Examining the Role of Integration in the Success of Building Construction Projects

A research report in support of the "Owner's Guide to Maximizing Success in Integrated Projects," available for download from bim.psu.edu/delivery

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GLOSSARY OF TERMS

Group cohesiveness: The degree to which project team members function as a single unit. In organizational research, the development of cohesion is believed to mark the transition from a coordinated work group to a collaborative team. Represented in this study as a latent variable, group cohesiveness is measured by goal commitment, team chemistry and timeliness of communication.

Project delivery strategy: A categorization system that represents common combinations for the owner's project delivery decisions, as seen in practice. In this study, each delivery strategy corresponds to a set of indicators derived from key differentiators of delivery methods, procurement processes and contractual terms. These indicators include the use of a single contract for design and construction, timing of involvement of builder and trades, use of a prequalification step in procurement, a cost-of-work based selection and the award of an open book contract to the builder.

Project organization: The temporary contractual arrangement of design and construction disciplines, structured by the owner, with the mission of delivering an operational building. In the project organization, participants remain a member of their parent organization, but have the added responsibility of becoming a contributing member of the project team. In this study, the project delivery strategy is considered as a driver of the structure and boundaries of the project organization.

Project team: The primary participants in a building construction project and the group tasked with the management and execution of project organization's mission. The consistent project team captured in this study is represented by the owner, architect, primary contractor or construction manager, mechanical and electrical trade contractors and structural trade contractors.

Team integration: The degree to which project team members from separate parent organizations engage in collaborative practices. A highly integrated team will leverage the expertise of individual members to improve the project delivery process. Represented in this study as a latent variable, team integration is measured by participation in joint goal-setting, design charrettes, greater use of Building Information Modeling (BIM) and co-location during construction.

EXECUTIVE SUMMARY

The architecture, engineering and construction (AEC) industry is often criticized for its fragmented approach to project delivery. Traditional procurement and contracting structures serve to isolate designers from contractors, limiting opportunities for collaboration. Viewed as the logical solution to fragmentation, team integration is the process of bring design and construction disciplines back together. Team integration has recently attracted the attention of building owners, made weary by the adversarial relationships common in traditional delivery. However, there is limited empirical evidence linking more integrated teams with improved project performance.

This research presents a structural modeling approach to studying the role of team integration in construction project performance. The focus of this research is the project organization, a temporary team of design and construction disciplines that forms for the duration of the project. Project organizations often consist of team members who have never worked together before and will disperse at the completion of the contracted scope. Recognizing the importance of team development in organizations, this research also considers the role of group cohesiveness in delivering a successful project. A sample data set of 204 building projects was used to compare cost, schedule and quality performance under different project organizations. To characterize the types of project organizations seen in industry, a latent class analysis was performed to group projects by their delivery strategy. Path analysis revealed complex relationships between the delivery strategy, team integration, group cohesiveness and project performance.

Integrated teams involved all tiers of the project organization, from designers to specialty contractor trades, in high-quality interactions. These interactions were collaborative in nature and included design charrettes, goal setting and multidisciplinary BIM uses. The owner’s project delivery strategy had a significant impact on team integration. Strategies that involved construction managers and specialty contractor trades before schematic design achieved higher levels of integration and were more equipped to control project schedule growth. Cohesive teams reported higher chemistry, goal commitment and timeliness of communication. Project delivery strategies that required cost transparency with open book contracts generally resulted in a more cohesive teams and a lower average project cost growth. Additionally, the owner’s perception of turnover experience and building system quality was consistently rated higher for cohesive teams.

Understanding these relationships will make building owners more aware of how early project delivery decisions influence the development of their project teams. Based on their specific goals, owners may select a project delivery strategy that creates the appropriate team environment for the project. The findings of this research are poised to expand methods for studying and implementing project organizations.

Chapter 1

INTRODUCTION

Due to a lack of experience and objective performance data, owners often make project delivery decisions on the basis of personal preference or comfort level. Organizational acquisition policies also constrain owners' decisions and are difficult to change without evidence-based comparisons of alternative project delivery approaches. There is a growing need among owners in the architecture, engineering and construction (AEC) industry for objective data on the performance impacts of their early project delivery decisions.

In 1997, the Construction Industry Institute (CII), led by the research of Victor Sanvido and Mark Konchar of Pennsylvania State University (Penn State) and CII Research Team 133, conducted seminal research in project delivery performance. The project entitled "Project Delivery Systems: CM at Risk, Design-Build, Design-Bid-Build," examined project performance based on data from more than 350 projects and provided owners with guidance on delivering successful projects (CII 1997). The resulting research report provided data to support the owner's project delivery decision-making and contributed fundamental knowledge on the integration of design and construction disciplines. This information was pivotal in helping the industry shift away from the traditional design-bid-build method of project delivery to more integrated arrangements, including design-build and construction management at risk (Konchar and Sanvido 1998, Molenaar, et al. 1999, El Wardani et al. 2006).

