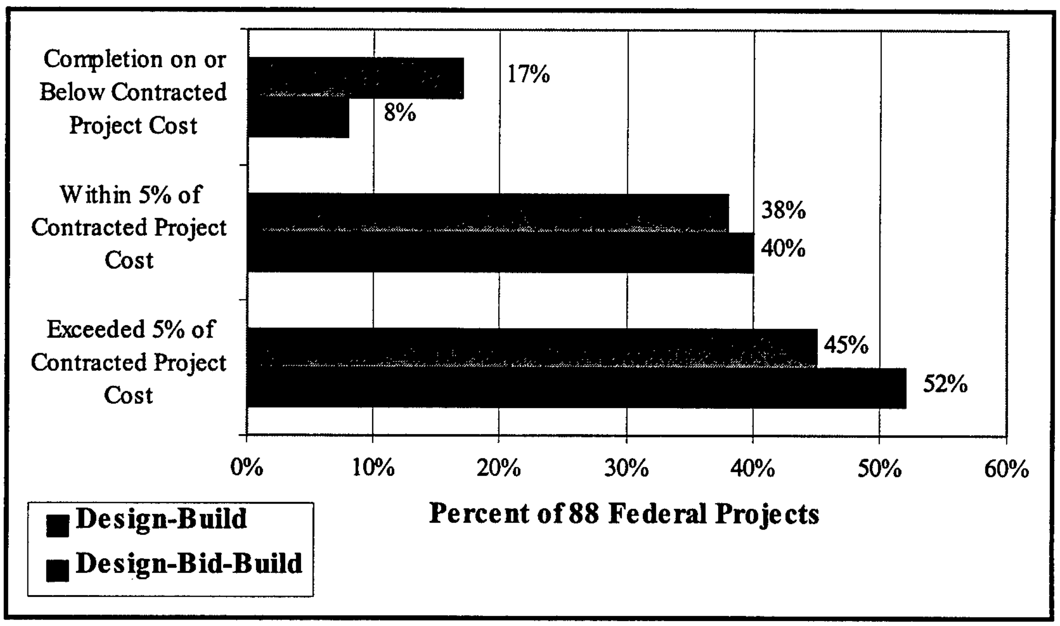


Figure 5.9: Occurrence of completion versus contracted project cost

Both delivery systems performed relatively equally regarding certainty of completion within 5 percent of the contracted project cost. Regarding cost overruns, design-build projects had fewer instances of exceeding 5 percent of the contracted project cost than did design-bid-build projects. Though small, 17 percent of the design-build projects experienced 0 or negative cost growth, more than twice the occurrence reported for the design-bid-build projects. Across the whole sample of federal projects, 55 percent of the design-build projects were more likely to achieve 5 percent or less cost growth as compared to 48 percent of design-bid-build projects.

### 5.3.2 Univariate Schedule Results

Four metrics were used to analyze project performance by project delivery system: schedule growth, delivery speed, construction speed, and procurement speed. Results of statistical univariate testing of each metric are presented in Table 5.2 by delivery system. Of these four metrics only schedule growth was significantly different for each delivery system by both median and mean values with a maximum standard error of plus or minus three percent growth.

| Metric | Delivery System | N | Median | p-value | Mean | p-value | St.Dev | Significance |
|---|---|---|---|---|---|---|---|---|
| Schedule Growth | DB<br>DBB | 40<br>48 | 0.2<br>6.9 | 0.003 | 1.5<br>11.2 | 0.005 | 10<br>20.4 | Yes |
| Delivery Speed | DB<br>DBB | 40<br>48 | 3325<br>1577 | 0.087 | 5448<br>4354 | 0.27 | 5271<br>7210 | No |
| Construction Speed | DB<br>DBB | 40<br>48 | 5865<br>3451 | 0.032 | 10310<br>7634 | 0.41 | 10547<br>12216 | No |
| Procurement Speed | DB<br>DBB | 40<br>48 | 20661<br>25532 | 0.669 | 34215<br>66221 | 0.042 | 5552<br>14386 | No |

Table 5.2: Sample statistics for schedule performance measures by delivery system.

Several of the performance metric results conflict with the univariate findings of the original federal project data presented previously in Figure 5.4. Interestingly, when one adds in the time for any design developed prior to the award of the construction contract for both design-bid-build and design-build projects, the significant differences between project delivery systems regarding *delivery speed* disappear. *Construction speed* remained insignificant for delivery system performance. *Procurement speed*, defined as the facility gross square footage divided by the as-built procurement time, measures the relative speed with which a project is advertised and subsequently contracted to begin the construction or design-build process. Design procurement speed was not calculated as the actual advertisement date for professional design services was not recorded. Furthermore, significant differences in *schedule growth* between the two delivery systems remained in favor of design-build projects having less growth than design-bid-build projects with the inclusion of this design time. A further investigation of schedule growth is provided.

The median schedule growth values for design-build and design-bid-build are 0.2 percent and 6.9 percent respectively as represented by the horizontal line dividing each boxplot. Figure 5.10 illustrates the distribution and range of each delivery system's schedule growth. This plot presents the range of schedule growth percentages by quartiles of each delivery system sample.

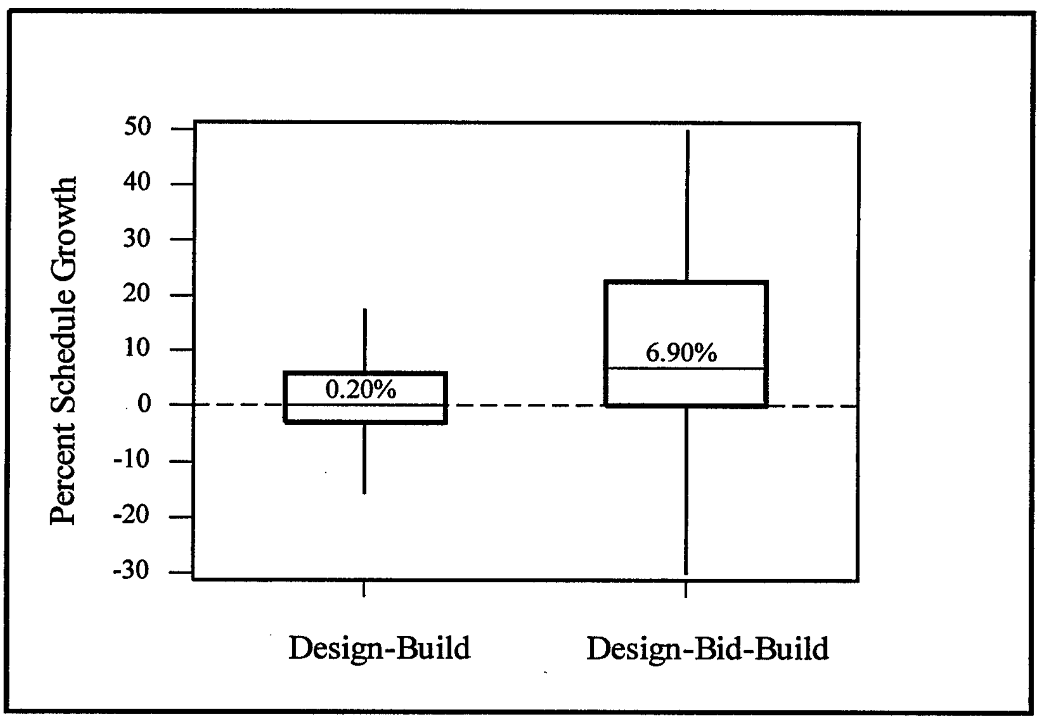


Figure 5.10: Schedule growth distribution by delivery system.

The boxplot reports 50 percent of all design-bid-build projects were completed with 6.9 percent or greater schedule growth. Only 25 percent of design-bid-build projects had less than 0 percent and schedule growth. In contrast, approximately 50 percent of all design-build projects experienced schedule growth at or below 0 percent.

Figure 5.11 explores more closely the distribution of schedule growth by charting the percentage of projects whose final schedule completion duration was below the planned schedule duration, within 5 percent above the planned schedule duration, or exceeded 5 percent of the planned schedule duration. This graph reports 50 percent of all design-build projects experienced 0 percent or negative schedule growth, nearly two times more frequent than that reported for the design-bid-build projects. Conversely, 58 percent of all design-bid-build projects were more likely to exceed 5 percent of planed project schedule duration, which is nearly twice the occurrence of the design-build projects.

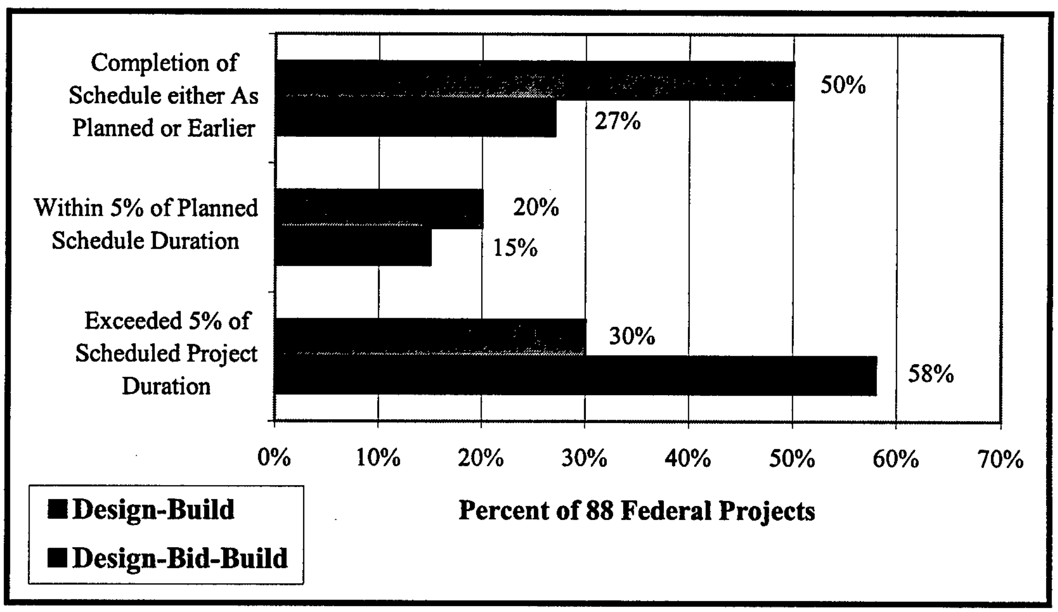


Figure 5.11: Occurrence of on-time project schedule performance.

### 5.3.3 UNIVARIATE QUALITY RESULTS

Seven specific items were used to measure project quality performance. Unlike the cost and schedule results, the quality results are based on categorical ratings of discrete variables with mean values more accurately representing the central tendency of the reported quality data. Significant findings between delivery systems were based on 2-sample mean tests satisfying testing at the 95 percent confidence level with p-values equal to or less than 0.05.

The seven quality metrics, previously combined to form aggregate turnover and system quality scores in Figure 5.4, are addressed individually in this section. Quality scores reported in this section were collected one year after the original CII study. Each of these items was rated against a fixed scale of 1, 2 or 3, with 1 representing the lowest possible quality score and 3 representing the highest possible quality score. Table 5.3 presents the results of statistical testing for each of the seven quality metrics by delivery system as reported one year after the initial CII study.

| Metric | Delivery System | N | Mean | p-value | SE Mean | Significance |
|---|---|---|---|---|---|---|
| Difficulty of Facility Start-up | DB<br>DBB | 40<br>48 | 2.575<br>2.167 | 0.003 | 0.087<br>0.100 | Yes |
| Number and Magnitude of Call-Backs | DB<br>DBB | 39<br>48 | 2.359<br>2.229 | 0.71 | 0.110<br>0.091 | No |
| Operation/Maintenance Cost | DB<br>DBB | 37<br>46 | 2.405<br>2.152 | 0.038 | 0.082<br>0.088 | Yes |
| Envelope/Structure/ Roof/Foundation | DB<br>DBB | 39<br>47 | 2.103<br>1.915 | 0.089 | 0.080<br>0.073 | No |
| Interior Space & Layout | DB<br>DBB | 40<br>48 | 2.100<br>2.000 | 0.36 | 0.070<br>0.084 | No |
| Environmental Systems | DB<br>DBB | 40<br>48 | 1.975<br>1.958 | 0.88 | 0.084<br>0.066 | No |
| Process Equipment & Layout | DB<br>DBB | 24<br>31 | 2.167<br>1.968 | 0.068 | 0.078<br>0.073 | No |

Table 5.3: Sample statistics for quality performance measures by delivery system one year after the CII study.

