



PROJECT DELIVERY SYSTEMS:  
CM AT RISK, DESIGN-BUILD, DESIGN-BID-BUILD

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## EXECUTIVE SUMMARY

A project delivery system defines the relationships, roles and responsibilities of project team members and the sequence of activities required to provide a facility. Several systems have evolved over the years. Construction management at risk, design-build and design-bid-build are three principal project delivery systems used in the U.S. today. This research presents an empirical comparison of the cost, schedule and quality attributes of these project delivery systems, using data from 351 U.S. building projects.

The study included collecting, checking and validating industry data, significance testing of univariate comparisons and the statistical development of multivariate linear regression models. A non-response study verified statistically that sample data was appropriate for analysis and representative of the industry from which it was drawn. Significance testing and multivariate comparisons used nearly 100 explanatory and interacting variables to explain project cost, schedule and quality performance. Several variables critical to project performance were also identified. Relationships between these variables and key performance metrics were identified through analysis of multivariate linear regression models.

An understanding of these relationships can help owners better select the project delivery system most suited for their specific facility goals. Specific comparisons between delivery systems, performance metrics and six facility classes are discussed. Results and the level of confidence that surrounds each finding are presented. Furthermore, this study provides quantitative data to support the selection of a specific delivery system and greatly increases the understanding of individual system performance.

# CHAPTER ONE

## INTRODUCTION

Today's project delivery systems have evolved from the medieval master builder. During those times, rulers had many resources and their resulting designs were on a grand scale. Owners hired the master builder to design, engineer and construct an entire facility (Branca, 1987). This system dominated the construction world until early in the 20<sup>th</sup> century. As empires fell, owners were faced with limited resources. Project designs became more modest and project schedule durations decreased. These projects required a new type of master builder who could accurately forecast costs for projects. Ultimately, more master builders gained experience and entered the market, creating a highly competitive industry.

While competition grew steadily, continuous changes in technology and the increasing sophistication in buildings required specialization of design and construction services. This led to the traditional design-bid-build delivery system. In design-bid-build, services are divided by specialty area and then competitively bid by consultants and contractors. They in turn subcontracted portions of the work to other specialists. This offered clients a sequential design, bid, then build approach.

As the specialization of services increased, single source master builder approaches to delivering projects decreased. Design and construction entities were sharing information only at the end of design and during the construction process. Interaction, particularly during the design phase, was extremely low. This resulted in inefficient designs, increased errors and disputes, higher costs and ultimately longer schedules. Also, facilities were becoming more complex, demanding greater owner input and in-house

cost, schedule and quality management (Potter, 1995). In the 1970's and 1980's this conventional approach became unacceptable to many clients and the construction manager was introduced. The construction manager's role was to provide input to the designer to increase the constructability of designs and to decrease schedule durations by overlapping design and construction phases.

In construction management at risk, the contractor usually has significant input in the design process and generally guarantees the maximum construction price. The range of services offered by construction managers, coupled with a direct advocacy between the owner and construction manager, created a team approach in project delivery (Borgstrom, 1995). However, substantial efforts by owners to downsize in-house project management manpower, costly disputes between design and construction parties and various levels of owner experience has forced several owners toward single source design-build contracting (Dell'Isola, 1987).

More recently the design-build delivery system has seen increased use. In design-build, projects are integrated by a single point of responsibility for design, construction, and project management (Branca, 1987). A design-build contract is an agreement between an owner and a single entity to provide a facility under a single contract. Portions or all of the design and construction may be performed by the entity or subcontracted to other companies. Design-build is now recognized for use in over half of the 50 U.S. states and accounted for over 24 percent of the 286 billion dollars of non-residential construction put in place in 1996 (Design 96, Tarricone 96, U.S. Dept. of Commerce 97). Congress recently enacted specific authorization that enables federal contracting officers to use the design-build project delivery system in the public sector. Similarly, civil and infrastructure industries have recently developed new applications of design-build to procure large highway and bridge projects (Powers, 1997). Consequently, with continued growth and its application to a variety of markets, there is a need to clearly distinguish

the contractual and operational merits of design-build from its predecessors and other principal procurement methods.

Construction researchers have made substantial efforts to expand project delivery research in the past decade. Attempts to explore the success, failure and application of delivery systems have been documented through various case studies of high profile projects such as the Sydney Opera House and the Texas Motor Speedway (Reina, 1997, Capps, 1997). Opinion surveys of clients who frequently administer design and construction services have been successful in investigating attitudes toward specific delivery methods (Songer, 1996, Truong, 1996). Detailed analyses of builders and clients have explained variations in the way procurement systems are administered both privately and in the public sector (Fraga, 1996, Bruns, 1997, Myers, 1994). Other researchers have approached this research using empirical performance data.

Oberlender (1993) performed a quantitative study to identify factors known prior to the commencement of construction which are early warning signs of project cost and schedule growth. Pocock (1996) developed a method for measuring the impact of project integration on performance of public sector projects. The University of Reading Design and Build Forum (1996), using multivariate analysis techniques, compared the cost, schedule and quality performance of 332 design-build and design-bid-build projects recently built in the United Kingdom. These researchers have laid the groundwork for a more focused study of delivery systems in the U.S.

## **1.1 PROBLEM STATEMENT**

Despite the research efforts discussed above, there is no study that can definitively show the quantifiable cost, schedule, and quality performance differences between construction management at

risk, design-build, and design-bid-build delivery systems in the U.S. (Sanvido, 1996). Before theoretical research in this field can start, a performance-based, empirical investigation of the three principal delivery systems used in the U.S. construction industry is needed. Furthermore, without an objective study of these modes of delivery, present day owners lack the basic knowledge that is critical in deciding the method by which to deliver their facility.