Since the publication of the original Penn State/CII study in 1997, the industry has evolved substantially, particularly in the area of team integration. The crisp lines that previously defined the three delivery methods of design-bid-build, design-build, and construction manager at risk have become blurred. Integrated project delivery arrangements have arisen with the drafting of multi-party contracts (AIA C191-2009; ConsensusDOCS 300), but few projects with true multi-party contracts have been completed due to owner's operational, legal and cultural constraints. Owners are attempting to implement pieces of the integrated project delivery process in hopes of improving project success (El Asmar and Hanna 2013). Owner's now need empirical evidence to assist them in selecting an overall project delivery strategy that addresses team organization, procurement processes, and contract payment methods. This strategy results in a project environment that is more conducive to developing team integration and group cohesion in support of improving project outcomes.

Team integration is seen as the logical solution to fragmentation in the construction industry. Baiden and Price (2011) define team integration as "where different disciplines or organizations with different needs and cultures merge into a single cohesive and mutually supporting unit." Integration has been suggested to improve project performance (Egan 2002; Payne et al. 2003), but the empirical evidence linking the two concepts is limited. Quantifiable examples of successfully integrated teams are scarce, although at least one exception demonstrates the benefits of integration using case studies from practice (Constructing Excellence 2004).

Group cohesion has historically been considered the most important variable in studying small groups (Carron and Brawley 2000). More cohesive groups perform better in organizations where efficiency is an important goal, as opposed to simply the successful completion of the task (Beal et al. 2003). The concept of group cohesion has applications to project teams in the construction industry, who are tasked with delivering a facility within the owner's time and budget constraints, while maintaining the desire level of quality and functionality of the facility.

1.1 Research Objectives

The research seeks to determine, analytically and without bias, the role of project delivery methods and the project team in project success. The research explores successful owner practices regarding roles, team integration, team behavior, delivery methods, procurement methods, and project performance in the building design and construction industry. The research ultimately uses the constructs of team integration and group cohesiveness to better understand how the elements of a project delivery strategy relate to cost, schedule and quality performance. Specifically, the research project addressed the following essential and supporting research questions:

1. How can the owner contribute to the successful delivery of their project?
    a. What, from an owner's point of view, is the project delivery success?
    b. What approaches must an owner undertake to promote a successful project environment?
2. How do the project delivery method, procurement process and contractual payment terms impact project success?
3. How does project team integration impact project delivery success?
    a. What attributes can be used to identify the level of team integration, and how are those tied to the industry definitions of project delivery systems?
4. How does team behavior (i.e., group cohesion) impact project success?
    a. What attributes can be used to identify the cohesiveness of the team, and how are those tied to the industry definitions of project delivery systems?

1.2 Research Scope

This study collected project information for a subset of projects in the general building industry. These projects were predominantly new construction and located only within the United States. They were completed between 2008 and 2013. This sample specifically excludes renovations, civil or highway work, single-family residential, international projects and older or incomplete projects. Performance measurements were limited to cost, schedule and quality metrics. Construction and total project costs were documented at the time of contract award and at final completion. Schedule dates were requested for design start, construction start and substantial completion. Quality was assessed on a semantic differential scale (i.e. Likert scale) that asked *owners* to rate their turnover experience and overall system quality in the facility. Lastly, various measures of group cohesiveness and indicators of integrated processes were captured to assist with defining team behaviors and relationships.

1.3 Research Approach

This research was divided into six phases. First, an industry Advisory Board was formed to assist in scoping the research and creating the data collection questionnaire. Next, a survey questionnaire was developed to collect detailed information on recently completed buildings from project participants. This survey was created with a combination of literature review and feedback from the Advisory Board. The survey captured quantitative cost, schedule and quality data, as well as qualitative perceptions of the team behaviors and group cohesiveness. Phase three broadly distributed the survey across the United States using mailing lists for various AEC professional organizations. Phase four focused on the verifying the quality of the submitted data and the research team spent extensive time following-up with survey respondents on key project information. The fifth phase applied multivariate analysis techniques to simultaneously model project delivery strategy, team integration and group cohesiveness with project performance outcomes. The final phase leveraged the results to develop an owner's guide for project delivery that provides a structured approach to apply the findings in the AEC industry. This final phase also employed the Advisory Board for validation of the results and appropriate interpretation for the guide development. Each of these phases is discussed in greater detail in the sections that follow.