New quality data ordered survey responses into time categories of within 2, 3 to 4, and greater than 4 years since project completion. Approximately 45 percent of each delivery systems' project data were provided within 2 years of project completion, and an additional 34 percent between 3 to 4 years. Typically, quality results for all measures received higher mean scores for project responses provided greater than 4 years since project completion. The quality assessments for completed projects greater than 4 years old may not accurately represent quality performance for facility start-up or call-backs which focus on the early stages of a project's operational life.

Two quality performance metrics consistently identified significant differences between delivery systems over time: difficulty of facility-start-up and operation/maintenance costs. Rated on low, medium or high difficulty (3, 2 and 1 respectively) design-build projects yielded the highest overall mean score for facility start-up, significantly outscoring design-bid-build projects. Both systems achieved results above the accepted limit of medium difficulty with a maximum standard error of plus or minus 0.10. However, 60 percent of all the design-build projects were consistently rated as having low difficulty, compared to 30 percent of all design-bid-build projects receiving the same low difficulty assessment. No changes were reported by the owners and facility managers for start-up quality over the one-year time period between the original and new quality assessments.

Regarding the operation and maintenance costs, owners measured their facilities based on a low, medium or high cost assessment of facility performance to date, with low cost assigned a score of 3 and high cost assigned a score of 1. The new quality assessments yielded significantly different mean scores of 2.400 for the design-build projects and 2.152 for the design-bid-build projects. Interestingly, original quality assessments for this measure did not identify any difference in performance between systems. Figures 5.12 and 5.13 graph the original and new operation and maintenance scores respectively by delivery system and years since project completion.

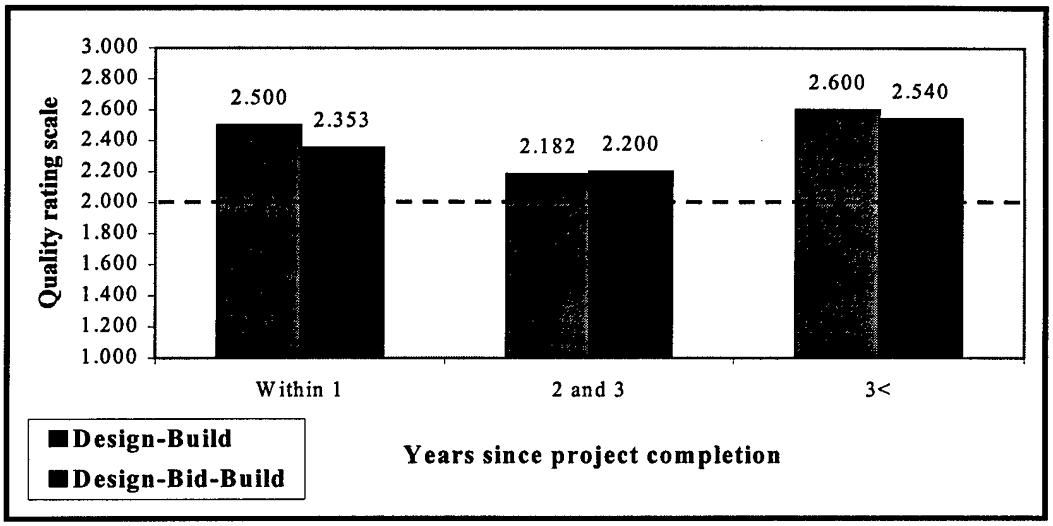


Figure 5.12: Original mean operation/maintenance scores by delivery system and years since project completion.

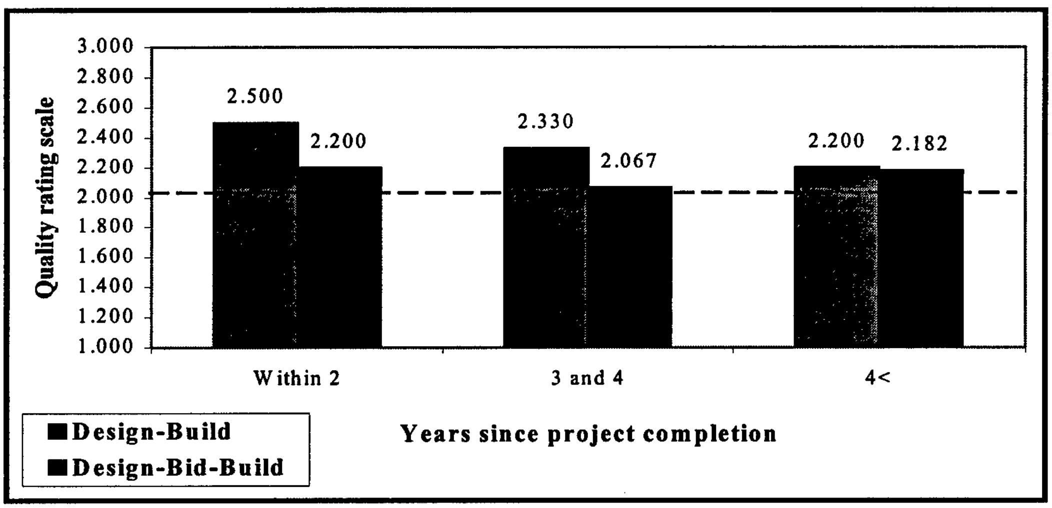


Figure 5.13: New mean operation/maintenance scores by delivery system and years since project completion.

Overall the design-bid-build projects noted a small increase in their mean score from the original survey results regarding operation/maintenance costs. This increase is attributed to 6 increased scores from project responses provided within three and four years since project completion. It is interesting to note that the mean scores of both design-build and design-bid-build project quality responses provided greater than 4 years since project completion decreased. All design-bid-build projects experienced decreased mean scores within each year since project completion.

For call-backs, both systems received high mean scores, however, no significance was identified based on the new quality data. Approximately 5 percent of the updated design-build project responses within 2 years of project completion noted decreased scores from the original quality assessment which decreased their delivery system's overall mean scores. In contrast, only one design-bid-build project reported a decreased score. Again no significance was achieved between systems.

The remaining quality measures rated the performance of four systems for each completed facility: envelope, roof, structure and foundation; interior space and layout; environmental; and process equipment and layout. Quality ratings for these systems were based on the owner's perception of whether systems did not meet, met, or exceeded expectations. Systems exceeding expectations received a high quality score of 3 and those systems not meeting expectations received the lowest score of 1.

For *envelope, roof, structure, and foundation* quality, design-build projects generally met expectations with a mean score of 2.108, whereas design-bid-build projects achieved their lowest mean score of 1.915 (see Table 5.3). Seventy five percent of projects for both delivery systems received scores of 2, signifying consistent performance without undue influence by extreme high/low values over time. *Interior space and layout quality* for each delivery system nearly replicated the scores previously reported for the envelope, roof, structure, and foundation with no significance noted between design-build and design-bid-build. *Environmental systems* quality results provided the lowest and closest mean ratings of 1.975 and 1.957 respectively for design-build and design-bid-build. 75 percent of projects surveyed in both the original and new rating were scored as having met expectations; however, on average, both systems did not meet expectations. Of all responses, only one design-build project noted a decrease in score over one year's time.

Thirty eight percent of responses reported that *process equipment and layout* were not applicable to their project. Furthermore, those owner responses reporting process equipment and layout represented many different applications among and between the different facility types, i.e.: cafeterias/kitchens, assembly line and conveyor systems, specialty apparatus and equipment integral to the facility.

### 5.3.4 FEDERAL UNIVARIATE RESULTS BY FACILITY TYPE

Figure 5.14 presents the results of statistical testing of delivery system performance by facility type. Unlike the previous overall univariate comparisons, this figure presents findings of univariate testing that investigated whether facility type alone had any direct impact on delivery performance. Results are based on satisfying 95 percent confidence levels with significant findings identified by darkened ovals with the corresponding relationship between the delivery systems noted below the ovals.

Of the four facility types tested, only two identified significant differences between delivery systems: complex office and multi-unit dwelling facilities. Measured in terms of facility gross square footage procured per month, the procurement speed metric identified 6 complex office design-bid-build projects to have a median speed nearly 6 times faster than 8 similar design-build projects. When addressed by facility type, this is the only measure in which design-bid-build projects performed better than design-build projects.

Only multi-unit dwelling facilities were significantly different by delivery system concerning the call-back measure. Here 9 design-build projects received a mean score of 2.667, significantly higher than the 11 design-bid-build projects' mean score of 2.091 (0.024) with a maximum standard error of plus or minus 0.17. No significance was noted within the overall combined sample of projects for this same measure. No other differences were noted by facility type for the other quality measures.

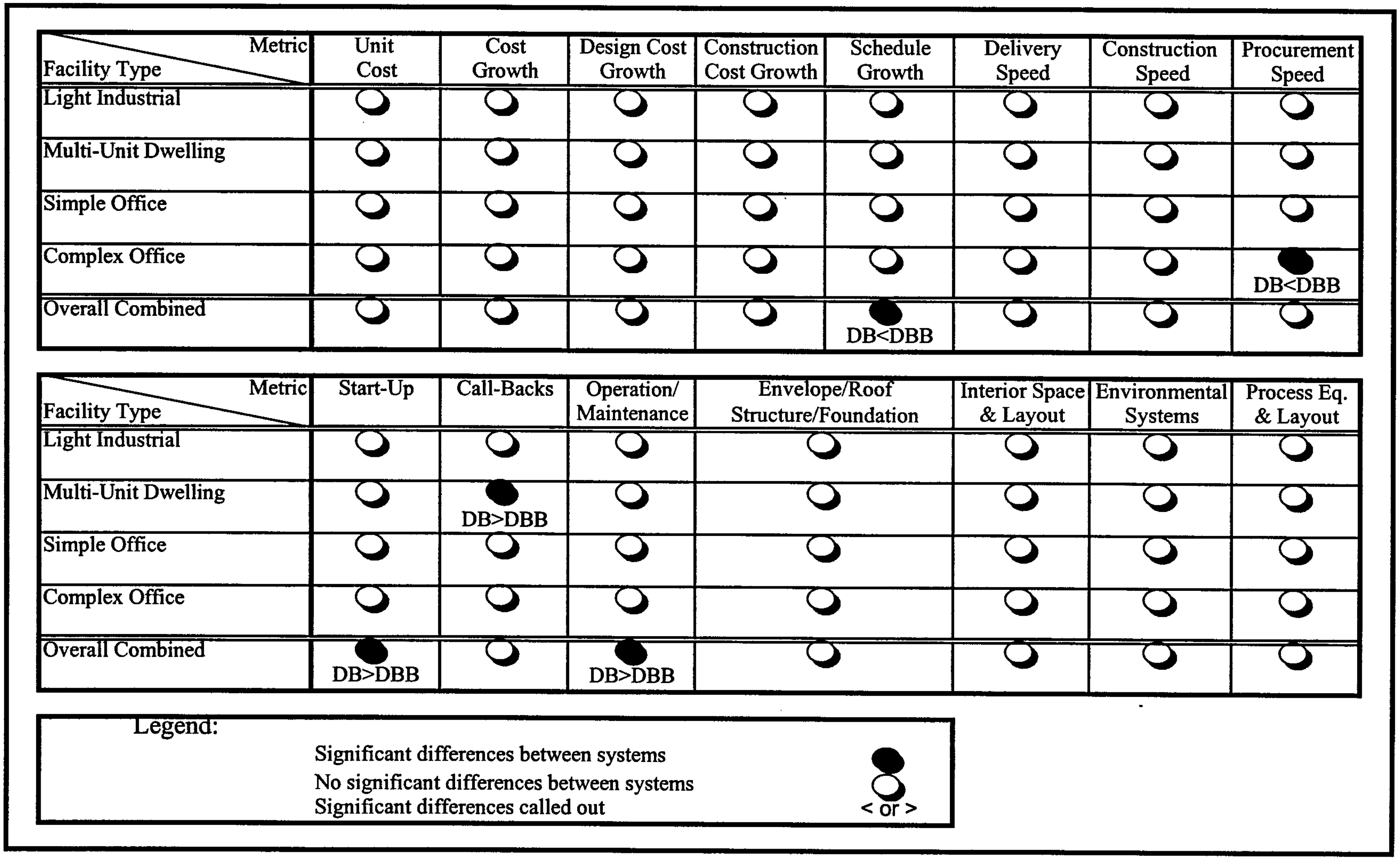


Figure 5.14: Matrix of significant project delivery performance for new federal project data by facility type and metric.