## **1.2 OBJECTIVES**

The purpose of this research study was to compare the cost, schedule and quality performance of construction management at risk, design-build and design-bid-build delivery systems empirically for U.S. building projects. This research had two distinct objectives:

1. to develop, test and implement a method to collect detailed performance data from U.S. construction projects, and
2. to compare total project cost, schedule and quality performance between construction management at risk, design-build and design-bid-build delivery systems.

### **1.2.1 SCOPE**

The scope of the study was limited to measuring cost, schedule and quality performance of select categories of buildings. Cost and schedule dates for both design and construction were documented at the time of contract award and at project completion. Quality was limited to asking facility owners to measure the difficulty of the turnover process and the actual versus expected performance of each

principal facility system. Tenant and process work items were not included. General building projects studied were completed within the past five years in the U.S. Qualitative factors that described the project and team context were identified and measured. Specific definitions referenced terms and of cost, schedule and quality performance are described in the glossary of terms. Definitions of each project delivery system are discussed further in Chapter Two.

### **1.2.2 RELEVANCE**

A study that objectively measures cost, schedule and quality performance of the major delivery systems in use in the U.S. was needed for several reasons. For research to progress, performance differences between project delivery systems must first be identified, then described and their causes must be defined.

The industry can also benefit from an objective comparison in several ways. First, a private owner that has to decide whether or not to utilize a particular delivery approach, may have several concerns. One may be losing control over the delivery process. Another may be realizing cost, schedule and quality benefits. They usually base their decision on their experience or anecdotal evidence. A second case may be the general contractor who can deliver projects using any of the three systems and must convince an owner that one system better fulfills facility needs. They have the same sources upon which to base their decisions as the owner. Finally, public agencies governed by federal acquisition regulations have been frustrated by a history of poorly performing design-bid-build projects (Pocock, 1996). As these regulations change, government owners have project delivery choices and need objective evidence to support selection of specific delivery systems based on their performance.

Never before has an empirical comparison been made of principal U.S. delivery methods. The U.S. construction industry will benefit from an unbiased investigation that outlines the specific relationships of cost, schedule and quality between principal delivery systems. An understanding of performance of these systems will help an owner better select the project delivery system most suited for their specific facility goal. Furthermore, the collection of quantitative data supporting the selection of the specific delivery system can greatly increase the understanding of these systems.

### **1.3 RESEARCH APPROACH**

Since a limited amount of research has been performed on empirically evaluating project delivery methods, an investigation of the variables describing project performance was a critical first step. Concurrently, methods for economically and comprehensively collecting factual data on a large scale were analyzed. A data collection instrument had to allow the researcher to collect field data from a large cross section of the U.S. construction industry. The selected data collection method had to also allow the researcher to thoroughly cross check data for accuracy. Research was divided into four distinct phases.

The first phase developed an instrument to collect and analyze project data in an objective manner. A comprehensive data collection instrument including quantitative cost, schedule and quality performance data was created and pilot tested with a research team of industry experts. Phase two used the data collection instrument to collect extensive project data from the U.S. construction industry. Phase three used several data checking techniques to verify project data. These improved the consistency and accuracy of project data. A non-response study targeted a random sample of survey non-respondents to determine how well the sample represented the industry. Finally, the fourth phase tested several hypotheses to distinguish significant differences in delivery performance. Multivariate

linear regression identified those variables having the most impact on project delivery performance. Each of four phases of research is discussed below.

#### **1.4 RESEARCH STEPS**

##### **1. Develop and test the data collection instrument and performance metrics.**

This research benefited directly from the extensive interaction with an expert, industry research team organized by the principal research sponsor, the Construction Industry Institute (CII). Members of this research team provided continual input in all phases of the research particularly in topic definition, the brainstorming of survey questions, the development of principal definitions and metrics, and the review of results. They also identified several sources for project data.

This research required objective cost, schedule and quality comparisons. Input from the research team and methods from related literature shaped the development of seven metrics used for these comparisons. The design of performance metrics identified critical data for collection. Literature regarding project delivery systems, applied linear statistical modeling, survey research and construction contracts was examined and confirmed the existence of other explanatory data known to affect project performance. The researcher held numerous discussions with researchers conducting related studies within the U.S. and abroad. Pertinent research from agencies such as the CII, the Design-Build Institute of America (DBIA), the Associated General Contractors of America (AGC) and other research institutions was also studied.

Evaluating the performance of project delivery systems required a large amount of project specific data collected directly from the U.S. construction industry. The success of this data collection depended largely on the length and complexity of the data collection instrument [Dillman, 1978]. For this reason it was critical to pilot test the data collection instrument. The initial data collection instrument contained extensive questions and required much project data. The first five sections collected data used for calculating seven performance metrics. The latter sections were based on factors identified in the literature and by the research team, which were known to affect project performance. After review by the Penn State statistical consulting center, the data collection instrument was tested on 25 projects supplied by the research team. Based on the analysis of the respondents' interpretation of the questions and the value of the data in the responses, the instrument was modified and retested on an additional 25 projects. Testing in this fashion allowed the researcher to rewrite ambiguous questions and shorten the instrument by discarding unnecessary or unsuccessful questions.

The final version of the Project Delivery System data collection instrument is located in Appendix B. The final version examined the three principal types of project organization being studied, considered seven different contract types and provided data for seven critical performance metrics. The instrument also collected information on nineteen characteristics of the project team and its environment, nine classes of major building systems, the success criteria for the project and lessons learned from the project.

## 2. Collect data.

Data was collected by mail, fax and through phone interviews. Telephone interview techniques increased the response rates typically obtained in mail surveys and assisted respondents with questions

regarding survey content. The data collection instrument was mailed to a random industry sample targeting companies in several professional organizations. These were the Construction Industry Institute (CII), the Design-Build Institute of America (DBIA), the Associated General Contractors of America (AGC), the Partnership for Achieving Construction Excellence (PACE), the U.S. military and Penn State architectural engineering alumni. Members of these organizations were targeted because they represent a good cross section of contractors who design and build projects within the general building sector of the U.S.