1.3.1 Formation of the Industry Advisory Board

The research team worked with two industry champions, Mr. Greg Gidez, Corporate Director for Preconstruction and Design Management Services for Hensel Phelps Construction Co., and Dr. Mark Konchar, Vice President Business Acquisition for Balfour Beatty Construction, to form an industry Advisory Board with leaders from the design and construction industry. These leaders were chosen through their active participation with the Charles Pankow Foundation, the Construction Industry Institute and through the recommendations of other panel participants. The Advisory Board assisted the team with the development of the final data collection questionnaire, helped with testing, contributed project data to the study, and reviewed the final results. The following members actively participated in the project:

- Mr. Greg Gidez (co-chair), Hensel Phelps Construction Co.
- Dr. Mark Konchar (co-chair), Balfour Beatty Construction
- Mr. Howard W. Ashcraft, Esq., Hanson Bridgett LLP
- Dr. Russell Manning, Department of Defense
- Mr. Spencer Brott, Trammell Crow Real Estate Services, Inc.
- Dr. John Miller, Barchan Foundation, Inc.
- Mr. Bill Dean, M.C. Dean, Inc.
- Mr. Brendan Robinson, U.S. Architect of the Capitol
- Mr. Tom Dyze, Walbridge
- Dr. Victor Sanvido, Southland Industries
- Mr. Matthew Ellis, US Army Corps of Engineers
- Mr. Ronald Smith, Kaiser Permanente
- Ms. Diana Hoag, Xcelsi Group, LLC
- Mr. David P. Thorman, FAIA, Former California State Architect
- Mr. Mike Kenig, Holder Construction

The Advisory Board met in person four times over the course of the research project and periodically through telephone or internet conferences. To ensure that all industry members had a common vocabulary and understanding in regards to research in project delivery, the research team developed a white paper for distribution before the first Advisory Board meeting. The white paper, entitled "Owner's Guide to Maximizing Success in Integrated Projects: A Summary of Study Performance Metrics," is included in Appendix E of this report.

1.3.2 Develop the Survey Questionnaire

The survey questionnaire underwent both internal and external pilot testing prior to distribution. The internal pilot included four projects for which the project owner was contacted via phone and completed a survey-style interview on a paper-based version of the survey. The external pilot was a test of both the survey distribution methodology and an electronic, web-based version of the survey. A letter of introduction to the study and a link to the survey were distributed via email to a small sampling of industry contacts. The external pilot produced twelve responses for ten unique projects. The result of the pilot process was eliminating several redundant and onerous questions to shorten the length of the survey. A final version of the survey questionnaire is provided in Appendix A. The survey was separated into eleven sections to collect information on the delivery of the project, organizational integration, team behaviors and performance outcomes. Additional information on the survey and specific sections can be found in Chapter 3.

1.3.3 Collect Completed Project Data

Data were collected by email and postal mail distribution of the survey questionnaire. Portable Document Format (PDF) form versions of the questionnaire were emailed to the national mailing lists for multiple design and construction professional organizations. These included the American Public Works Association (APWA), Association of Higher Education Facilities Officers (APPA), the Construction Management Association of American (CMAA), the Construction Owners Association of America (COAA), the Design-Build Institute of America (DBIA), the Federal Facilities Council (FFC), the Higher Education Facilities Management Association (HEFMA) and the Partnership for Achieving Construction Excellence (PACE) at Penn State. These organizations were selected because they have diverse memberships across the building industry. Paper versions of the survey were mailed to alumni from Penn State's Architectural Engineering program and PDF versions were sent to the alumni from the University of Colorado's Department of Civil, Environmental and Architectural Engineering and the Real Estate Development program. These alumni groups were selected to increase the rate of response on the survey due to the individual's previous affiliation with the industry. To avoid bias, all respondents were asked to complete the survey for their most recently completed building project. No specific type of facility was targeted in this research. Projects in the data set represented the general building sector, which includes both simple and complex facilities.

1.3.4 Verify Survey Response Data

A member of the research team at Penn State or the University of Colorado Boulder verified each survey response. The verification procedure included an email and/or phone call to the respondent to confirm key project information and obtain any missing data. If a contractor or designer returned the survey, efforts were made to contact the project owner directly. Completed responses were entered into a Microsoft Access® database using form inputs to reduce the likelihood of data entry errors. After completing the data collection phase, verified data was exported to a Microsoft Excel spreadsheet for screening. Unverified projects and those outside the scope of the research were removed from the data set, leaving a total of 204 projects for analysis. Descriptive statistics of the data were reviewed for out-of-range values and outliers.

1.3.5 Perform Multivariate Data Analysis

Using MPlus statistical software, a latent class analysis was performed to classify each project by their most likely project delivery strategy. These classifications were based on response patterns to survey questions on the delivery method, procurement processes and contractual terms. Next, a confirmatory factor analysis was run to validate the constructs of team integration and group cohesiveness. Lastly, relationships between the class of project delivery strategy, team integration, group cohesiveness and project performance were investigated using structural equation modeling.