### 5.3.5 Univariate Results By Percent Design Complete

Results of project performance by metric according to percent design complete at time of construction contract award are presented in Figure 5.15 with significant findings identified by darkened ovals. Calculated p-values are presented in parenthesis for each metric in the following dialogue.

Project responses were categorized into four groups based on reported design complete percentages when the design-build or construction contract was awarded. These were: (1) concept design (within 0 to 15 percent); (2) schematic design (within 15 to 35 percent); (3) design development (within 35 to 65 percent); and (4) contract documents (within 65 to 100 percent) (AIA, 1987). Based on this classification, 17 design-build projects fell within the concept phase, 19 within the schematic phase, and the remaining 4 projects were contracted in the design development phase. All 48 design-bid-build projects were contracted within the contract documents phase consistent with traditional practice.

Comparative results of projects by design complete phase against each performance metric yielded a closer evaluation of project delivery system outcome. Project contracted within the concept design phase had significantly less cost growth (0.05, 0.048) and construction cost growth (0.05, 0.05) than projects contracted during the construction documents phase. Projects contracted within either the concept (0.020, 0.040) or schematic (0.001, 0.037) phases had significantly less schedule growth than the design-bid-build projects, all of which were contracted within the contract documents phase. With 90 percent of all design-build projects within either phase 1 or 2, these schedule growth findings are consistent with the earlier univariate schedule growth results supporting design-build projects performed better than design-bid-build projects. The procurement speed metric identified projects contracted in phase 3 to be slower than the design-bid-build projects comprising phase 4 (0.001, 0.037). This is the only instance where design-bid-build projects have performed better than any design-build projects.

| Performance by Design Complete Phase \ Metric | Unit Cost | Cost Growth | Design Cost Growth | Construction Cost Growth | Schedule Growth | Delivery Speed | Construction Speed | Procurement Speed |
|---|---|---|---|---|---|---|---|---|
| Performance by Design Complete Phase | ○ | ● 1 < 4 | ○ | ● 1 < 4 | ● 1, 2 < 4 | ○ | ○ | ● 3 > 4 |

| Performance by Design Complete Phase \ Metric | Start-Up | Call-Backs | Operation/ Maintenance | Envelope/Roof Structure/Foundation | Interior Space & Layout | Environmental Systems | Process Eq. & Layout |
|---|---|---|---|---|---|---|---|
| Performance by Design Complete Phase | ● 1, 2 > 4 | ○ | ● 1 > 4 | ○ | ○ | ○ | ○ |

**Legend:**

| | |
|---|---|
| Design Complete Phases: | |
| Concept Design ( 0% < x < 15%) | 1 |
| Schematic Design ( 15% < x ≤ 35%) | 2 |
| Design Development ( 35% < x ≤ 65%) | 3 |
| Contract Documents ( 65% < x ≤ 100%) | 4 |
| Significant differences between systems | ● |
| No significant differences between systems | ○ |
| Significant differences called out | < or > |

Figure 5.15: Matrix of significance for federal projects by design complete phase at construction contract and metric.

For the quality measures, start-up produced significant differences by noting projects within phases 1 and 2 achieved higher scores than projects within phase 4 (0.004). Also, operation and maintenance quality measured phase 1 projects to have scored lower costs on average than projects classified into phase 4 (0.034). Interestingly, phase 4 projects which have the greatest level of design scored significantly lower in each quality measure noted on Figure 5.15 than projects contracted with much less design information (phases 1 and 2).

### 5.3.6 Summary Of Univariate Results

The univariate findings focused on identifying any possible direct relationships between delivery systems and project performance. These univariate comparisons were unadjusted for any other variables. They explored the sample population by delivery system for each of the 15 performance metrics. The effects of facility type and percent design complete on delivery system performance were also investigated. Comparison of results between the original CII findings and the federal findings revealed 1 key difference; the inclusion of all design time from zero percent design complete provided no significant differences between delivery systems for delivery speed. This is a change from the original CII study data which identified significant differences between delivery systems for this metric.

Differences between delivery system performance were reported at the 95 percent confidence level. The objective results collected with the data collection tool, the data checking, and telephone interview of each project owner provided high confidence in the data as accurate and representative of the selected federal projects' performance. The relatively few instances of statistical differences between design-build and design-bid-build both overall and facility specific by metric supported further investigation beyond univariate analysis. A project's delivery system is one of 65 possible explanatory variables collected in this study. Multivariate regression analysis was conducted to explore the interaction of these delivery systems with all other reported variables.

## 5.4 Multivariate Results For Delivery Speed

The conflicting univariate results identified for federal projects between the original and new data for delivery speed supported further statistical analysis of this performance measure. Multivariate regression analysis investigated the presence of delivery systems and facility type in conjunction with other variables in explaining delivery speed performance. Variables exhibiting the greatest influence on delivery speed for federal projects were next compared to the original CII study delivery speed model to identify similarities or differences in variation.

### 5.4.1 Federal multivariate results

An explanatory model was developed for the delivery speed metric based on multivariate regression analysis of all reported project data. Resultant computer output of the final delivery speed regression model and the influence of its associated explanatory variables are provided in Appendix C. The final regression model achieved a p-value of 0.000 providing statistical significance in the explanation of delivery speed variation.

Of the 88 total federal projects, this model incorporated data from 77 projects to explain 82 percent of the variation in the delivery speed metric. Ten projects did not report sufficient variables identified in the model, and therefore were unable to contribute to any explanation. One project was intentionally removed due to its strong level of influence exerted on this model identified through residual diagnostic analysis and examination of Cook's Distance (Minitab, 1995). This design-bid-build project was awarded for construction more than two years after the design effort had been completed. Due to funding appropriations, this project resulted in an overall four year project duration which directly increased delivery speed.

The 82 percent R-squared value calculated by the model provides strong statistical support for the variables identified as having the greatest proportion of variation for delivery speed. The model identified the following variables ranked by relative influence in explaining delivery speed performance variation:

1. Project size
2. Facility type
3. Delivery system
4. Design time prior to construction advertisement
5. Contract unit cost
6. Percent design complete at construction contract award
7. Team's prior experience as a unit
8. Project team chemistry
9. Procurement time
10. Experience of members with similar facilities

Initial investigation of best subset regression models identified a non-linear relationship between delivery speed and the explanatory variables; a transformation of delivery speed was required. Using the Minitab® statistical software, several trial transformations identified that the natural log of delivery speed best provided a linear relationship in defining the model. Of the independent variables identified, project size explained approximately 48 percent of the total variation in delivery speed performance. A direct, positive relationship between area and delivery speed was identified by the model, such that larger project size resulted in faster delivery speed. Most noticeably, specific interaction between light industrial facilities and their respective gross square footage provided the next highest single explanation accounting for 11 percent of the variation. Again, as size of the project increased for this particular facility type so too did delivery speed.

Facility type was identified as important by collectively explaining 18 percent of the variation for delivery speed. In addition to the specific relationship identified for light industrial facilities and their size, other facility types held strong, positive relationships with resultant delivery speed as identified by their model coefficients. Delivery speeds increased for complex office and simple office projects regardless of delivery system. Facilities within the "other" facility type category also maintained a positive yet noticeably less significant relationship with delivery speed. Again, it must be noted that all projects within the "other" facilities category were delivered using design-bid-build.

The delivery system used on a project provided less importance in explaining delivery speed, accounting for only 8 percent of the variation. Solving the regression equation individually for each delivery system, comparisons between design-build and design-bid-build delivery speed identified only marginal differences between their respective performance. Based on the model output for each delivery system, design-build was, on average, 1.1 percent faster than design-bid-build.

The seven remaining variables provided less significant explanation. The model identified the shorter the design time, the faster the resultant delivery speed noting a very direct positive correlation in that the time to complete 35 percent design is shorter than a 100 percent design complete effort. Contract unit costs were identified as having a negative relationship, such that delivery speed decreased as contract unit costs increased. This finding appears logical since the heavy industrial and high-technology projects comprising the "other" facilities category had the highest contract unit costs of which all were design-bid-build projects. Light industrial projects had the lowest contract unit costs with no significant differences between delivery systems within this category.

The negative coefficient for percent design complete at design-build or construction contract award indicated that projects contracted within the earliest stage of design achieved higher delivery speeds than projects contracted after 35 percent design complete. Most noticeably, complex office projects achieved high delivery speeds benefiting from contract award at the earliest stage of design complete. However, these projects reported longer procurement times. This in turn directly relates to the model's findings that longer procurement periods resulted in slower delivery speeds. For example, more complex projects more often experienced longer procurement time periods based on the level of detail required in submitting design-build proposals and the subsequent proposal review and selection process.

Though less influential in explaining delivery speed variation, bad project team chemistry decreased delivery speed whereas project team's prior experience as a unit positively impacted delivery speed effectiveness. Competitive bidding of federal projects often prevents repeat project relationships, which conflicts with the positive influence of prior team experience on improving delivery speed performance as identified in this research. Furthermore, project team member's experience with similar facilities, particularly excellent design-build entities' experience increased delivery speed. This relationship is important since a design-builder's experience with a particular facility type is often a factor in prequalification and selection for a project (Potter et al., 1995).

### 5.4.2 Comparison of Federal and CII Delivery Speed Model Results

Table 5.4 presents a comparison of the variables identified through multivariate regression analysis of delivery speed derived from the new federal data and original CII study data. Numerical rankings of each variable identify their relative influence in explaining delivery speed variation.

Interestingly, project size, facility type and contract unit cost provided high levels of explanation for delivery speed in each study. Percent design complete, delivery system, and team member experience with similar facilities were also identified as significant explanatory variables yet each provided different levels of influence for each respective model. Each study's respective delivery speed model also identified several other variables uncommon to each other's model. These variables contributed significantly less influence in explaining delivery speed variation.

Based on the this study's focus on design start time, two variables identified in the federal delivery speed model were not considered in developing the original CII study delivery speed model: design time prior to construction contract award and procurement time. Multivariate results indicate that federal government projects devote more time to design and procurement prior to construction contract award. It is unknown how these variables might have contributed to the original CII study had they been included. With only 10 projects reporting renovation efforts greater than 10 percent, the federal delivery speed model did not recognize level of new construction as significant. Possible explanation for these differences may stem from competitive federal acquisition requirements in procuring design-build services as well as lack of federal renovation projects for comparison.

| | New Federal Data | CII Data |
|---|---|---|
| Number of Projects | 77 | 328 |
| Explained Variation | 82% | 88% |
| Project size | 1 | 1 |
| Facility type | 2 | 4 |
| Delivery system | 3 | 8 |
| Design time prior to construction advertisement | 4 | N/A |
| Contract unit cost | 5 | 2 |
| Design complete percentage | 6 | 3 |
| Team's prior experience as a unit | 7 | N/A |
| Project team chemistry | 8 | N/A |
| Procurement time | 9 | N/A |
| Experience of members with similar facilities | 10 | 6 |
| Project team communication | N/A | 5 |
| Project complexity | N/A | 7 |
| Level of new construction | N/A | 9 |
| Presence of onerous clauses in contracts | N/A | 10 |

Table 5.4: Ordered influence of explanatory variables in delivery speed variation for new federal data and original CII data.

## 5.5 SUMMARY

Univariate comparisons of the original CII project data for private, public, and federal projects showed several differences in delivery system performance. Results confirmed that design-build projects performed better than design-bid-build projects for several performance measures for all projects and for certain facility types; however, results were different for each owner type. New cost, schedule and updated quality data collected from the original 85 and three new federal project owners resulted in significantly different findings from the original univariate results. Updated quality ratings collected one year after original data collection identified facility start-up and operation and maintenance cost quality measures to have the highest number of changed scores over time. Both measures statistically proved scores for design-build projects to be significantly higher than design-bid-build project scores. Further univariate analysis identified significant differences in project performance by percent design complete prior to design-build or construction contract award.

Univariate differences in delivery speed performance between the original CII data and the new federal data indicated possible differences resulting from inclusion of design concept time. Multivariate regression analysis using new design data identified ten variables, inclusive of delivery system and facility type, that collectively explained 82 percent of the variation in delivery speed. When compared to the original CII study delivery speed model, only three variables provided similarly high levels of explanation in each model: facility size, facility type, and contract unit cost. Five of the remaining seven less significant variables were different between the two models.

# Chapter 6

# Discussion And Conclusions

This chapter summarizes the main findings of this research and discusses the quality and delivery speed performance results. Limitations of the research methods, project performance data collection, measurement and analysis are presented. Contributions of this study to current project delivery system research are followed by areas for future research. Finally, this study is concluded.