Projects were drawn from the general building sector of the industry. They were later classified into six facility classes based on detailed descriptions of their building systems (See section 5.3.2). They are light industrial, multi-story dwelling, simple office, complex office, heavy industrial and high technology. Where possible, respondents were asked to select pairs of projects that were similar in scope, yet different in delivery system. For instance, one which used construction management at risk and the other which used design-build or design-bid-build.

### 3. Verify data.

Every project response was scrutinized for errors in the project data. Follow-up phone interviews were made to complete information and check project facts. In each case where the respondent was not the owner, facility owners or users were contacted directly to obtain quality data. Finally, data was sorted and independently entered three times into a Filemaker® database and Microsoft Excel® spreadsheets. Additional data checks by people trained by the researcher detected and corrected several recording errors and increased the consistency and accuracy of project data collection, organization and entry.

A non-response study was conducted to verify the appropriateness of collected data. By gaining additional project data from a sample of those who did not respond during the initial data collection effort, the researcher was able to validate the fact that collected data was representative of the industry from which it was drawn.

#### 4. Analyze Data.

Using Minitab® statistical software, each project was first classified based upon its origin, type and source. For each of these classifications, data sets including size, cost, delivery system, owner type, facility type, and respondent origin were calculated. Next, descriptive statistics such as standard deviations, medians, means and ranges were calculated for each key metric. These statistics were repeated for the original sample, the non-response sample and the combined sample. Then, hypothesis testing and multivariate regression used the entire sample for each key metric. Finally, relationships between empirical results and qualitative survey data, such as team and building characteristics, were investigated.

## 1.5 RESEARCH RESULTS

This study produced several important results. These are:

1. The development of an effective method to obtain quantitative cost, schedule and quality data from the U.S. construction industry.
2. The execution of a non-response study to verify the appropriateness of the collected sample to the industry from which it was drawn.

3. A direct comparison of construction management at risk, design-build and design-bid-build project delivery systems through the evaluation of 351 U.S. projects.
4. The identification and description of project characteristics that explain the highest proportion of variation in project performance measures.

## **1.6 READER'S GUIDE**

Chapter One provided an overview of this study. Chapter Two presents a review of related project delivery system research, project delivery systems, construction contracts, applied linear statistical modeling and survey research methods. This chapter illustrates the current state of project delivery research. It distinguishes between the anecdotal and empirical research. Chapter Two summarizes the work of others and identifies where the researcher is departing from their work.

Chapter Three identifies the variables included in this research. Performance metrics are described and defined. Chapter Three also describes the data collection instrument used to collect project specific data.

Chapter Four justifies the detailed data collection and analysis methods implemented in this research. It explains the metric and question development, data collection, data checking, and analysis. This chapter also explains how the findings of other researchers guided the methodology for this study.

Chapter Five explains initial data collection response rates and verification procedures performed before combining data samples. It also discusses data standardization procedures such as the cost indexing of projects and the classification of projects by facility type. Chapter Six describes the detailed

results of project data analysis. It illustrates the significant findings based on standard testing procedures and summarizes regression results into primary and secondary findings. Chapter Seven summarizes results, acknowledges the limitations of this research, provides an outline for future research and discusses the contributions of this study.

## CHAPTER TWO

### LITERATURE REVIEW

This chapter describes the definitions of each principal project delivery system studied in this research. Related project delivery research is discussed with specific mention of several empirical research studies recently completed in the U.S. and abroad. Chapter Two summarizes the work of other researchers and gives a background to the current state of project delivery system research in the construction industry.

#### 2.1 PROJECT DELIVERY SYSTEMS

Project delivery systems are referred to in many different ways. In this thesis, a project delivery system defines the relationships, roles, and responsibilities of parties and the sequence of activities required to provide a facility. More commonly stated, delivery methods “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” (Ireland, 1982).

While many delivery systems are available, this thesis considers the three most common project delivery methods employed in the U.S. today. These are construction management at risk, design-build, and design-bid-build. Two other commonly used systems are agency construction management and program management. As with construction management at risk, these systems offer an owner a consultant type relationship for planning and management, yet they differ slightly in that the program manager does not perform or hold construction contracts (Associated, 1991). Multiple-prime contracting

is another project delivery system where the owner holds separate prime contracts for the design and construction of each separate building system (Lynch, 1996).

### 2.1.1 DEFINITIONS

While several variations do exist for construction management at risk, design-build and design-bid-build, the following definitions represent the basic understanding of these project delivery systems used in this thesis.

Design-Bid-Build is the traditional project delivery system in the U.S. construction industry where the owner contracts separately with a designer and a constructor. The owner normally contracts with a design company to provide "complete" design documents. The owner or owner agent then usually solicits fixed price bids from construction 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. These three steps follow sequentially, characterizing design-bid-build as the separation of design and construction disciplines. Assuming there are no changes to the plans, this results in a firm cost for the project and a somewhat simpler selection process. However, the owner must perform two selections, first the architect, and second, the constructor. The constructor is selected after the completion of design, thus omitting constructability reviews [Associated, 1991]. This separation and the subsequent lack of a team approach from the beginning, typically makes the owner and contractor adversaries. They have different financial interests which can lead to disputes and costly changes.