1.3.6 Develop Owners Guide to Apply Findings

To apply the findings, the research team developed a structured owner’s guide for making early project delivery decisions. The research team investigated multiple guides that had been published in the literature and/or applied in practice before ultimately choosing a five-step process for selecting the appropriate project delivery strategy. This structured approach requires the owners to: (1) define project goals and constraints; (2) consider team organization options; (3) consider contract payment methods; (4) consider team procurement processes; and (5) select a project delivery strategy. All five of these steps seek to increase the aspects of team integration and group cohesion that were found to influence success. Ultimately, each project is unique and there is no one project delivery strategy that is appropriate for every project. However, this owner's guide will help to promote team integration and group cohesion, two constructs that were found to influence success, in all project delivery strategies.

1.4 Research Results

The primary results of this research include:

1. A classification of project delivery strategies, using differentiators of team organization, procurement processes and contractual terms;
2. The use of latent constructs to represent team integration and group cohesiveness in construction projects;
3. The use of structural equation modeling to begin exploring the mechanisms by which project teams yield more desirable project outcomes; and
4. An owner's project delivery selection guide with a structured process by which owners can apply the results of this research to increase the likelihood of achieving team integration, group cohesiveness, and ultimately overall project success.

1.5 Benefits to the Industry

The primary benefit to the construction industry is to provide a repeatable process for making highly effective, early project delivery decisions. It will allow owners to select delivery methods, project teams and contracting methods that offer the greatest likelihood of success. A second benefit to public sector owners will be to help them demonstrate a transparent decision-making process regarding delivery method, as well as assurance of cost and schedule savings, attainment of best value for the dollar, and quality outcomes. Underlying both of these benefits is an enhanced understanding of how team integration and group cohesion affect project success in the AEC industry. The basic knowledge is being disseminated through academic research journals and the applied knowledge is being disseminated at industry conferences and through the application of the user's guide.

1.6 Reader's Guide

Chapter 1 provided an introduction to the research including: a review of relevant literature to contextualize the problem statement and an overview of the research approach. Chapter 2 presents a literature review that identifies the gap in knowledge that serves as the motivation of this research. Chapter 3 describes the theoretical framework for this research, defines the variables used in the analysis and provides an overview of the survey questionnaire. The data collection and analysis methods are discussed in Chapter 4. Chapter 5 presents the latent class analysis and descriptions of the resulting classes of project delivery strategy used in this research. Chapter 6 explains the sample data set and describes the detailed results of the structural equation modeling effort. Lastly, Chapter 7 summarizes the findings of this research, presents the background for the development of the owner's project delivery selection guide, acknowledges limitations in the methodology, discusses contributions and provides an outline for future research.

Chapter 2

LITERATURE REVIEW

This chapter reviews current literature on empirical studies that relate project delivery and project performance, with specific emphasis on the owner's role in the delivery process. The gap in literature related to the role of team integration in construction project performance is identified. Background on the AEC industry leading up the present state of fragmented teams is reviewed and discussed with attention also given to organizational studies on team integration. Additional literature on project delivery methods, procurement processes and contractual terms are reviewed in Chapter 3 alongside the development of a theoretical model for this research.

2.1 Project Delivery Methods

Key owner decisions made during the early stages of a project, such as selecting a delivery method, team members or a contractual payment method, have a role in determining project success (Konchar and Sanvido 1998). There is a growing interest among owners to understand the relationships between key decisions and their impact on typical definitions of project success, such as cost growth, schedule growth and quality. In response, a number of studies have compared the performance of common forms of project delivery (e.g. Konchar and Sanvido 1998; Ibbs et al. 2003; Hale et al. 2009; El Asmar et al. 2013). The objective of these studies was to help owners to understand the implications of their decisions with more objectivity by providing empirical data.

Historically, project delivery methods have been found to influence project outcomes in large-scale statistical studies. Several of these studies were conducted to compare the performance of construction projects under design-bid-build, design-build, and construction management at risk delivery methods (Pocock et al. 1996; CII 1998; Konchar and Sanvido 1998; Molenaar et al. 1999; and Gransberg et al. 1999). A summary of significant empirical studies related to delivery systems are presented at Table 2-1. No study concluded a significant relationship between specific delivery method and better quality performance.