## 6.1 Main Findings

Univariate comparisons of cost, schedule, and quality identified several differences in project performance by delivery system for each of three project owner types: private, public, and federal. Based on the original 273 projects' cost and schedule data collected in phase one of this study, design-build projects were significantly faster than design-bid-build projects in overall delivery speed for all owners. However, data verification identified inconsistencies in 43 project timelines relating to the accurate start of project design. New cost and schedule data collected in phase two of this study acquired directly from federal project owners provided direct comparison of project delivery timelines from zero percent design complete. Inclusion of this concept design time from the start of project design resulted in no significant speed differences between project delivery systems by facility type.

Comparison of original quality assessments to new quality data collected one year later provided fairly consistent results between delivery systems over time. Of the seven quality measures, only the number and magnitude of call backs and the operation/ maintenance cost metrics changed. Regarding call backs, scores decreased minimally over the one year time period between quality assessments done within the first two years since project completion. The greatest change in score occurred for operation/

maintenance costs which identified design-build projects to perform better than design-bid-build projects. Between the original and new data, design-build scores increased over time compared to decreased design-bid-build scores providing statistical differences between delivery systems. The most dramatic and influential changes occurred within three and four years and greater than four years since project completion. These varying scores suggest that operation/maintenance costs are not a static measure since time is necessary to establish whether energy consumption goals are being met and to evaluate the life-cycle costs of the facility.

Investigation of project performance measures by percent design complete at construction contract award provided statistical differences between and within delivery systems. By categorizing projects into one of four design phases, various forms of design-build project delivery were directly compared. No significant differences in project performance were noted between projects contracted within either the concept or schematic design phase. However, projects within the concept design phase consistently performed better than projects contracted within the contract documents phase.

Multivariate linear regression analysis of delivery speed identified 10 variables providing the highest proportion of explanation for delivery speed variation. Three variables explained 74 percent of the variation of this model: facility size, facility type, contract unit cost, and delivery system. These primary variables are fairly consistent with previous delivery speed model findings (Konchar, 1997) however several other less significant variables were identified in addition to the three in the original CII delivery speed model. Inclusion of percent design complete at construction contract award, design time prior to construction advertisement and procurement time were identified as less important explanatory variables. Interestingly, a lower percentage of design complete at construction contract award improved the delivery speed, whereas increased procurement time decreased delivery speed. Coupled with less design complete percentages, shorter design times also improved delivery speed. Other variables explaining delivery speed performance included: team member's experience as a unit, project team chemistry, and team member experience with similar facilities. Except for team chemistry, these last few variables are all known prior to project commencement and should be considered in planning the project.

## 6.2 DISCUSSION

Two primary findings presented above warrant further discussion: the quality results and measurement of delivery speed. Each topic is presented individually below.

### 6.2.1 QUALITY

The quality findings provide a better understanding of the relative results obtained through measuring and comparing quality over a period of time since project completion. It must be noted that the quality scores reported in this research measured owner satisfaction rather than actual quantifiable facility quality performance. The researcher notes a distinction between conformance with design drawings and adherence with performance criteria in measuring facility quality. Without pre-set evaluation criteria, measuring facility quality in terms of design, construction, and operation is limited to the subjective opinion of the facility owner and their degree of satisfaction with the facility. However, both the Navy's Post Occupancy Evaluation (POE) program (Naval Facilities Engineering Command, 1995) and current quality research (Corbett, 1997) have identified the importance of measuring customer satisfaction or customer confidence in the resultant facility. It must be noted that owners might not have the same expectations or levels of satisfaction which would impact their evaluation.

The unchanged facility start-up quality scores between the original and new data suggests consistent interpretation and reliable measurement of building commissioning and initial building start-up. This consistent scoring provides strong confidence in the statistical differences reporting design-build to perform better than design-bid-build for this measure. In contrast, the call back measure changes over time and may be impacted by number of latent defects not found during project inspection. Though operation/ maintenance costs were not collected by the data collection tool, owners were asked to make their assessment based on recorded costs to operate and maintain the facility relative to the facility's operation budget. Changes in operation and maintenance costs identify the dynamic nature of facilities' life cycle costs over time with performance requirements used on design-build projects performing better than detailed, prescriptive facility requirements used on design-bid-build projects. However, changes in operation/ maintenance costs could also reflect changes in building occupancy and function from the original design.

The unchanged quality scoring for each of the four systems quality measures suggest that no building functions changed since project completion and as a result owner expectations did not change. However, the consistently low mean quality scores reported for each of the four building systems could suggest owners or facility users are not knowledgeable of or familiar with actual system requirements. Additionally, these low scores could in fact suggest that the facility systems were not adequate for their intended purpose. Furthermore, owner expectations for system performance may not be as high or as important as other quality measures.

### 6.2.2 Delivery Speed

The 1.1 percent difference in delivery speed performance between design-build and design-bid-build projects is the second issue requiring further discussion. Earliest possible delivery of a project through shortened project delivery was identified as the primary reason for public project owners to select design-build for the delivery of their projects (Molenaar, 1995). Though new cost and schedule data was acquired to account for initial concept design for design-build projects, no other direct explanatory evidence was collected to explain this finding. Four possible explanations for these findings are:

1. Project owners may have misinterpreted telephone interview questions or inaccurately provided data regarding concept design start.

Project data provided from several federal agencies was collected to compare design-build and design-bid-build projects from equal starting dates. Responses from the Department of Veterans Affairs provide an interesting case study of how project schedule data was recorded for comparison between design-build and design-bid-build projects.

By their own measure, the Department of Veterans Affairs have noted a 33 percent reduction in project duration for design-build projects when compared to design-bid-build projects (Anglim, 1998). Their project duration metric for design-build projects started with the preparation of the request for proposal. They equated this to the start of construction documents with approximately 35 percent design complete at that time. Design start dates provided for design-bid-build projects were reported at the start of design development. Thus the actual start from zero percent design complete for both delivery systems is not reported in the project duration, rather an equivalent start point was selected for both systems—35 percent design complete.

2. Fixed funding cycles may suggest lack of importance or urgency in completing the initial concept design prior to construction advertisement date.

Design and construction are funded separately and sequentially for federal projects based on congressional appropriations (Enloe, 1997). As design funds are approved at the beginning of each fiscal year, initial concept design may commence immediately and be completed several months in advance of construction funding approval or continue at a less critical pace until construction funding is provided. These two different approaches to completing design within a fixed time frame may illustrate the inaccuracy of actual design time used in the delivery process.

3. The noted lack of significance in project delivery speed between delivery systems could suggest inaccurate or unrealistic project schedules.

The use of design-build requires owner capability in conceptual design, accurate parametric estimating and scheduling to develop request for proposals. Seventy percent of all military project responses devoted at least five months to developing concept design and the request for proposal for projects using design-build. Though this concept design time is on average shorter than the entire design time for design-bid-build projects, this research has identified procurement time to acquire the design-build contract to influence the resultant delivery speed. Though 50 percent of design-build projects were completed on or below schedule, their overall project durations were not significantly dissimilar than design-bid-build projects. Careful project pre-planning and continued experience with design-build project delivery might more accurately establish optimum, shorter project schedules (Bruns, 1997, Songer, 1992).

4. All projects delivered via the design-build method in this study were executed as test cases and procured under the restrictions set forth in the old Federal Acquisition Regulations prior to the implementation of the Federal Acquisition Reform Act of 1996.

The old regulations did not formally address how design-builders should be qualified or selected nor how much design was required prior to design-build contract award. Previous literature (Potter et al, 1994, NSPE, 1994) identified public agencies created their own unique approaches to design-build qualification. This research identified the higher the percentage of design complete prior to construction contract award, the slower the delivery speed. Furthermore, procurement speed decreased with lower percentages of design complete prior to construction contract award. In contrast, the reformed acquisition guidelines provide more flexibility in selecting and applying design-build project delivery for federal project execution.

## 6.3 Implications for Federal Project Owners

An important distinction exists between statistical significance and practical significance that warrants further discussion relating to the delivery of federal projects. Though previous public owner opinion polls identified shortened project duration as the primary reason for design-build project delivery selection, delivery speed may not have been the critical factor in executing and measuring all projects. Rather, the funding cycles may drive project durations. Federal agencies are charged with expending allocated funds within specified time periods. Because design and construction occur in series and are funded sequentially, there is no incentive to speed up the design process.

Though design-build projects had significantly less schedule growth than design-bid-build projects, there were no significant differences in delivery speed. Since design funds to accomplish initial design for a design-build project are separate from the construction funds to accomplish the single source design-build effort, there is no incentive to expedite the process. Therefore, the current method of separately funding design and construction provides not method to optimize parallel activities of design and construction for design-build projects. In addition to design and construction, procurement time constitutes another component of delivery speed that the federal government must shorten in order to improve design-build project delivery speed.

Project specific goals may place more weight on costs than schedule for successful project completion. The government's goal is to acquire projects based on the lowest responsive cost that satisfies construction of a defined facility. The government is also allowed to spend the budgeted amount and may add work scope to maximize the facility quality for the given budget. The use of guaranteed maximum price contracts with possible shared savings clauses might provide more cost savings to the owner if the government can "retain" those unspent funds.

Projects executed using the design-bid-build delivery system incorporate periodic design reviews throughout the duration of the design phase to allow owner input in the development of the design. Typically, reviews are conducted at 35, 65, and 95 percent design complete phases (Duncan, 1998). In executing design-build projects, federal owners still participated in periodic design reviews though the design-build entity was not always contractually bound to incorporate changes. However, incorporated owner changes resulted in change orders to the contract. Though no actual change order cost or time data was collected, design-build contracts awarded in the concept design phase experienced less construction cost growth than design-bid-build projects. This suggests that the federal government benefits from early design-build creativity and constructability innovation which in-turn experiences less changes in the construction phase. Interestingly, design accomplished in the design-build contract did not always proceed to 100 percent design complete documentation. Anecdotal evidence from project owners identified that the 65 percent design complete review was often the last opportunity to provide design input as no further drawings or specifications were accomplished for the project. From that point on, all work focused on construction.

Recognizing the importance of time in assessing facility performance, the Navy's POE program is currently being redesigned to incorporate periodic and systematic facility quality surveys based on quantitative data collected after project completion. The facility start-up, call backs and operation/ maintenance cost quality measures used in this research directly address the Navy's POE goal of evaluating operational deficiencies of completed facilities after project completion. To accomplish this goal, previous research (Perkinson, 1991) stated that clear and measurable operational requirements defined during project programming allow objective measurement of facility quality throughout all phases of a facility's life. Therefore, quality assessments should address facility output rather than design and construction input based on pre-determined operational goals over a facility's lifecycle.

## 6.4 LIMITATIONS

Five limitations were identified in planning and conducting this research. They are as follows:

1. Cost and time to perform project pre-planning and programming activities were not included in this study.

Project programming documentation as well as final site selection were completed prior to the start of the delivery process as measured from zero percent design complete in this study. Federal project programming documentation is often completed several years in advance of actual start of design (Enloe, 1997) With no cost or time data collected prior to the design start, it is unknown whether programming effort for a design-build project is less than or greater than programming a design-bid-build project in terms of time or cost.

2. Design procurement cost and schedule data were not collected in this research.

Professional design services are selected and contracted for federal projects via qualification, not price (Brooks Act, 40 U.S.C. SS 541). This applies equally to the selection of design professionals for design-build bridging design efforts as well as design-bid-build projects. It was assumed in this research that design procurement for both delivery systems was approximately equal based on the selection procedures mandated by the Brooks Act. However, some federal agencies may have selected the designer from a pool of pre-contracted design professionals for a project several years prior to the start of the design, or they may have indefinite quantity delivery orders for design services. This selection of design professionals can possibly vary the equitable comparison of project delivery timelines.

3. The number and cost of change orders and claims were not collected.

This research did not specifically record the number and cost of change orders and claims. The design cost growth, construction cost growth, and total cost growth measures attempted to capture the relative change in costs from the contracted cost to final cost. Without specific knowledge of what actually caused any increase in design, construction or their combined total, and the timing of these changes, it cannot be ascertained whether cost increases resulted from scope changes, redesign, owner initiated changes, or claims.

4. Quality performance measures were analyzed only on a univariate basis.

Due to the discrete nature of the quality assessment ratings, nominal logistic regression could have been used to test the statistical likelihood of one delivery system's quality score over the other delivery system. Without the use of nominal logistic regression, no explanation of the variation in quality scores could be provided inclusive of delivery system and facility type. However, for the callback and operation/ maintenance cost quality measures, the noted change in these ratings over time precluded the use of nominal logistic regression in explaining consistent variation in quality performance.