Construction Management at Risk is a project delivery system where the owner contracts separately with a designer and a contractor. The owner contracts with a design company to provide a facility

design. The owner 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. This system represents a departure from the traditional design-bid-build method in two distinctive ways. First, the client has the opportunity to engage the construction entity much earlier in the design process. Early brainstorming sessions which involve the constructor offer the owner great advantage [Capps, 1997]. The second distinction is a result of the first. Planning, through this early integration of team players, allows for phased design, advanced ordering of long lead items and early construction start dates for critical excavation and foundation packages [Branca, 1987]. These operational distinctions are slight while comparing them to design-build delivery. However significant difference is noticed contractually.

Design-Build is a project delivery system where the 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. This is different from construction management at risk and design-bid-build, where the owner must administer at least two separate contracts. Portions or all of the design and construction may be performed by a single design-build entity or may be subcontracted to other companies. Even in cases where the design-build entity subcontracts directly or partners for design, the owner maintains the same, single contact. The difference between design-build and construction management at risk is sometimes slight (Tulacz, 1995). Private and public sectors alike have seen more requests for design-build, a consequence of a further evolution of customers who expect a broader range of service from a single entity.

### 2.1.2 COMPANY CONFIGURATIONS

Each of these delivery systems can be performed by teams that are configured in different manners. Various team configurations exhibit the wide variety of alternative project delivery systems which have been introduced. These teams are drawn from companies that have different capabilities. Several company configurations found are (Sanvido, et al., 1996, p. 5):

- construction/ project managers and designers that act as agents of the owner;
- constructors, designers or project managers that act as brokers and subcontract all activities;
- designers or construction contractors that self perform select disciplines, typically architectural, structural and finish items and subcontract the balance;
- contractors with full service in-house design, fabrication and construction installation ability;
- contractors with full service in-house design and construction ability;
- contractors with in-house design and construction management ability; and
- design/construction joint ventures and strategic alliances.

In these organizations above, the word "designer" can also mean "specialty consultants," and the word "contractor" includes "specialty subcontractors." Also note that above classifications apply to construction management at risk, design-build or design-bid-build delivery systems.

## 2.2 RELATED STUDIES

Several areas have been explored to document the use of project delivery systems. Numerous case study attempts have explored instances of success and failure, the advantages and disadvantages of

systems and unique applications of procurement systems (Reina, 1997, Capps, 1997). Opinion surveys of clients who frequently administer design and construction services have been successful in investigating the attitudes toward specific delivery methods (Molenaar, 1995, Songer, 1996, Truong, 1996). Several more 'in depth' case studies of industry builders and clients, such as the U.S. Postal Service, explain variations in the way project delivery systems are administered both privately and in the public sector (Fraga, 1996, Bruns, 1997, Myers, 1994). Several researchers have collected specific project data from the industry through survey research (Bennett, Potheary and Robinson, 1996, Pocock, 1996).

The Design-Build Institute of America (DBIA) has compiled many articles related to design-build practice and project specific case studies. These publications (Master..., 1996, Fraga, 1996) offer insights to the effectiveness of particular systems but do not offer a direct comparison of their merits. Songer (1996) has compiled a substantial reference list of design-build literature which includes several articles containing general and anecdotal information with limited empirical research findings.

The following paragraphs describe three main types of project delivery system research. These are: the general impacts of planning and management functions on project delivery, opinions on delivery system benefits and empirical studies of project delivery systems.

### **2.2.1 PLANNING / MANAGEMENT EFFECTS ON PROJECT DELIVERY**

Project planning and management strategies have been explored in many ways. In particular, their potential to positively or negatively effect the outcome of a project has received a great deal of attention. One such study (Songer, 1992) examined and developed an improved approach to owner planning of the design-build contract management process for public sector agencies. This study created a process

model specifically designed for the administration of public design-build contracts. It identified and incorporated planning, analysis and pivotal decisions made by the owner.

Another study focused on the relationships between the levels of pre-project planning and subsequent cost, schedule and contract modification outcomes (Bruns, 1997). The correlation used historic data from 37 projects completed within the University of Texas System. Using 11 previously developed pre-planning criteria, Bruns investigated the extent to which these criteria were correlated with project performance. Results indicated a positive correlation in a single case. This occurred between the managers' individualized responses to the defined pre-planning criteria and when they were asked to subjectively rate the overall pre-planning effort on a project. Cost, schedule and contract modifications indicated no direct relationships to pre-project planning. The calculations used to create the pre-planning index utilized an aggregate score for all 11 criteria. If these were taken individually they might have introduced different relationships. Other reasons for the potential lack of correlation were recognized. Time lapse between project completion and the pre-planning questionnaire might have affected a manager's perspective of the pre-planning effort actually implemented. Also, pre-planning efforts were not formally practiced on many of the projects.

Engineering-procure-construct (EPC) contracts used in the process industry are a form of single source design-build contracting. McFall investigated the impacts of information management on project success by using the engineer-procure-construct process model (1997). Using process activities within this model, a methodology was provided for predicting the impact of proposed information process changes on project cost and schedule performance. The research team, using the large level 164 activity EPC model, 'micro-modeled' only those activities known to be affected by a proposed process change. Three specific information management strategies were identified. They are data management, document management and information sharing. By speculating how the manipulation of these

strategies could alter the process outcome, the team could prepare separate models for comparison. This led to an analysis of average performance improvement calculated by comparing speculated, present and historical EPC process models. Results indicated that information management practices can significantly improve project performance. Furthermore, this research has identified a method which allows a project team to manipulate certain activities in the EPC process and consequently predict the effect those changes could have on project schedule and cost outcomes.

Although these studies did not directly measure project performance, they greatly improved the understanding of certain factors, which when acting as a group, might be associated with excellent or poor project performance. The following list summarizes the pre-planning and information management criteria identified in the above referenced works.