Table 2-1: Summary of studies examining delivery method and performance

Study	**Type of Project**	**Sample Size**	**Significant Findings**
Konchar and Sanvido (1998)	General	351	Unit cost: DB < CMR < DBB Cost growth: DB < DBB < CMR Schedule growth: DB < CMR < DBB Delivery speed: DBB < CMR < DB Construction speed: DBB < CMR < DB
Ibbs et al. (2003)	--	67	Schedule Growth: DB < DBB
Hale et al. (2009)	Military	77	Cost Growth: DB < DBB
El Asmar et al. (2013)	Institutional	35	The following metrics were significantly different for IPD and non-IPD projects (*p*-value=.01): • Change order processing time • Deficiency issues • Request for information • Punch list costs

Notes: DBB=Design-bid-build; CMR=Construction manager at risk; DB=Design-build

The Construction Industry Institute (CII) and Penn State University completed a seminal study for improving project delivery method selection and as a result provided practical decision guidelines, backed by empirical evidence (CII 1998, Konchar and Sanvido 1998). The study included performance metrics for cost, schedule, and quality for projects delivered under the three most common project delivery methods for buildings in the United States. Comparing 351 building projects, the study concluded that design-bid-build projects had statistically significant higher unit cost, and slower construction and delivery speeds. Additionally, the design-build projects had the lowest schedule and cost growth. While the unit cost, construction speed, and delivery speed had higher levels of certainty, the variation in cost and schedule growth were not able to be explained fully. The most prominent contribution of the study was to provide guidance for owners on how to leverage delivery decisions to support a successful project.

In another study, Ibbs et al. (2003) analyzed characteristics of 67 global projects, finding that design-build does not outperform design-bid-build across all project performance criteria. The results indicated that design-build had a definite advantage on time savings, but correlations with cost and productivity were unsupported. The study stated that the project management expertise and experience of the contactor may have a greater impact on project performance outcomes than delivery method alone. Hale et al. (2009) compared the performance of 39 design-bid-build projects and 38 design-build projects and found that design-build projects takes less time to complete and have less time and cost growth. The strength of their study was in sampling only similar military buildings of the same typology, which results in a more meaningful comparison (Hale et al. 2009). Hale’s study concluded that owners selecting a design-build method can expect less cost and schedule growth in comparison to other delivery arrangements.

In addition to design-bid-build, design-build and construction manager at risk, researchers have examined emerging delivery systems, such as integrated project delivery (IPD). Owners who use integrated project delivery aim to enhance project outcomes through increasing collaboration among different party members (AIA California Council 2007). The main principals of integrated project delivery can be summarized as multiparty agreement, early involvement of all parties, and shared risk and rewards (Kent and Becerik-Gerber 2010). In a recent empirical study, El Asmar et al. (2013) collected performance data of 35 completed projects and found that IPD and projects delivered employing some elements of IPD without the multiparty contract, provided higher quality facilities, faster and at no significant extra cost. While several studies have suggested IPD’s superior performance to traditional delivery methods, the adoption of integrated project delivery in the US is still very low and the evidence has been based primarily upon case studies. The work of El Asmar et al. (2013) is suggestive of the value of a more empirical study, but with a small pool of projects that limited the ability to delve into the aspects of the integrated approach that were influential in the improved project outcomes.

While many studies compared project performance of delivery methods for building construction, there were also several studies conducted for highway projects. To expand delivery method research into the civil domain, Shrestha et al. (2012) investigated the relationship between cost and schedule metrics and the project characteristics of 130 large (>$50 million) highway projects in Texas. This study concluded that the construction speed and project delivery speed per lane mile of design-build projects were significantly faster than of design-bid-build projects. In another study, Minchin et al. (2013) compared the performance of design-build and design-bid-build highway and bridge projects at the state of Florida. In contrast with most of the previous studies, they found that design-bid-build projects performed significantly better than design-build projects in cost performance.

Most of the previous studies compared project performance of design-build and design-bid-build project delivery methods for building or industrial projects; however, there were limited studies to compare performance of these project delivery methods for highway projects. To expand delivery method research into the civil domain, Shrestha et al. (2012) investigated the relationship between project performance metrics (i.e., cost, schedule, and change orders) and project characteristics of 130 large highway projects (>$50 million) in Texas. The study concluded that the construction speed and project delivery speed per lane mile of design-build projects were significantly faster than of design-bid-build projects. In another study, Minchin et al. (2013) compared cost and time performance of design-build and design-bid-build highway and bridge projects at the state of Florida. In contrast with most of the previous studies, they found that design-bid-build projects performed significantly better than design-build projects in terms of cost performance.