5. Multiple linear regression focused on the delivery speed metric.

A better understanding of delivery systems and facility types in explaining each performance metric could have been provided through the use of multiple linear regression. As identified between the univariate and multivariate comparisons performed on delivery speed, the presence of all possible variables in explaining performance variation can identify the relative impact of project delivery system and facility type.

## 6.5 CONTRIBUTIONS

This study provided three valuable contributions to project delivery system research and project performance measurement. These contributions follow:

1. Objective comparison of project delivery system performance by owner type.

Specific inquiry into project performance by private, public and federal project owners identified several differences in project delivery system performance by owner type. Previous CII research (Konchar, 1997) favored the use of design-build over design-bid-build separately for each owner type by performance metric. Further analysis of project performance within the public sector identified significant differences between state/local public projects and federal projects. Based on this data, both owner types identified similar differences between delivery systems for delivery speed, though the federal projects also noted differences within the schedule growth measure. Therefore, univariate comparisons suggested that project delivery systems differ by owner type in some manner. Specific investigation of new federal project data further identified the impact of measuring projects based on equal starting points. These results contradicted the delivery speed performance findings of the original public project data.

2. Objective comparison of project performance by percent design complete.

Previous research (Federal Construction Council, 1993) subjectively compared design-build and design-bid-build federal projects based on federal agencies' previous experiences using these two delivery systems. Anecdotal evidence provided by that study identified projects contracted between 15 to 35 percent design complete achieved the best project performance results. This is different to the objective results of this study. Objective performance measures based on specific cost and schedule project data identified projects contracted prior to 15 percent design complete actually performed significantly better than projects contracted after 65 percent design complete. In this instance, design-build projects contracted between zero and 15 percent design complete actually performed better than all design-bid-build projects in six of the 15 performance measures. However, no statistical differences were found between the concept, schematic or design development phases for the design-build projects.

3. Measurement of project quality performance over time.

Two quality assessments were measured one year apart to address the influence of time in measuring facility quality. Projects responses were provided for projects completed within the past five years within the United States. Scores between the original and new data identified start-up quality to be most accurately reported within the first two years since project completion when knowledge of the turnover process is still current in contrast to five years after completion. Changes in operation/maintenance quality for projects within each time period since project completion identified the dynamic nature of measuring life-cycle costs over the life of a facility.

### 6.6 FUTURE RESEARCH

Three areas worthy of future research were identified as a result of this research. Each area of future inquiry is individually discussed as follows:

1. Objectively compare various forms of design-build project delivery methods to identify successful project attributes for each.

This study recognized that various forms of design-build project delivery systems exist, though all forms were collectively grouped under the general design-build definition provided in this research. A similar investigation comparing sole source, two-phase design-build, bridging, and turnkey design-build project delivery methods could identify performance differences.

2. Objectively compare projects acquired under the guidelines of the old Federal Acquisition Regulations to projects completed under the auspices of the Federal Acquisition Reform Act of 1996.

This study utilized project specific data from design-build projects executed over the past five years by several federal agencies unfamiliar with the design-build project delivery process. Many of these projects were executed using the design-build method simply as test cases. As such, these projects might not present the best examples of successful design-build project execution possibly due either to lack of owner experience in administering design-build projects or due to the restrictions set forth in the old Federal Acquisition Regulations.

3. Model the facility programming and project acquisition process for federal design-build projects.

An understanding of the activities and decisions necessary to define facility performance requirements and their implementation into request for proposals would benefit owners' knowledge of design-build project management. Though this research focused on the design and construction phases of project delivery, inclusion of procurement time in the delivery speed model provided interesting results suggesting factors other than design and construction activities impact project performance. It is during this procurement time that design-builders respond to the requirements established in the request for proposals from the owners.

## 6.7 CONCLUSIONS

Project specific data collection is valuable in the objective measurement of project performance. The 15 project performance metrics of cost, schedule and quality indices and the data collection tool and interview questions used to capture factual data were effective tools to evaluate project performance. Objective measurement of key cost, schedule and quality metrics provided direct and statistically supported comparisons between design-build and design-bid-build project delivery systems. Therefore, this study's data collection, objective performance measurement and comparison, and statistical modeling methods met all research objectives.

Univariate statistical analysis of project performance measures identified conclusive differences between delivery systems based on the central tendencies of the reported data. These findings supported federal design-build projects perform better than federal design-bid-build projects for schedule growth, facility start-up quality and operation/ maintenance cost quality. This study's univariate findings provided benchmarks of federal project performance for present and future comparison. However, comparison of the original data to the new federal project data identified time to be a factor in measuring project performance both in terms of elapsed time since project completion and start of project delivery timelines. Quality results indicated facility start-up assessments should be accomplished within the first two years after project completion. In contrast, increases or decreases in the number and magnitude of call backs over time suggest the existence or absence of latent defects in the construction of a facility. Moreover, several changes in operation/ maintenance cost ratings identified the importance of measuring and comparing project performance throughout its lifecycle.

The investigation of project performance by percent design complete prior to construction contract award suggests that federal design-build projects should be contracted within the concept design phase. Projects contracted within the concept design phase capitalized on early construction input and design creativity which resulted in both lower cost growth and construction cost growth performance as well as less schedule growth. Furthermore, simple and concise performance requirements conveyed during the concept phase provided less difficulty in building commissioning and start-up and lower operation/ maintenance costs over time.

Regarding project timelines, measurement and comparison of overall delivery speed requires consistent interpretation of the sequence of activities, specifically the delivery process start date. As no changes were noted for the construction speed measure by delivery system, this suggested that the change in delivery speeds were influenced by either design prior to construction contract award and/or procurement time to acquire the design-build or construction contract.

Unlike previous public sector project research in the United States, this study's use of multivariate analysis allowed for explanation of variation in delivery speed performance given the influence of several variables acting on the model at one time. Facility size, facility type and delivery system explained the greatest proportion of variation in delivery speed which federal owners should use to estimate the project duration. Seven of the 10 key explanatory variables identified were within the control of the project owner. This suggests owner knowledge of the delivery process prior to both the start of design and the creation of the project team could aid the owner in his/her project acquisition strategy.

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# APPENDIX A

## PROJECT DELIVERY SYSTEM DATA COLLECTION TOOL

# PROJECT DELIVERY SYSTEM SURVEY

THE CONSTRUCTION INDUSTRY INSTITUTE
THE PENNSYLVANIA STATE UNIVERSITY

## INSTRUCTIONS

Penn State has been selected to conduct a national survey of the three principal project delivery systems in the U.S. today. Please help us by completing the survey for at least one project you have completed in the last 5 years in the U.S. You may submit up to ten. At your request we will provide you a copy of the survey results.

Each survey form should be coordinated by your Project Manager. Thorough responses to survey sections 1 to 5 are the most critical to this study. Other sections are important to explain the reasons for the measured differences.

Upon receipt of your data, Penn State will number each copy, remove company identification, and remove project identification. The information you provide will be kept in strict confidentiality.

Please return the completed questionnaire by mail or fax before Dec. 31, 1996 to:

Dr. Victor E. Sanvido, Dept. of Architectural Engineering, Penn State University, 104 Engineering Unit "A", University Park, PA 16802-1416
Fax: (814) 863-4789 Phone: (814) 865-2869

## DEFINITIONS

**Design Bid Build** is a traditional process in the US construction industry where the owner contracts separately with a designer and a contractor. The owner normally contracts with a design company to provide "complete" design documents. The owner or his/her agent then solicits fixed price bids from contractors to perform the work. One contractor is usually selected and enters into an agreement with the owner to construct a facility in accordance with the plans and specifications.

**Design Build** is an agreement between an owner and a single entity to perform both design and construction under a single design build contract. Portions or all of the design and construction may be performed by the entity or subcontracted to other companies.

In **CM at Risk,** the owner contracts with a design company to provide a facility design. The owner separately selects a contractor to perform construction management services and construction work in accordance with the plans and specifications for a fee. The contractor usually has significant input in the design process and generally guarantees the maximum construction price.

## SECTION I: PROJECT CHARACTERISTICS

Project name: ____________________ Project location: ______________

Project executive/ respondent who provided data: ______________________

Phone number: ________________________________________

Company name: ________________________________________

O Owner    O Design-Builder    O Architect/Designer    O Contractor

Please mark the appropriate oval for project type:

| | | | |
|---|---|---|---|
| O Office | O Light Manuf. | O Micro-Elec. | O Parking |
| O Schools | O Warehouse | O Pharmaceutical | O Other |
| O Recreation | O Grocery | O Food Proc. | |
| O Housing | O Postal | O R & D | |

Building gross square footage __________ sf   No of floors __________

Percentage of the project: Renovation ______ %  New construction ______ %

## SECTION II: PROJECT DELIVERY SYSTEM

Mark the appropriate oval for the project delivery system which best suits that used on your project:

| | |
|---|---|
| Construction Management @ Risk | O |
| Design-Build | O |
| Design-Bid-Build | O |

Mark the appropriate oval for the commercial terms used for the design-builder or designer and contractor: (*If Cost plus, please state fee type in blank provided*)

| | | | | | | |
|---|---|---|---|---|---|---|
| Design-Builder | O | Lump Sum | O | Cost Plus___Fee | O | GMP |
| Architect/Designer | O | Lump Sum | O | Cost Plus___Fee | O | GMP |
| Contractor | O | Lump Sum | O | Cost Plus___Fee | O | GMP |

## SECTION III: PROJECT SCHEDULE PERFORMANCE

Please provide the following **schedule** information:

| Item | As Planned (mm/dd/yy) | As Built (mm/dd/yy) |
|---|---|---|
| Date Project was Advertised | | |
| Design Start Date (Notice to Proceed) | | |
| Construction Start Date (Notice to Proceed) | | |
| Construction End Date (Substantial Completion) | | |

## SECTION IV: PROJECT COST PERFORMANCE

What were the following total **project costs**. Indicate whether estimated (E) or actual (A). Please deduct all property costs; owner costs; costs of installed process or manufacturing equipment; furnishings, fittings and equipment; or items not a cost of the base building.

| Stage / Cost | Design Costs | Construction Costs | Total Project Costs |
|---|---|---|---|
| Budget | | | |
| Contract Award | | | |
| Final Cost | | | |

Please estimate the cost of site work (work done outside the footprint of the building) as the percent (%) of final construction costs: ________________ %

## SECTION V: PROJECT QUALITY PERFORMANCE

*If you are the owner, please complete section V. If not, please provide the owner's name or point of contact* ________________________________
*and phone number* ____________________, *and proceed to survey section VI.*

Mark the appropriate ovals to evaluate the **quality** of the building:

Difficulty of facility startup:
**O** High **O** Medium **O** Low

Number and magnitude of call backs:
**O** High **O** Medium **O** Low

Operation/maintenance cost for building/site:
**O** High **O** Medium **O** Low

Did the quality of envelope/roof/structure/foundation meet your expectations?
**O** Exceeded **O** Yes **O** No

Did the quality of interior space/layout meet your expectations?
**O** Exceeded **O** Yes **O** No

Did the quality of environmental systems (light,HVAC) meet your expectations?
**O** Exceeded **O** Yes **O** No

Did the quality of process equipment/layout meet your expectations?
**O** Exceeded **O** Yes **O** No

## SECTION VI: PROJECT TEAM CHARACTERISTICS

Mark the appropriate oval for each of the following attributes of your project team:

Project team selection:

O Open Bidding     O Prequalified Bidding
O Negotiated Contract     O Contract Documents

| | | |
|---|---|---|
| Ability to restrain contractor pool: | O High | O Low |
| Was there a pool of qualified contractors? | O Yes | O No |

What percentage of design was complete when the construction entity joined the project team? ___________ %.