1. Scope definition
2. Customer participation
3. Project objectives and priorities
4. Execution approach
5. Pre-authorization design data
6. A/E selection and qualifications
7. Communications
8. Project controls
9. Alternatives analysis
10. Constructability
11. Risk assessment
12. Data management
13. Design and materials management

14. Document management

15. Information sharing.

### **2.2.2 NON-EMPIRICAL PROJECT DELIVERY RESEARCH**

Research efforts designed to collect perspectives, opinions or feelings about selected project delivery systems are presented. While these studies are limited in terms of empirical data, they offer reasons why clients select certain project delivery systems.

Truong quantified an owner's confidence level that the choice to use one delivery method over another would produce improved project results. This study compared design-bid-build and design-build. This research analyzed types of owner organizations and types of projects for which it was believed design-build was best suited. It then evaluated project characteristics by which design-build was consistently the method of choice (1996).

Truong collected rankings of project objective criteria from 51 respondents. These included items such as the potential to reduce project time and cost, the potential to involve the constructor early in the design process, the flexibility to accommodate design changes, various levels of owner experience, reduced litigation and other criteria surrounding design and planning decisions. A weighted decision factor was calculated by combining rankings with information collected during a literature survey on the effective use of design-build. Based on this factor and the number of projects in each category, an assertion was made as to the desirability of using design-build. Possible outcomes included: desirable, potential or no valid conclusions. A variety of conclusions were reached amongst the different owner organizations and project types. This research also identified objectives that a variety of owners were consistently basing project delivery selection decisions.

A more extensive survey by Molenaar (1995), tested the existence of primary factors for selecting design-build. This study was restricted to public sector owner organizations such as local, state and federal agencies. Using a combination of expert owner interviews and subjective data from 88 respondents, this study ranked 15 project characteristics known to affect project success. Of these 15, five project characteristics were concluded to be the most critical to project success. These were (p.89):

1. Well defined scope
2. Shared understanding of scope
3. Owner sophistication
4. Adequate owner staffing
5. Established budget.

It is interesting to recognize that when asked, owners ranked characteristics which are directly controlled by the owners themselves as critical. Also, while characteristics were organized as those affecting success, there was no attempt made to empirically measure their correlation with project performance.

As an extension of Molenaar's work, Songer (1996) polled private and public sector owners to gain a fundamental understanding of attitudes toward the top selection factors identified for choosing design-build. Two goals were to understand why owners were selecting design-build and to directly compare results from private and public sector owners. Of 290 mailed surveys, 182 owners responded. One hundred eight (60%) of these responses were usable. The following factors were cited when owners chose design-build:

1. Shorten duration
2. Establish cost
3. Reduce cost
4. Offer constructability / innovation
5. Establish schedule
6. Reduce claims
7. Accommodate large project size / complexity.

This research concluded that owners felt very strongly that design-build should be selected to shorten overall project duration. Factors one, two and seven were identical for public and private sector owners. Pooled variance hypothesis testing indicated that six of the seven factors for public and private sector owner's mean rankings were not significantly different. Therefore, despite the differences between public and private delivery strategies and constraints, their attitudes for selecting design-build should be viewed as consistent.

### **2.2.3 EMPIRICAL PROJECT DELIVERY RESEARCH**

Empirical research requires extensive, unbiased performance data from an adequate sample of industry projects. The following research was empirical in nature.

Oberlender and Zeitoun (1993) performed a quantitative study to identify factors known prior to the commencement of construction, which are early warning signs of project cost and schedule growth. A total of 106 U.S. projects collected from 23 CII member companies listed several early warning signs for construction projects and distinguished between fixed price and cost reimbursable contract strategies. This separation was included because fixed priced jobs generally expect fewer changes due to a more

defined scope, whereas cost reimbursable jobs are typically awarded prior to the completion of design. Other factors included the selection of bidders via either open bid invitations or the pre-qualification of a group of contractors and price competition measured by ‘money left on the table’ (MLOT). They also measured the effect of different project delivery types on cost and schedule growth but was unable to correlate these figures with project delivery type due to a small sample. This study represents conclusions about the effect of various factors on project performance. It also documents the negative effect of the ‘ripple effect,’ a consequence of several successive changes due to a previous change, on project performance. Finally, this research incorporated a data collection method that categorized cost and schedule growth into distinct quartiles of the construction phase. This technique illustrated at which phase certain projects departed from planned budgets and schedules.

Pocock and Liu (1996), used objective performance measures to document differences in four delivery systems used on 209 military projects. Table 2.1 lists the mean values for design-build, design-bid-build, partnering and combinations of these. The authors defined partnering as a “Non-contractual arrangement that changes relationships among owners, contractors, designers, and others on construction projects. It aims to create a team effort, to promote mutually beneficial goals (p. 58).” The combination category was made up of projects utilizing aspects of both partnering and design-build.

Table 2.1: Summary results of delivery system performance (From Pocock and Liu, 1996).

| Delivery     | # of Projects | % Cost Growth | % Schedule Growth |
|--------------|---------------|---------------|-------------------|
| Design-build | 90            | 8.48          | 27.76             |
| Traditional  | 40            | 6.37          | 26.23             |
| Partnering   | 63            | 8.62          | 17.06             |
| Combination  | 16            | 10.44         | 18.76             |

The authors also tracked the number of modifications to the contract and the number of those due directly to design deficiencies. Summary results indicate that no clear distinction can be made between these modifications for all delivery methods. Rather, they show that specific project constraints and characteristics should be considered in combination with the indicators analyzed within this study.

In a more detailed study of the same data, Pocock (1996) developed a method for measuring the impact of project integration on project performance. General comparisons were made using univariate statistical testing such as averages, t-tests, and correlations. Results indicate that each of the alternative methods of delivery possess higher average degrees of team interaction than do traditional projects.