While the contributions of these previous studies to the understanding of delivery methods and project performance were valuable, there are several limitations. First, the previously well-defined boundaries between delivery methods are becoming blurred, as owners pursue hybrid or custom delivery arrangements. Therefore, there is a need to explore the performance of delivery approaches based on more fundamental attributes, such as time of involvement of different parties. Secondly, as more integrated delivery methods are introduced, there is a need to collect empirical data and compare performance of these new delivery systems with traditional methods. Lastly, the performance criteria used in previous studies were limited to cost, schedule, or quality. However, new performance criteria have been introduced in the context of delivery decisions over the past decade, such as sustainability, safety, and owners' satisfaction (Wuellner 1990; Pocock et al. 1996; and Atkinson 1999). Including these success criteria in large project delivery database can provide a better assessment of project success.

2.2 Procuring a Team for Success

Another important decision that an owner must make for a project is the approach used to solicit and select the design and construction team. Factors within the owner's organization often guide the procurment decision. This is particularly true in the public sector where agencies typically have stringent procurement rules, but it also applies to private companies who may have policies and norms that inhibit them from trying alternative procurement approaches.

In one study that evaluated the impact of procurement on project performance, Molenaar et al. (1999) compared public design-build projects under three different procurement methods: one-step, two-step, and qualifications-based. The two-step method was found to have the least cost growth (3%) and schedule growth (2%). The one-step projects were delivered, on average, 4% over budget and 3.5% behind the schedule. Qualifications-based procurement had the highest cost growth (5.6%) and schedule growth (3.5%). In another study, data from 76 design-build projects was collected to develop a series of guidelines to help owners in selecting the design-build team aligned with their project goals (El Wardani et al. 2006). The performance metrics were based on the traditional outcomes of time, cost, and quality and the team selection methods were sole source, qualification-based, best value, and low bid selection. While the findings of the study illustrated that there were no specific team procurment methods that outperform all others across every performance metric, the qualification-based selection method showed the lowest cost growth.

Alongside typical metrics such as cost, schedule, quality and owner satisfaction, some researchers studied the impact of project procurement methods on an owner's administrative burden (Molenaar and Songer 1998; Gransberg et al. 1999). According to these studies, a qualifications-based approach is usually pursued on projects with a low level of design completion. Using best value selection in delivery methods such as design-build has been shown to simplify control on the project scope, cost, and time schedule for the contractor and reduces the administrative burden on the owner's side (Gransberg et al. 1999).

2.3 Payment Terms

Contract payment provisions can impact the relationship between an owner and a contractor. Three common types of payment terms are seen in practice: lump-sum, cost-plus fee, and cost-plus a fee with a guaranteed maximum price (GMP). Characteristics of each of these contract structures, including the time at which the price of the project is fixed, will influence the responsibilities and roles of the contract parties (Beard et al. 2001). Bogus et al. (2010) addressed this variation by collecting project data for 99 water and wastewater infrastructure projects completed after 2003. They study compared the performance of projects procured under cost-plus fee with and without a guaranteed maximum price and those with traditional lump sum payment provisions. The results showed that the mean cost growth of projects procured under cost-plus fee with GMP contract was significantly less than projects procured under lump sum contracts. The direct relationship between payment terms and project performance has not been studied extensively in the building construction industry.

2.4 Organizational Collaboration

Collaborative working practices are frequently discussed in literature and considered to have a positive impact on the delivery of construction projects. Aggregating from multiple sources, Greenwood and Wu (2012) define collaboration between parties as "working together for mutual advantage, through which they can achieve greater benefits than by working separately." Although broad, this description of collaboration is closely related to discussions on cooperation in partnerships (Bresnen and Marshall 2002) and project team integration (Baiden et al. 2006). In organizational literature, these related levels of 'working together' are often viewed as a scale or continuum as shown in Figure 2-1. Peterson (1991) suggested three stages of inter-agency interaction in care providers, beginning with cooperation, moving to coordination and ending with collaboration. Konrad (1996) expanded by proposing five levels for human services firms, including information sharing, a combination of cooperation and coordination, collaboration, consolidation and integration. Lastly, Bailey and Konley (2000) posit a similar five levels of cooperation, coordination, coalition, collaboration and integration.