Individual experience of members with similar facilities:

| | | | |
|---|---|---|---|
| Owner's Representative | O Excellent | O Limited | O None |
| Design-Builder | O Excellent | O Limited | O None |
| Architect/Designer | O Excellent | O Limited | O None |
| Contractor | O Excellent | O Limited | O None |
| Subcontractors | O Excellent | O Limited | O None |

Individual experience of members using your project's delivery system:

| | | | |
|---|---|---|---|
| Owner's Representative | O Excellent | O Limited | O None |
| Design-Builder | O Excellent | O Limited | O None |
| Architect/Designer | O Excellent | O Limited | O None |
| Contractor | O Excellent | O Limited | O None |
| Subcontractors | O Excellent | O Limited | O None |

| | | | |
|---|---|---|---|
| Team's prior experience as a unit: | O Excellent | O Limited | O None |
| Project team communication: | O Excellent | O Limited | O None |
| Project team chemistry: | O Excellent | O Adequate | O Poor |
| Owner type: | O Public | O Private | |
| Owner-project team relationship: | O First Time | O Partnering | O Repeat |
| Owner representative's capability: | O Excellent | O Adequate | O Poor |
| Owner's ability to define scope: | O Excellent | O Adequate | O Poor |
| Owner's ability to make decisions: | O Excellent | O Adequate | O Poor |
| Project complexity: | O High | O Average | O Low |
| Regulatory/legal constraints: | O Many | O Few | O None |
| Onerous contract clauses: | O Numerous | O Several | O None |
| Labor type: | Union ___% | Non Union ___% | |
| Contractor's work split: | Direct Hire ___% | Subcontracted ___% | |

# SECTION VII: PROJECT DATA

For the following items please mark the appropriate oval in each category to identify the appropriate systems and/or descriptors that apply to your project:

FOUNDATION:
- O Slab on grade with spread footings
- O Mat foundation
- O Caissons, piles or slurry walls
- O Other:

STRUCTURE:
- O Pre-engineered metal building
- O Bar joists or precast planks on bearing walls
- O Steel frame and metal deck
- O Precast concrete frame and decks
- O Cast-in-place concrete structure
- O Complex geometry/mixed framing types
- O Other:

ARCHITECTURAL INTERIOR FINISHES:
- O Minimal (eg. warehouse, factory)
- O Standard commercial office
- O Corporate office
- O Clean room environment
- O Monumental building finishes (e.g. marble)
- O Other:

EXTERIOR ENCLOSURE:
- O All glass curtain wall
- O Metal panels
- O CMU, brick, or stone
- O Precast panels
- O Cast-in-place exterior walls
- O Other:

ROOFING:
- O Asphalt shingle
- O Steep roof with tile/slate
- O Built-up /single-ply membrane
- O Architectural standing seam
- O Other:

HEATING/COOLING:
- O Roof top units
- O Central plant
- O Split system
- O Heating only
- O Cooling only
- O Ventilation only
- O Other:

ELECTRICAL:
- O Uninteruptable power supply
- O Electric heat
- O General lighting and computer use
- O Intensive computer use
- O Process equipment loads
- O Security system

CONTROLS:
- O Direct digital controls
- O Pneumatic controls
- O Other:

SITE:
- O Urban
- O Suburban
- O Rural
- O Existing utilities
- O Existing roads
- O Mass excavation
- O Other:

## SECTION VIII: PROJECT SUCCESS CRITERIA

Please list the criteria your organization uses to measure success and then mark the appropriate oval to rank each as it applied to your project:

1. ______________________________
   O Excellent O Average O Poor

2. ______________________________
   O Excellent O Average O Poor

3. ______________________________
   O Excellent O Average O Poor

4. ______________________________
   O Excellent O Average O Poor

5. ______________________________
   O Excellent O Average O Poor

Mark the appropriate oval to rate the overall success of the project:
O Excellent O Average O Poor

## SECTION IX: LESSONS LEARNED

If the answers to any of the following are yes, please list examples or reasons in the space below each question.

List any lessons you learned on this project about the project delivery system:

Could this project have been better delivered or more successful? How?

Did the delivery system enhance or hinder your ability to perform? How?

Did the project meet the intended needs?

Describe any unique features about this building that influenced its cost, schedule, or quality.

# APPENDIX B

## SUMMARY STATISTICS – PHASE ONE: ORIGINAL CII STUDY DATA

The legend provided below applies to each of the tables presented in this appendix.

Legend:

| | |
|---|---|
| N | Sample size based on number of projects |
| St.Dev. | Standard deviation of the mean data variation |
| Q1 | First quartile, lower limit of the middle 50 percent of data |
| Q3 | Third quartile, upper limit of the middle 50 percent of data |
| * | Insufficient data due to sample size less than 2 projects |

| Metric | Owner Type | N | Mean | St.Dev | Median | Q1 | Q3 |
|---|---|---|---|---|---|---|---|
| Unit Cost | Private | 134 | 131.70 | 378.90 | 70.50 | 48.70 | 133.20 |
| | Public | 54 | 225.10 | 223.50 | 118.00 | 61.20 | 187.70 |
| | Federal | 85 | 133.36 | 64.32 | 128.00 | 97.50 | 163.50 |
| Cost Growth | Private | 134 | 4.60 | 13.64 | 1.92 | -0.04 | 9.09 |
| | Public | 54 | 7.93 | 11.50 | 4.30 | 0.55 | 11.26 |
| | Federal | 85 | 7.32 | 10.24 | 4.80 | 2.09 | 11.27 |
| Schedule Growth | Private | 134 | 5.52 | 17.57 | 0.00 | 0.00 | 11.63 |
| | Public | 54 | 6.28 | 15.87 | 3.51 | 0.00 | 10.20 |
| | Federal | 85 | 5.72 | 19.76 | 2.61 | -1.50 | 12.63 |
| Construction Speed | Private | 134 | 15887 | 18487 | 10081 | 2980 | 21512 |
| | Public | 54 | 13147 | 17300 | 7466 | 2937 | 16000 |
| | Federal | 85 | 9235 | 11937 | 4557 | 2002 | 11566 |
| Delivery Speed | Private | 134 | 11997 | 14847 | 7630 | 1946 | 16456 |
| | Public | 54 | 9904 | 15594 | 4120 | 1198 | 10148 |
| | Federal | 85 | 6417 | 8063 | 3617 | 1156 | 8376 |
| Turnover Quality (Maximum = 30, Minimum = 0) | Private | 121 | 22.27 | 7.39 | 20.00 | 15.00 | 30.00 |
| | Public | 49 | 20.61 | 7.68 | 25.00 | 15.00 | 27.50 |
| | Federal | 85 | 19.41 | 7.00 | 15.00 | 15.00 | 25.00 |
| Systems Quality (Maximum = 30, Minimum = 0) | Private | 122 | 17.05 | 6.95 | 15.00 | 15.00 | 20.00 |
| | Public | 50 | 14.80 | 5.15 | 15.00 | 15.00 | 15.00 |
| | Federal | 85 | 15.24 | 5.82 | 15.00 | 15.00 | 15.00 |
| Process Equipment (Maximum = 10, Minimum = 0) | Private | 91 | 5.60 | 2.22 | 5.00 | 5.00 | 5.00 |
| | Public | 28 | 5.18 | 2.14 | 5.00 | 5.00 | 5.00 |
| | Federal | 60 | 5.25 | 1.94 | 5.00 | 5.00 | 5.00 |

Table B.1: Summary statistics by project owner type.

| Metric | Facility Type | N | Mean | St.Dev | Median | Q1 | Q3 |
|---|---|---|---|---|---|---|---|
| Unit Cost | 1 | 52 | 48.71 | 29.00 | 48.50 | 30.00 | 63.50 |
| | 2 | 2 | 68.00 | 2.83 | 68.00 | * | * |
| | 3 | 29 | 106.40 | 105.30 | 73.00 | 52.50 | 125.00 |
| | 4 | 14 | 109.40 | 55.70 | 91.00 | 72.00 | 132.20 |
| | 5 | 37 | 280.20 | 374.30 | 159.00 | 98.50 | 274.00 |
| Cost Growth | 1 | 52 | 7.11 | 15.51 | 2.37 | 0.03 | 8.17 |
| | 2 | 2 | 2.52 | 3.57 | 2.52 | * | * |
| | 3 | 29 | 1.60 | 16.46 | 0.00 | -3.56 | 6.00 |
| | 4 | 14 | 2.09 | 9.52 | 0.00 | -4.58 | 8.23 |
| | 5 | 37 | 4.48 | 9.13 | 2.55 | -0.28 | 11.10 |
| Schedule Growth | 1 | 52 | 6.57 | 21.18 | 0.00 | 0.00 | 16.97 |
| | 2 | 2 | -1.10 | 6.22 | -1.10 | * | * |
| | 3 | 29 | 5.38 | 13.70 | 3.13 | 0.00 | 13.07 |
| | 4 | 14 | -0.39 | 12.81 | 0.00 | -6.69 | 6.39 |
| | 5 | 37 | 6.76 | 16.72 | 1.98 | 0.00 | 7.04 |
| Construction Speed | 1 | 52 | 26673 | 23859 | 18704 | 11158 | 32883 |
| | 2 | 2 | 10809 | 10857 | 10809 | * | * |
| | 3 | 29 | 7363 | 6880 | 5163 | 2558 | 10194 |
| | 4 | 14 | 10760 | 11283 | 7456 | 2100 | 14664 |
| | 5 | 37 | 9624 | 9512 | 6164 | 1964 | 16280 |
| Delivery Speed | 1 | 52 | 20576 | 19462 | 14622 | 8663 | 23803 |
| | 2 | 2 | 7259 | 6609 | 7259 | * | * |
| | 3 | 29 | 5260 | 5310 | 3371 | 1497 | 7626 |
| | 4 | 14 | 6943 | 7421 | 4936 | 1587 | 9646 |
| | 5 | 37 | 7389 | 7674 | 3886 | 1539 | 11872 |
| Turnover Quality (Maximum = 30, Minimum = 0) | 1 | 44 | 22.32 | 7.68 | 25.00 | 15.00 | 30.00 |
| | 2 | 2 | 22.50 | 10.61 | 22.50 | * | * |
| | 3 | 28 | 23.39 | 7.08 | 25.00 | 20.00 | 30.00 |
| | 4 | 12 | 22.50 | 7.54 | 22.50 | 15.00 | 30.00 |
| | 5 | 35 | 21.14 | 7.58 | 25.00 | 20.00 | 25.00 |
| Systems Quality (Maximum = 30, Minimum = 0) | 1 | 44 | 16.48 | 5.87 | 15.00 | 15.00 | 20.00 |
| | 2 | 2 | 10.00 | 7.07 | 10.00 | * | * |
| | 3 | 28 | 16.25 | 6.18 | 15.00 | 15.00 | 18.75 |
| | 4 | 12 | 16.25 | 8.01 | 15.00 | 10.00 | 22.50 |
| | 5 | 36 | 17.69 | 6.45 | 15.00 | 15.00 | 20.00 |
| Process Equipment (Maximum = 10, Minimum = 0) | 1 | 32 | 5.78 | 1.85 | 5.00 | 5.00 | 5.00 |
| | 2 | 1 | 5.00 | * | 5.00 | * | * |
| | 3 | 20 | 5.25 | 1.97 | 5.00 | 5.00 | 5.00 |
| | 4 | 8 | 6.25 | 2.32 | 5.00 | 5.00 | 8.75 |
| | 5 | 30 | 5.40 | 2.81 | 5.00 | 5.00 | 5.00 |

Table B.2: Summary statistics for private projects by facility type and metric.