By using specific project data from 16 building projects, Sanvido (1990) identified four critical project success factors. These factors include, “selecting team members with experience; allowing teams to work together using contracts that allocate risk and reward in the correct proportion; developing a team chemistry via common goals and activities; and involving qualified users, contractors and operators early in the design phase to provide optimization information to the team (p. 6-6).” These factors consistently appeared in project delivery literature.

## **2.3 READING DESIGN AND BUILD FORUM**

The University of Reading Design and Build Forum's recent study (referred to as ‘The Forum’ in this publication) is the most comprehensive comparison of project delivery systems and the only study based on objective data collected from a large section of the industry (Bennett, Potheary and Robinson, 1996). The Forum analyzed cost, schedule and quality data taken from design-build and design-bid-build projects recently built in the United Kingdom. The study recognized three distinct variations of design-

build and compared them to design-bid-build jobs and projects procured using a management contracting approach.

### **2.3.1 DELIVERY SYSTEMS**

The UK recognized several distinct types of delivery systems. Two were design-bid-build and design and manage. Another three were variations of design-build.

*Design-bid-build* in the UK represents the common, sequential approach to project delivery where design is completed before engaging the construction contractor. This system and *design and manage*, where the manager holds no construction contracts, are also used in the U.S.. The Forum excluded design and manage from the study since the contractor does not assume any risk for the ultimate performance of the facility.

*Traditional design-build* was used for approximately 20 percent of new design-build projects. Here, an owner would approach a contractor for early design assistance then negotiate with that contractor for design and construction responsibility. The design-build firm would then acquire outside design assistance or utilize in-house capabilities.

*Consultant novation* arrangements were used for approximately 50 percent of all new design-build work in the UK. Here, an owner sought independent design advice during the briefing stage from one or more design consultants. Design consultants advanced design to a stage when a contractor was engaged into the process. From this point forward the consultants employment was ‘novated’ or assigned to the contractor, thus shifting design and construction risk to the selected contractor for the remainder of the project.

*Develop and construct* accounted for twenty percent of the design-build market. This organizational arrangement differs from traditional design-build only in the extent to which the owner develops design before engaging the construction contractor. Projects varied from owners who had only outline specifications to those having detailed requirements. The owner would then utilize an in-house design staff or appoint a design consultant to further develop these varying levels of design.

Newer approaches to delivering design-build in the UK were using a fee-based management approach. This approach involved a management firm early in the delivery process, but then agreed to a guaranteed maximum price at an appropriate stage.

### **2.3.2 SUMMARY OF MAIN FINDINGS**

Because of the similarity between the efforts completed by The Forum and this study, a meeting was held between The Forum team and this researcher to exchange ideas, discuss procedural techniques and review analysis methods.

The Forum mailed a comprehensive survey to a select sample of owner agents to collect performance data in terms of cost, schedule and quality. Areas of qualitative data describing the project client, management approach, building functions, construction type, size and project location were also collected. The Forum conducted 150 interviews with clients and project team members on a select group of 35 projects. These interviews were conducted to evaluate the accuracy of collected data and to identify differences in project performance. The Forum analyzed 332 projects. One hundred sixty six used design-build approaches, 156 used traditional design-bid-build and 10 used a management approach.

Due to the limited number of projects procured using the management approach, the Forum did not attempt to offer conclusions regarding this arrangement. Therefore, comparisons were limited to project data taken from design-build and design-bid-build jobs. Data showed that design-build projects resulted in:

- a 12% improvement in construction speed
- a 30% improvement in project delivery speed
- a 13% reduction in unit cost
- more certainty in finishing on time
- a greater chance of finishing within 5% of budget
- a higher possibility of achieving specified quality.

In addition to basic univariate comparisons, the Forum conducted multivariate regression analyses to identify variables affecting the performance of certain metrics. To investigate the differences of speed and cost between design-build and design-bid-build, three regression models were developed.

*Construction speed* was defined as gross building area divided by the construction time period. *Total speed of delivery*, was defined as gross building area divided by design and construction time periods.

*Unit cost*, was defined as project cost per square meter. Each model was based on a reduced sample of project data and explained uneven levels of variation around set response variables. The study did not attempt to develop models for other critical metrics such as cost growth, schedule growth or quality.

Therefore, results describing these metrics were based only on univariate comparisons. Table 2.2, orders 11 variables that exerted the greatest influence on construction speed, total speed and unit cost. The table also indicates the number of projects used to build each model and the amount of variation explained by the model.

Table 2.2: Ordered influence of variables on metrics (From Bennett, et al., 1996)

|                        | <b>Construction Speed</b> | <b>Delivery Speed</b> | <b>Unit Cost</b> |
|------------------------|---------------------------|-----------------------|------------------|
| No. of Projects        | 223                       | 176                   | 240              |
| Explained Variation    | 90%                       | 80%                   | 51%              |
| Project size           | 1                         | 1                     | 5                |
| Building type          | 2                         | 4                     | 1                |
| Unit cost              | 3                         | 2                     | NA               |
| Complexity             | 4                         | 6                     | 2                |
| Procurement            | 5                         | 3                     | 4                |
| Technology             | 6                         | 11                    | 7                |
| Innovation             | 7                         | 5                     | 8                |
| Building structure     | 8                         | 10                    | 9                |
| Existence of basements | 9                         | 9                     | 10               |
| Quality                | 10                        | 8                     | 6                |
| Aesthetics             | 11                        | 7                     | 11               |
| Location               | NA                        | NA                    | 3                |

Regression results indicated that project size, unit cost and facility type are critical to explain speed and cost performance of projects. Delivery system (procurement approach), ranked third in one case, was less important in determining project performance. These findings are important to this study in two primary ways. First, The Forum attempted to measure differences between delivery systems while considering a wide range of variables by using multivariate regression modeling. Second, while explaining only modest levels of variation from a prediction standpoint, these results identified variables other than the chosen delivery method, which are critical to project success.