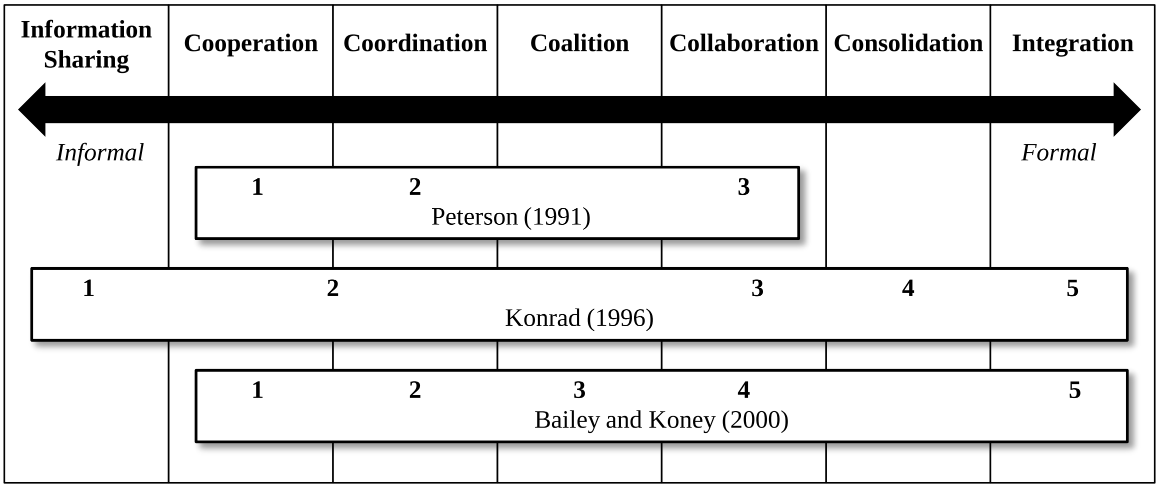


Figure 2-1: Collaboration continuum interpretations in literature

Empirical research in the AEC industry along these continuums is limited, although two recent studies look specifically at the role of cooperation and collaboration in project performance. Studying the Hong Kong construction industry, Phua and Rowlinson (2004) found that cooperation and contractual characteristics were predictors of project success, and with varying levels of importance between contractor and consultant organizations. An important contribution of this study was starting to identify indicators of cooperation on projects to allow for more detailed analyses. Greenwood and Wu (2012) attempted a similar line of inquiry, but considered the group cohesiveness by collecting data on both positive and negative attributes of collaborative working. Their analysis demonstrated a clear association between collaboration and the control of cost and schedule, and the quality of work and user satisfaction on building projects. However, these studies either ignore the concept of team integration or use delivery methods to approximate some level of organizational integration.

2.5 Stages of Group Development

In organizational literature, a clear distinction is made between groups and teams. Katzenbach and Smith (1993) describe a group as a collection of individuals working in the same area or placed together to complete a task. All teams are groups, but not all groups become teams. The transition to a team occurs when the group is committed to a common purpose, sets performance goals and holds themselves mutually accountable for success. Teams are not always more desirable than groups, but are more suited to higher level tasks, such as problem-solving (Majchrzak and Wang 1996).

Studies on the stages of group development provide insight into the conditions needed for an effective team (Tuckman 1965). The first stage, orientation to the task, occurs when group members learn about each other and the task for which the group was formed. Intragroup conflict is the second phase and is characterized by uneven interactions and resistance to the task, as group members struggle to balance their needs as individuals against the needs of the group. The third stage, development of group cohesion, occurs when group members accept the idiosyncrasies of other members and establish themselves as their own unique entity. Functional role-relatedness is the final stage where groups become a fully realized problem-solving instrument for their given task. The progression of groups through each of these stages is linear, but not all groups reach the final stage, and regression to earlier stages is also possible.

Development of group cohesion is the stage where newly formed groups begin transitioning to an efficient team. Group cohesion has historically been considered the most important variable in studying small groups (Carron and Brawley 2000). As a construct, group cohesiveness is evident in measures of interpersonal attraction (Festinger et al. 1950), group pride (Bollen and Hoyle 1990) and task commitment (Zaccaro and McCoy 1988). Interpersonal attraction is a shared liking and attachment to individuals within the group or to the group itself. Group pride is an understanding of the importance of being a member of the group and lastly, task commitment is the extent to which members share a common dedication to the given task. A recent meta-analysis found cohesive groups to perform better in organizations where efficiency was an important goal, as opposed to simply the successful completion of the task (Beal et al. 2003). These findings have applications to project teams in the construction industry, who are tasked with delivering a facility within budget constraints, while maintaining design quality.

2.6 Strategies to Reduce Fragmentation

Team integration is seen as the logical solution to fragmentation in the construction industry. If the need for specialization drove team members apart, then new forms of organizing and managing teams are needed to pull them together. Baiden and Price (2011) define team integration as “where different disciplines or organizations with different needs and cultures merge into a single cohesive and mutually supporting unit.” Integration has been suggested to improve project performance (Egan 2002; Payne et al. 2003), but the empirical evidence linking the two concepts is limited. Quantifiable examples of successfully integrated teams are scarce, although at least one exception demonstrates the benefits of integration using case studies from practice (Constructing Excellence 2004).