| Metric | Facility Type | N | Mean | St.Dev | Median | Q1 | Q3 |
|---|---|---|---|---|---|---|---|
| Unit Cost | 1 | 17 | 292.00 | 560.00 | 73.00 | 25.00 | 366.00 |
| | 2 | 5 | 110.60 | 36.90 | 103.00 | 78.50 | 146.50 |
| | 3 | 14 | 120.80 | 55.90 | 111.50 | 88.80 | 144.00 |
| | 4 | 9 | 144.60 | 131.90 | 115.00 | 70.50 | 158.00 |
| | 5 | 9 | 405.00 | 470.00 | 254.00 | 114.00 | 606.00 |
| Cost Growth | 1 | 17 | 10.96 | 9.91 | 11.13 | 3.79 | 18.13 |
| | 2 | 5 | 17.40 | 23.90 | 10.60 | -0.40 | 38.70 |
| | 3 | 14 | 2.78 | 2.78 | 2.34 | 0.24 | 5.46 |
| | 4 | 9 | 4.43 | 7.86 | 2.27 | -2.03 | 9.44 |
| | 5 | 9 | 8.45 | 13.54 | 3.45 | 0.26 | 13.97 |
| Schedule Growth | 1 | 17 | 5.51 | 18.89 | 5.10 | 0.00 | 10.57 |
| | 2 | 5 | 15.85 | 11.74 | 21.17 | 3.45 | 25.60 |
| | 3 | 14 | 5.99 | 11.40 | 0.74 | 0.00 | 5.93 |
| | 4 | 9 | 5.96 | 21.85 | 0.00 | -5.76 | 9.61 |
| | 5 | 9 | 3.18 | 11.35 | 3.65 | -5.60 | 10.57 |
| Construction Speed | 1 | 17 | 20609 | 19161 | 21464 | 2657 | 33080 |
| | 2 | 5 | 8101 | 5887 | 7826 | 3157 | 13183 |
| | 3 | 14 | 8898 | 10244 | 6941 | 2481 | 9529 |
| | 4 | 9 | 14712 | 27869 | 5596 | 3189 | 9029 |
| | 5 | 9 | 6900 | 8453 | 4262 | 1398 | 8892 |
| Delivery Speed | 1 | 17 | 15884 | 15711 | 15546 | 924 | 23356 |
| | 2 | 5 | 4699 | 2606 | 4886 | 2090 | 7214 |
| | 3 | 14 | 5366 | 7321 | 3664 | 1585 | 5103 |
| | 4 | 9 | 13453 | 28335 | 4637 | 1356 | 7640 |
| | 5 | 9 | 5011 | 7345 | 2513 | 913 | 5103 |
| Turnover Quality (Maximum = 30, Minimum = 0) | 1 | 16 | 20.00 | 7.53 | 15.00 | 15.00 | 28.75 |
| | 2 | 5 | 15.00 | 10.61 | 15.00 | 5.00 | 25.00 |
| | 3 | 12 | 20.83 | 7.02 | 20.00 | 15.00 | 28.75 |
| | 4 | 8 | 24.37 | 6.23 | 25.00 | 17.50 | 30.00 |
| | 5 | 8 | 21.25 | 7.91 | 22.50 | 12.50 | 28.75 |
| Systems Quality (Maximum = 30, Minimum = 0) | 1 | 16 | 11.87 | 5.12 | 15.00 | 10.00 | 15.00 |
| | 2 | 5 | 13.00 | 5.70 | 15.00 | 7.50 | 17.50 |
| | 3 | 13 | 18.08 | 4.35 | 15.00 | 15.00 | 22.50 |
| | 4 | 7 | 15.71 | 1.89 | 15.00 | 15.00 | 15.00 |
| | 5 | 8 | 15.62 | 4.17 | 15.00 | 15.00 | 15.00 |
| Process Equipment (Maximum = 10, Minimum = 0) | 1 | 10 | 4.20 | 1.75 | 5.00 | 4.25 | 5.00 |
| | 2 | 2 | 5.00 | 0.00 | 5.00 | * | * |
| | 3 | 6 | 5.00 | 0.00 | 5.00 | 5.00 | 5.00 |
| | 4 | 3 | 5.00 | 0.00 | 5.00 | 5.00 | 5.00 |
| | 5 | 7 | 6.43 | 3.78 | 5.00 | 5.00 | 10.00 |

Table B.3: Summary statistics for public projects by facility type and metric.

| Metric | Facility Type | N | Mean | St.Dev | Median | Q1 | Q3 |
|---|---|---|---|---|---|---|---|
| Unit Cost | 1 | 20 | 118.35 | 42.71 | 115.00 | 76.75 | 152.25 |
| | 2 | 15 | 93.73 | 35.85 | 100.00 | 58.00 | 122.00 |
| | 3 | 25 | 141.96 | 47.58 | 136.00 | 121.00 | 168.50 |
| | 4 | 16 | 143.96 | 60.30 | 144.50 | 111.80 | 199.80 |
| | 5 | 9 | 191.70 | 124.50 | 162.00 | 113.50 | 200.50 |
| Cost Growth | 1 | 20 | 7.76 | 15.86 | 4.35 | 0.38 | 10.19 |
| | 2 | 15 | 5.96 | 5.09 | 4.24 | 2.21 | 11.10 |
| | 3 | 25 | 6.11 | 6.15 | 5.73 | 1.90 | 8.05 |
| | 4 | 16 | 5.52 | 7.38 | 3.89 | 0.76 | 11.61 |
| | 5 | 9 | 15.17 | 12.62 | 17.06 | 4.07 | 23.34 |
| Schedule Growth | 1 | 20 | 2.52 | 23.66 | 0.50 | -7.36 | 6.69 |
| | 2 | 15 | 6.55 | 21.41 | 0.10 | -1.92 | 10.03 |
| | 3 | 25 | 3.93 | 15.81 | 2.61 | 0.00 | 17.07 |
| | 4 | 16 | 9.38 | 17.28 | 5.83 | -2.18 | 12.36 |
| | 5 | 9 | 9.92 | 24.00 | 18.31 | 2.84 | 22.12 |
| Construction Speed | 1 | 20 | 10926 | 11009 | 7557 | 2609 | 18256 |
| | 2 | 15 | 8637 | 9050 | 5935 | 4224 | 9403 |
| | 3 | 25 | 2993 | 3625 | 1738 | 896 | 3538 |
| | 4 | 16 | 15403 | 15330 | 10239 | 4361 | 23808 |
| | 5 | 9 | 12847 | 19093 | 3197 | 1761 | 18866 |
| Delivery Speed | 1 | 20 | 7950 | 7392 | 4842 | 1634 | 13939 |
| | 2 | 15 | 6045 | 6843 | 4275 | 2675 | 5966 |
| | 3 | 25 | 1633 | 1655 | 1138 | 467 | 2314 |
| | 4 | 16 | 11260 | 9472 | 8376 | 3334 | 19401 |
| | 5 | 9 | 8314 | 12881 | 1456 | 944 | 12927 |
| Turnover Quality (Maximum = 30, Minimum = 0) | 1 | 20 | 22.50 | 6.98 | 25.00 | 16.25 | 30.00 |
| | 2 | 15 | 18.67 | 5.50 | 15.00 | 15.00 | 25.00 |
| | 3 | 25 | 17.80 | 6.93 | 15.00 | 12.50 | 22.50 |
| | 4 | 16 | 21.25 | 8.27 | 25.00 | 11.25 | 30.00 |
| | 5 | 9 | 15.00 | 3.54 | 15.00 | 12.50 | 17.50 |
| Systems Quality (Maximum = 30, Minimum = 0) | 1 | 20 | 16.00 | 5.76 | 15.00 | 15.00 | 20.00 |
| | 2 | 15 | 15.00 | 2.67 | 15.00 | 15.00 | 15.00 |
| | 3 | 25 | 13.40 | 6.24 | 15.00 | 10.00 | 15.00 |
| | 4 | 16 | 17.81 | 6.05 | 15.00 | 15.00 | 20.00 |
| | 5 | 9 | 13.89 | 7.41 | 15.00 | 7.50 | 15.00 |
| Process Equipment (Maximum = 10, Minimum = 0) | 1 | 17 | 5.00 | 1.77 | 15.00 | 5.00 | 5.00 |
| | 2 | 7 | 5.00 | 0.00 | 5.00 | 5.00 | 5.00 |
| | 3 | 14 | 4.64 | 1.34 | 5.00 | 5.00 | 5.00 |
| | 4 | 14 | 6.43 | 2.34 | 5.00 | 5.00 | 10.00 |
| | 5 | 8 | 5.00 | 2.67 | 5.00 | 5.00 | 5.00 |

Table B.4: Summary statistics for federal projects by facility type and metric.

# APPENDIX C

## SUMMARY STATISTICS – PHASE TWO: NEW FEDERAL DATA

The legend provided below applies to the tables presented in this appendix.

Legend:

| | |
|---|---|
| N | Sample size based on number of projects |
| St.Dev. | Standard deviation of the mean data variation |
| Q1 | First quartile, lower limit of the middle 50 percent of data |
| Q3 | Third quartile, upper limit of the middle 50 percent of data |
| * | Insufficient data due to sample size less than 2 projects |
| DF | Degrees of freedom of the sample |
| SS | Sum of the squared deviations from the estimated mean |
| Seq SS | Sequential sum of squared deviations based on the total sum of squares |
| R-Sq | Coefficient of determination: the proportion of variability in the dependent variable that is accounted for by the independent variables |
| Coefficient | Coefficient of each independent variable |
| p-value | Level of significance |

| Metric | Facility Type | N | Mean | St.Dev | Median | Q1 | Q3 |
|---|---|---|---|---|---|---|---|
| Unit Cost | 1 | 19 | 116.53 | 41.23 | 113.00 | 77.00 | 138.00 |
| | 2 | 20 | 118.10 | 53.10 | 115.50 | 68.30 | 152.00 |
| | 3 | 26 | 134.35 | 41.26 | 134.50 | 113.75 | 168.25 |
| | 4 | 14 | 137.00 | 64.80 | 140.50 | 96.00 | 176.80 |
| | 5 | 9 | 191.70 | 124.50 | 162.00 | 113.50 | 200.50 |
| Cost Growth | 1 | 19 | 7.23 | 16.09 | 3.78 | 0.00 | 9.65 |
| | 2 | 20 | 5.41 | 4.89 | 4.02 | 1.68 | 8.70 |
| | 3 | 26 | 7.72 | 7.01 | 6.30 | 2.18 | 11.76 |
| | 4 | 14 | 5.61 | 7.75 | 3.80 | 0.85 | 12.17 |
| | 5 | 9 | 15.17 | 12.62 | 17.06 | 4.07 | 23.34 |
| Design Cost Growth | 1 | 19 | 1.35 | 5.39 | 0.00 | 0.00 | 0.00 |
| | 2 | 20 | 9.41 | 30.42 | 0.00 | 0.00 | 2.33 |
| | 3 | 26 | 4.43 | 10.07 | 0.00 | 0.00 | 1.28 |
| | 4 | 14 | 5.06 | 9.53 | 0.00 | 0.00 | 11.13 |
| | 5 | 9 | 11.46 | 14.50 | 3.00 | 0.00 | 21.68 |
| Construction Cost Growth | 1 | 19 | 7.52 | 16.69 | 3.82 | 0.00 | 10.08 |
| | 2 | 20 | 5.37 | 5.03 | 3.72 | 1.80 | 8.73 |
| | 3 | 26 | 7.96 | 7.41 | 6.55 | 2.32 | 13.10 |
| | 4 | 14 | 5.60 | 7.96 | 3.34 | 0.87 | 12.49 |
| | 5 | 9 | 15.57 | 13.73 | 17.04 | 3.86 | 23.53 |
| Schedule Growth | 1 | 19 | 5.37 | 19.04 | 3.09 | -3.10 | 11.23 |
| | 2 | 20 | 8.81 | 18.32 | 4.55 | -0.28 | 11.23 |
| | 3 | 26 | 5.14 | 11.97 | 3.01 | 0.00 | 15.83 |
| | 4 | 14 | 7.41 | 18.30 | 3.11 | -2.03 | 11.83 |
| | 5 | 9 | 9.15 | 23.71 | 13.89 | 2.84 | 22.12 |
| Construction Speed | 1 | 19 | 11303 | 11111 | 7549 | 3687 | 18442 |
| | 2 | 20 | 6542 | 5988 | 4563 | 3496 | 8123 |
| | 3 | 26 | 3081 | 3593 | 1785 | 844 | 4199 |
| | 4 | 14 | 16964 | 15725 | 11399 | 5107 | 24975 |
| | 5 | 9 | 12847 | 19093 | 3197 | 1761 | 18866 |
| Delivery Speed | 1 | 19 | 5784 | 4552 | 4401 | 1646 | 10651 |
| | 2 | 20 | 3962 | 4550 | 2708 | 2100 | 4178 |
| | 3 | 26 | 1454 | 1465 | 1048 | 440 | 1996 |
| | 4 | 14 | 9329 | 7878 | 7791 | 3216 | 13548 |
| | 5 | 9 | 7705 | 12446 | 1456 | 944 | 10186 |
| Procurement Speed | 1 | 19 | 60874 | 56037 | 38500 | 14674 | 119508 |
| | 2 | 20 | 30901 | 22000 | 21489 | 15026 | 49752 |
| | 3 | 26 | 23390 | 40295 | 10685 | 5638 | 19817 |
| | 4 | 14 | 77922 | 87649 | 41636 | 18885 | 114908 |
| | 5 | 9 | 119282 | 176532 | 36051 | 21981 | 143320 |

Table C.1: Summary statistics for new federal project data by facility type and metric.