### **2.3.3 LIMITATIONS**

The procedures, methods and subsequent findings of The Forum's study were limited in several ways. First, there was no indication of the overall respondent population size in the UK building market, therefore it was unknown how representative the collected 332 projects were of the population from which they were drawn. Second, principal metrics of cost and schedule were not analyzed using a multivariate approach. Therefore the effective consideration of a number of identified variables in explaining the differences between design-build and design-bid-build performance was limited. In terms of quality, this study was successful in collecting both intended and achieved quality ratings on 16 different characteristics. Scores were combined and averaged for comparison. This aggregate procedure may have incorrectly assumed the importance of each question or characteristic as equal.

## **2.4 SUMMARY OF RELATED LITERATURE**

These research findings and the lessons learned from the researchers through discussions with them have provided valuable background for the data collection instrument and methodology utilized in this research. These initial efforts have established a clear need to expand the direct comparison of systems through a detailed investigation of a large number of projects. It is also evident that several factors have the potential to explain project performance, thus supporting the need for a multivariate analysis. Likewise it is important to recognize that factors are frequently project specific. Variables such as these may act alone in describing performance or may interact with other explanatory variables or the response variables that they attempt to explain.

Studies performed in the area of project delivery have depended largely on survey research and active industry participation. The current state of project delivery research, although not always

empirical, identifies numerous variables that have the potential to impact project performance. A collection of these variables were used to develop a data collection instrument. The instrument and each performance metric are presented in Chapter Three.

## CHAPTER THREE

### PROJECT DELIVERY MEASUREMENT

This study developed and utilized a data collection instrument to obtain project specific data, which when checked and compiled, could be used to test several project delivery hypotheses. The data collection instrument had to be able to collect factual project data that would allow the researcher to compare seven specific performance metrics for each of the candidate project delivery systems. It also had to provide sufficient project data to accurately identify each project. Finally, the instrument had to collect qualitative data on a collection of variables known to impact project delivery performance. These variables were identified in the literature in Chapter Two and by the research team. This chapter first defines seven project performance metrics used for project delivery system comparisons.

#### 3.1 PERFORMANCE METRICS

Seven project performance metrics were used to describe the performance of the facility delivery process. These were the dependent or response variables. These variables were measured after project completion. The following paragraphs define each performance metric.

##### 3.1.1 COST MEASURES

*Cost* was defined as the investment a facility owner makes in developing a facility and was measured in U.S. dollars. Costs were limited to the design and construction of the facility and did not include land

acquisition, extensive site work, process or owner costs. Cost measures included unit cost, project cost growth and intensity (a hybrid of unit cost and schedule measures).

*Unit cost*, the first metric, was measured to indicate the relative cost of a facility for its given area. It was represented by the formula:

$$\text{Unit Cost (\$/SF)} = [\text{Final Project Cost} / \text{Area}] / \text{Index} \quad (1)$$

Where:

*Final Project Cost* was the final design cost plus the final cost of construction. A cost *index* was essential to make accurate comparisons of projects built in different cities in different years. Cost data, with the exception of cost growth (%), were adjusted for time and location using Means 1996 historical cost indexes.

The second metric, *Cost Growth*, provided an indication of the growth of project costs over the life of the job. It was defined by the formula:

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

Where:

*Contract Project Cost* was the design contract cost plus the construction contract cost.

The final cost metric, *Intensity*, indicated the unit cost of design and construction work put in place in a facility per unit time. It was introduced as a hybrid cost/schedule measure and was defined by the formula:

$$\text{Intensity } ((\$/\text{SF})/\text{Month}) = [(\text{Unit Cost}) / \text{Total Time}] \quad (3)$$

Where:

*Total Time* was the period from the as built design start date to the as built construction end date.

### 3.1.2 SCHEDULE MEASURES

Three *schedule* metrics defined the time taken by the facility team and the owner to deliver the facility. Schedule measures included construction speed, delivery speed and schedule growth.

*Construction speed* was the rate at which the construction team built the facility. It was defined by the formula:

$$\text{Construction Speed (SF/Month)} = [\text{Area} / ((\text{As Built Construction End Date} - \text{As Built Construction Start Date}) / 30)] \quad (4)$$

*Delivery speed* was the rate at which the project team designed and built the facility. It was defined by the formula:

$$\text{Delivery Speed (SF/Month)} = [\text{Area} / (\text{Total Time} / 30)] \quad (5)$$

*Schedule growth* was the percentage by which the schedule grew over the life of the project. It was defined by the formula:

$$\text{Schedule Growth (\%)} = \frac{(\text{Total Time} - \text{Total As Planned Time})}{\text{Total As Planned Time}} * 100 \quad (6)$$

Where:

The *Total As Planned Time* was the period from the as planned design start date to the as planned construction end date.

### 3.1.3 QUALITY MEASURES

Quality was defined as the degree to which the facility met the expected facility requirements. Quality was measured in seven areas. Each was a measure of the actual performance versus the facility user's or owner's expectations of the referenced building. Individual quality scores, based on a maximum of 10, were used for primary univariate comparisons.

The first three quality indices measured the difficulty of the turnover of the facility. It was important to differentiate between poor turnover and poor facility performance. The turnover quality measures included the difficulty of facility startup; the number and magnitude of call backs; and the operation and the maintenance cost for the building/site.

*Turnover quality* was defined by the formula:

$$\text{Turnover Quality} = Q_{\text{start up}} + Q_{\text{call backs}} + Q_{\text{operation and maintenance}} \quad (7a)$$

Where:

*Qstart up* was the difficulty of the facility startup process, *Qcall backs* was the number and magnitude of call backs during the turnover process and *Qoperation and maintenance* was the achievement of expected operation and maintenance costs for the facility/ site. Each of these was scored on a scale of 10. Aggregate scores were used as summary metrics for univariate comparisons. This score combined individual ratings received for facility startup, the number and magnitude of call backs and the operation and maintenance cost scores for the building. A maximum score of 30 was possible for turnover quality.