| Metric | Facility Type | N | Mean | St.Dev | Median | Q1 | Q3 |
|---|---|---|---|---|---|---|---|
| Start-up (Maximum = 3, Minimum = 0) | 1 | 19 | 2.53 | 0.61 | 3.00 | 2.00 | 3.00 |
| | 2 | 20 | 2.30 | 0.66 | 2.00 | 2.00 | 3.00 |
| | 3 | 26 | 2.39 | 0.64 | 2.00 | 2.00 | 3.00 |
| | 4 | 14 | 2.50 | 0.65 | 3.00 | 2.00 | 3.00 |
| | 5 | 9 | 1.56 | 0.53 | 2.00 | 1.00 | 2.00 |
| Call-backs (Maximum = 3, Minimum = 0) | 1 | 19 | 2.47 | 0.61 | 3.00 | 2.00 | 3.00 |
| | 2 | 20 | 2.35 | 0.59 | 2.00 | 2.00 | 3.00 |
| | 3 | 26 | 2.15 | 0.68 | 2.00 | 2.00 | 3.00 |
| | 4 | 13 | 2.54 | 0.07 | 3.00 | 2.00 | 3.00 |
| | 5 | 9 | 2.00 | 0.71 | 2.00 | 1.50 | 2.50 |
| Operation/ Maintenance (Maximum = 3, Minimum = 0) | 1 | 16 | 2.50 | 0.52 | 2.50 | 2.00 | 3.00 |
| | 2 | 19 | 2.32 | 0.58 | 2.00 | 2.00 | 3.00 |
| | 3 | 25 | 2.20 | 0.50 | 2.00 | 2.00 | 2.50 |
| | 4 | 14 | 2.21 | 0.80 | 2.00 | 1.75 | 3.00 |
| | 5 | 9 | 2.00 | 0.00 | 2.00 | 2.00 | 2.00 |
| Envelope/Roof/ Structure/ Foundation (Maximum = 3, Minimum = 0) | 1 | 19 | 2.11 | 0.46 | 2.00 | 2.00 | 2.00 |
| | 2 | 20 | 1.90 | 0.31 | 2.00 | 2.00 | 2.00 |
| | 3 | 25 | 1.92 | 0.49 | 2.00 | 2.00 | 2.00 |
| | 4 | 13 | 2.30 | 0.63 | 2.00 | 2.00 | 3.00 |
| | 5 | 9 | 1.78 | 0.67 | 2.00 | 1.00 | 2.00 |
| Interior Space & Layout (Maximum = 3, Minimum = 0) | 1 | 19 | 2.00 | 0.47 | 2.00 | 2.00 | 2.00 |
| | 2 | 20 | 2.10 | 0.45 | 2.00 | 2.00 | 2.00 |
| | 3 | 26 | 1.92 | 0.63 | 2.00 | 1.75 | 2.00 |
| | 4 | 14 | 2.21 | 0.58 | 2.00 | 2.00 | 3.00 |
| | 5 | 9 | 2.11 | 0.33 | 2.00 | 2.00 | 2.00 |
| Environmental Systems (Maximum = 3, Minimum = 0) | 1 | 19 | 2.00 | 0.47 | 2.00 | 2.00 | 2.00 |
| | 2 | 20 | 1.95 | 0.39 | 2.00 | 2.00 | 2.00 |
| | 3 | 26 | 1.85 | 0.54 | 2.00 | 1.75 | 2.00 |
| | 4 | 14 | 2.29 | 0.47 | 2.00 | 2.00 | 3.00 |
| | 5 | 9 | 1.78 | 0.44 | 2.00 | 1.50 | 2.00 |
| Process Equipment & Layout (Maximum = 3, Minimum = 0) | 1 | 17 | 2.00 | 0.35 | 2.00 | 2.00 | 2.00 |
| | 2 | 7 | 2.14 | 0.38 | 2.00 | 2.00 | 2.00 |
| | 3 | 11 | 1.91 | 0.30 | 2.00 | 2.00 | 2.00 |
| | 4 | 12 | 2.25 | 0.45 | 2.00 | 2.00 | 2.75 |
| | 5 | 8 | 2.00 | 0.54 | 2.00 | 2.00 | 2.00 |

Table C.1 (cont): Summary statistics for new federal project data by facility type and metric.

| Metric | Design Complete Phase | N | Mean | St.Dev | Median | Q1 | Q3 |
|---|---|---|---|---|---|---|---|
| Unit cost | 1 | 17 | 121.20 | 50.10 | 126.00 | 74.00 | 155.00 |
| | 2 | 19 | 119.80 | 53.40 | 113.00 | 77.00 | 153.00 |
| | 3 | 4 | 152.80 | 42.00 | 153.00 | 112.00 | 193.30 |
| | 4 | 48 | 141.20 | 71.30 | 134.00 | 109.50 | 166.50 |
| Cost Growth | 1 | 17 | 4.53 | 6.05 | 2.38 | 0.57 | 8.07 |
| | 2 | 19 | 6.10 | 7.90 | 4.77 | 0.42 | 11.61 |
| | 3 | 4 | 8.96 | 8.60 | 6.29 | 2.52 | 18.07 |
| | 4 | 48 | 9.01 | 12.06 | 5.19 | 2.22 | 13.03 |
| Design Cost Growth | 1 | 17 | 0.72 | 2.21 | 0.00 | 0.00 | 0.00 |
| | 2 | 19 | 9.90 | 30.80 | 0.00 | 0.00 | 0.00 |
| | 3 | 4 | 2.82 | 3.32 | 2.46 | 0.00 | 6.02 |
| | 4 | 48 | 6.07 | 11.76 | 0.00 | 0.00 | 13.68 |
| Construction Cost Growth | 1 | 17 | 4.59 | 6.19 | 2.49 | 0.59 | 8.33 |
| | 2 | 19 | 6.08 | 8.22 | 4.31 | 0.44 | 12.43 |
| | 3 | 4 | 9.11 | 8.86 | 6.32 | 2.52 | 18.49 |
| | 4 | 48 | 9.29 | 12.65 | 5.56 | 1.97 | 13.29 |
| Schedule Growth | 1 | 17 | 2.25 | 9.55 | 0.00 | -0.19 | 4.87 |
| | 2 | 19 | -0.65 | 10.00 | 0.00 | -10.65 | 5.13 |
| | 3 | 4 | 8.66 | 10.66 | 7.41 | -0.78 | 19.34 |
| | 4 | 48 | 11.19 | 20.44 | 6.88 | 0.00 | 22.45 |
| Construction Speed | 1 | 17 | 12362 | 10959 | 6200 | 3693 | 22959 |
| | 2 | 19 | 9653 | 10944 | 5915 | 2250 | 13048 |
| | 3 | 4 | 4708 | 4314 | 3542 | 1504 | 9078 |
| | 4 | 48 | 7634 | 12216 | 3451 | 1642 | 8517 |
| Delivery Speed | 1 | 17 | 6824 | 6565 | 4101 | 2113 | 10557 |
| | 2 | 19 | 4635 | 4079 | 3066 | 1332 | 7258 |
| | 3 | 4 | 3462 | 3354 | 2451 | 1073 | 6863 |
| | 4 | 48 | 4354 | 7210 | 1577 | 648 | 4950 |
| Procurement Speed | 1 | 17 | 36394 | 35113 | 23077 | 9206 | 59985 |
| | 2 | 19 | 36308 | 38426 | 22648 | 10493 | 37612 |
| | 3 | 4 | 15010 | 7062 | 16491 | 7713 | 20826 |
| | 4 | 48 | 66221 | 99666 | 25532 | 11342 | 77187 |
| Start-up (Maximum = 3, Minimum = 0) | 1 | 17 | 2.53 | 0.63 | 3.00 | 2.00 | 3.00 |
| | 2 | 19 | 2.63 | 0.49 | 3.00 | 2.00 | 3.00 |
| | 3 | 4 | 2.50 | 0.58 | 2.50 | 2.00 | 3.00 |
| | 4 | 48 | 2.17 | 0.69 | 2.00 | 2.00 | 3.00 |
| Call-backs (Maximum = 3, Minimum = 0) | 1 | 17 | 2.35 | 0.78 | 3.00 | 2.00 | 3.00 |
| | 2 | 18 | 2.33 | 0.69 | 2.00 | 2.00 | 3.00 |
| | 3 | 3 | 3.00 | 0.00 | 3.00 | 3.00 | 3.00 |
| | 4 | 47 | 2.34 | 0.60 | 2.00 | 2.00 | 3.00 |

Table C.2: Summary statistics for new federal project data by percent design complete phase at construction contract award and metric.

| Metric | Design Complete Phase | N | Mean | St.Dev | Median | Q1 | Q3 |
|---|---|---|---|---|---|---|---|
| Operation/ Maintenance (Maximum = 3, Minimum = 0) | 1 | 15 | 2.27 | 0.59 | 2.00 | 2.00 | 3.00 |
| | 2 | 16 | 2.44 | 0.51 | 2.00 | 2.00 | 3.00 |
| | 3 | 3 | 2.67 | 0.58 | 3.00 | 2.00 | 3.00 |
| | 4 | 44 | 2.36 | 0.61 | 2.00 | 2.00 | 3.00 |
| Envelope/Roof/ Structure/Foundation (Maximum = 3, Minimum = 0) | 1 | 16 | 2.19 | 0.54 | 2.00 | 2.00 | 3.00 |
| | 2 | 19 | 2.11 | 0.46 | 2.00 | 2.00 | 3.00 |
| | 3 | 4 | 2.00 | 0.82 | 2.00 | 1.25 | 3.00 |
| | 4 | 47 | 1.91 | 0.50 | 2.00 | 2.00 | 3.00 |
| Interior Space & Layout (Maximum = 3, Minimum = 0) | 1 | 17 | 2.12 | 0.49 | 2.00 | 2.00 | 2.75 |
| | 2 | 19 | 2.11 | 0.46 | 2.00 | 2.00 | 2.00 |
| | 3 | 4 | 2.25 | 0.50 | 2.00 | 2.00 | 2.75 |
| | 4 | 48 | 2.04 | 0.58 | 2.00 | 2.00 | 2.00 |
| Environmental Systems (Maximum = 3, Minimum = 0) | 1 | 17 | 2.06 | 0.56 | 2.00 | 2.00 | 2.00 |
| | 2 | 19 | 1.95 | 0.52 | 2.00 | 2.00 | 2.00 |
| | 3 | 4 | 1.75 | 0.50 | 2.00 | 1.25 | 2.00 |
| | 4 | 48 | 1.98 | 0.48 | 2.00 | 2.00 | 2.00 |
| Process Equipment & Layout (Maximum = 3, Minimum = 0) | 1 | 11 | 2.27 | 0.47 | 2.00 | 2.00 | 3.00 |
| | 2 | 15 | 2.00 | 0.00 | 2.00 | 2.00 | 2.00 |
| | 3 | 2 | 2.50 | 0.71 | 2.50 | * | * |
| | 4 | 33 | 1.97 | 0.39 | 2.00 | 2.00 | 2.00 |

Table C.2 (cont): Summary statistics for new federal project data by percent design complete at construction contract award and metric.

| Analysis of Variance of Regression Model | DF | SS | R-Sq | p-value |
|---|---|---|---|---|
| Regression | 18 | 117.342 | 82.2 | 0.000 |
| Error | 69 | 25.4666 | | |
| Total | 87 | 142.8086 | | |
| **Regression Model Components/ Variables** | **Coefficient** | **St.Dev.** | **p-value** | **Seq SS** |
| Constant | 8.44220000 | 0.65200000 | 0.000 | N/A |
| Area | 0.00000180 | 0.00000022 | 0.000 | 57.2815 |
| Area*Light industrial facilites | 0.00000503 | 0.00000117 | 0.000 | 9.7659 |
| Light Industrial facilities | 0.08770000 | 0.30930000 | 0.778 | 0.8402 |
| Multi-unit dwelling facilities | 1.16660000 | 0.25200000 | 0.000 | 5.2294 |
| Complex office facilities | 1.35270000 | 0.32830000 | 0.000 | 9.6238 |
| Other facilities | 1.09450000 | 0.29200000 | 0.000 | 2.3532 |
| Design-build delivery | -0.49770000 | 0.50520000 | 0.328 | 13.0721 |
| Design-build* light industrial facilities | 0.13750000 | 0.39680000 | 0.730 | 0.1658 |
| Design-build*multi-unit dwelling facilities | -0.24170000 | 0.37420000 | 0.521 | 0.5008 |
| Design-build*complex office facilities | -0.05780000 | 0.45030000 | 0.898 | 0.8888 |
| Design time | -0.01769300 | 0.00633300 | 0.007 | 4.1492 |
| Contract unit cost | -0.00337500 | 0.00130500 | 0.012 | 3.4171 |
| Design complete percentage | -0.01434500 | 0.00630800 | 0.026 | 2.6283 |
| Excellent team experience | 0.48390000 | 0.19950000 | 0.018 | 0.9262 |
| Limited team experience | 0.37730000 | 0.15630000 | 0.018 | 1.3669 |
| Project team chemistry | -0.41990000 | 0.15920000 | 0.010 | 2.3484 |
| Procurement time | -0.03340000 | 0.01439000 | 0.023 | 1.2943 |
| Design-builder experience with similar facilities | 0.29420000 | 0.14640000 | 0.048 | 1.4902 |

Table C.3: Summary statistics for multivariate regression model for delivery speed.