The next three indices measured specific *system quality*. System quality measures were the performance of the envelope, roof, structure and foundation; the interior space and layout; and environmental systems. System quality measured whether or not these specific systems met, exceeded or did not meet the expectations of the owner and was defined by the formula:

$$\text{System Quality} = Q_{\text{ersf}} + Q_{\text{is\&lo}} + Q_{\text{environment}} \quad (7b)$$

Where:

*Qersf* was the quality of the envelope, roof, structure and foundation systems, *Qis&lo* was the quality of the interior space and layout and *Qenvironment* was the quality of environmental systems such as the lighting, heating, ventilating or air conditioning. Each of these was scored on a scale of 10. A maximum score of 30 was possible for system quality.

The last category was process equipment and its layout. Equipment quality was defined by the formula:

$$\text{Equipment Quality} = Q_{\text{process equipment \& layout}} \quad (7c)$$

Where:

*Qprocess equipment & layout* was the quality of process equipment if it was included in the facility. Process equipment and layout was based on a maximum score of 10.

This concludes the description of the performance metrics. The variables included in each section of the project delivery system data collection instrument are explained next.

### **3.2 PROJECT DELIVERY SYSTEM DATA COLLECTION INSTRUMENT**

An instrument was developed to collect the data needed to calculate metrics defined to measure the performance of the facility delivery process (Appendix A). Information was organized into nine sections. The data collection instrument did not prearrange or organize the variables for two reasons. First, the researcher did not want to bias the data collection process by revealing the critical relationships between variables. Second, the organization of the data collection instrument allowed the respondent to

initially complete critical cost, schedule and quality questions and later describe less objective project characteristics. Survey sections one and two provide data to identify the facility and delivery system. Sections three through five contain quantitative and qualitative data describing the key metrics most critical to this study. Sections six through nine allowed the respondent to explain the reasons for measured differences. These sections requested information on variables found in the literature, input from the expert research team, and on the relationships discussed in the previous section.

### **3.2.1 SECTION I: PROJECT CHARACTERISTICS**

Of greatest importance to tracking the project were the project name, its location, the respondent who provided the data and the type of organization they were representing. Respondents had to classify their facility into one of 14 facility categories representing six classes of buildings. Facility classes were light industrial, multi-story dwelling, simple office, complex office, heavy industrial and high technology. Physical characteristics such as the area, number of floors and the percentage of new construction included in the project were also requested.

### **3.2.2 SECTION II: PROJECT DELIVERY SYSTEM**

The respondent was provided definitions for design-bid-build, design-build and construction management at risk and was asked to select the system used on their project. The respondent was also asked to identify the commercial terms used for either the design-builder or for the designer and contractor. Contract types were lump sum, guaranteed maximum price (GMP), cost plus fixed fee, cost plus percentage fee, cost plus GMP and cost plus incentive fee.

### **3.2.3 SECTION III: PROJECT SCHEDULE PERFORMANCE**

Schedule information was collected by asking respondents to list as planned and as built dates for four separate project events. These included the date the project was advertised, the design start or notice to proceed date, the construction start or notice to proceed date and the construction end date, defined by substantial completion. Dates were given in mm/dd/yy format, from which the researcher calculated the duration of each project phase.

### **3.2.4 SECTION IV: PROJECT COST PERFORMANCE**

Budgeted cost, contract award and final cost figures were requested. Contract award amount and final costs were most critical to this study. Contract costs represent the amount agreed upon at the time the contract was signed. Final cost included changes or modifications to the contract. Costs were identified for design, construction and total project costs. In cases where estimated figures were given, owners were contacted to verify the accuracy of estimates. Respondents were asked to deduct items not a cost to the base building, such as, property costs, owner costs, costs of installed process or manufacturing equipment, furnishings and fittings. Respondents were also asked to estimate the cost of site work completed outside the footprint of the building as a percentage of final construction costs.

### **3.2.5 SECTION V: PROJECT QUALITY PERFORMANCE**

Section five was reserved for client input. In each case where the owner was not the initial survey respondent, section five requested a client contact and phone number. Respondents were then

instructed to proceed directly to survey section six. The majority of quality data was obtained through phone interviews conducted by the research team. Seven quality questions were asked of each owner. To help reduce potential client bias formed during project turnover, quality data was measured separately for the turnover process and for system performance.

Three questions asked the client to rate the difficulty of the turnover process for startup, the number and magnitude of callbacks and the operation and maintenance cost for the facility. Responses were recorded as low, medium or high. Low represented the best possible rating. Four other questions asked the client to rate whether or not the quality of specific facility systems met, did not meet or exceeded expectations. Literature and expert review identified four systems which represent critical performance and high cost areas of a facility. These included the building envelope, roof, structure and foundations; interior space and layout; environmental systems such as lighting and air conditioning; and where applicable, the quality of process equipment and its layout.

### **3.2.6 SECTION VI: PROJECT TEAM CHARACTERISTICS**

Section six collected data about qualifying and selecting the team, team experience, team dynamics, owner capabilities, and general project constraints. Nineteen characteristics, based on current project delivery literature and input from the CII research team, were measured.

First, respondents were asked to record the manner in which the team was selected. Choices included procurement through open bidding procedures, prequalified bidding, negotiated contracting or contract documents. The ability to restrain the contractor selection pool and the existence of a qualified group of contractors was noted. Respondents were also asked to state the percentage of design complete when the construction entity joined the project team.