In response to fragmentation in the industry, partnering strategies that emerged during the 1990s attempted to develop and sustain relationships in the project team. Defined by the Construction Industry Institute (CII) as “a long-term agreement between companies to cooperate to an unusually high degree to achieve separate yet complementary objectives" (CII 1991), partnering is frequently studied from the owner-contractor perspective, but also has applications in relationships further down the supply chain. Regardless of where partnering occurs, common activities in the process include team-building sessions, drafting of a team charter and formalized dispute resolution procedures (Cowan et al. 1992). The relationships between partnering strategies, both formal and informal, and measures of project success are primarily documented in case studies, although a large-sample empirical analysis was conducted by Larson (1995). Weston and Gibson (1993) compared 44 projects from the U.S. Army Corp of Engineers and found a lower average cost growth on partnered cases, attributed to fewer change orders and claims. In an analysis of 280 building construction projects, Larson (1995) found significant differences in performance, depending on how the owner-contractor relationship was managed. While non-partnered projects performed slightly worse, there was no significant difference in schedule performance between formal and informal partner relationships. The benefits of formal partnerships were seen in better cost control and higher customer satisfaction rating.

Despite this evidence supporting partnering as a means of encouraging team integration, there is little agreement on its implementation. Thus both formal and informal partnering arrangements struggle in their ability to affect real changes in behavior when applied on a project, and are challenged in translating partnering from an 'espoused theory' to a 'theory in use' (Argyris and Schon 1978). Rather than an overly prescriptive best practice, Bresnen and Marshall (2000) suggest the benefits of a partnering philosophy are achieved through customizing the process to the group cohesiveness by recognizing the diversity of interests and motivations brought into the project by each organization. Therefore, the core of partnering in practice is recognition of the interconnectivity of construction projects and finding ways to collaborate despite organizational barriers.

2.7 The Project Organization and Integration

Delayed communication, difficulty in coordination and goal misalignment are common challenges across the industry, driving project teams to seek more integrated forms of interaction. While team integration is rarely directly studied, prior research suggests that the project organization has a role in project performance. Specifically, delivery methods that enable early builder involvement and provide integrated design and construction services are positively correlated with project cost, schedule and sustainability outcomes (Konchar and Sanvido 1998; Ibbs et al 2003; Bogus et al. 2010; Korkmaz et al. 2010). Team interaction on projects has also received attention, as evidenced by the application of project network theory to construction (Chinowsky et al. 2010). These studies consider team integration indirectly in the form of linkages and communication across organizational boundaries. From an industry perspective, many owners are beginning to focus on the structure of the project team. They are experimenting more with relational contracting strategies, such as integrated project delivery (IPD) and partnering, and attempting to use technology, such as building information modeling (BIM), to bring teams together.

2.8 Chapter Summary

Existing empirical studies have explored the relationship between project delivery methods, procurement processes, contract payment terms and project performance. However, these studies have not examined these attributes in a systematic fashion to consider the interrelationships amongst the variables. Underlying these variables is evidence that team integration and group cohesion may address some of the fragmentation that stems from the manner in which owners design, procure and construct projects. There is a notable gap in the understanding of factors that influence team development on construction projects and the magnitude of its effect on project performance.

Chapter 3

THEORETICAL FRAMEWORK

This chapter describes a theoretical framework, which posits the role of design and construction team integration and group cohesiveness as contributors to project performance. Five components of the model are identified and the variables used to measure each component are discussed. These include the project delivery strategy, team integration, group cohesiveness, project outcomes and programming factors.

3.1 A Framework for Studying Team Integration

Construction projects involve multiple organizations and disciplines, but team integration and group cohesiveness are rarely considered when assessing project performance. Figure 3-1 illustrates the theoretical framework for this research. This model was developed to identify known and suspected variables, and the structure of their relationships, that drive project performance. The components of the framework represent areas of research that were previously discussed separately in Chapter 2, but are now combined into a single theoretical model.

The project delivery strategy (Box A) is the owner’s plan for structuring design and construction services, which manifests as some combination of delivery method, procurement process and payment terms. The resulting project organization has an impact on team integration (Box B) and group cohesiveness (Box C). Team integration in this context is the extent to which design and construction team members were brought together in a systematic manner (Puddicombe 1997). Integration is reflected in the team’s participation in high-quality interactions, including BIM, design charrettes, joint goal-setting, physical co-location and offsite prefabrication. Group cohesiveness is the extent to which design and construction team members develop work in unity (Tuckman

1965). A cohesive team is evident in the timeliness of communication, commitment to project goals, chemistry, frequency of compromise, and formality of communication. The combination of team integration and group cohesiveness contribute to project outcomes (Box D). Measures of cost, schedule and quality are commonly used to gauge the success of construction projects. Lastly, programming factors (Box E) are present in each stage of the project execution. Owner type, facility size and facility type are decided early in project programming, but have lasting effects on the design and construction process. The following sections describe each component of the framework in greater detail and identify the specific variables or measures used in this research.

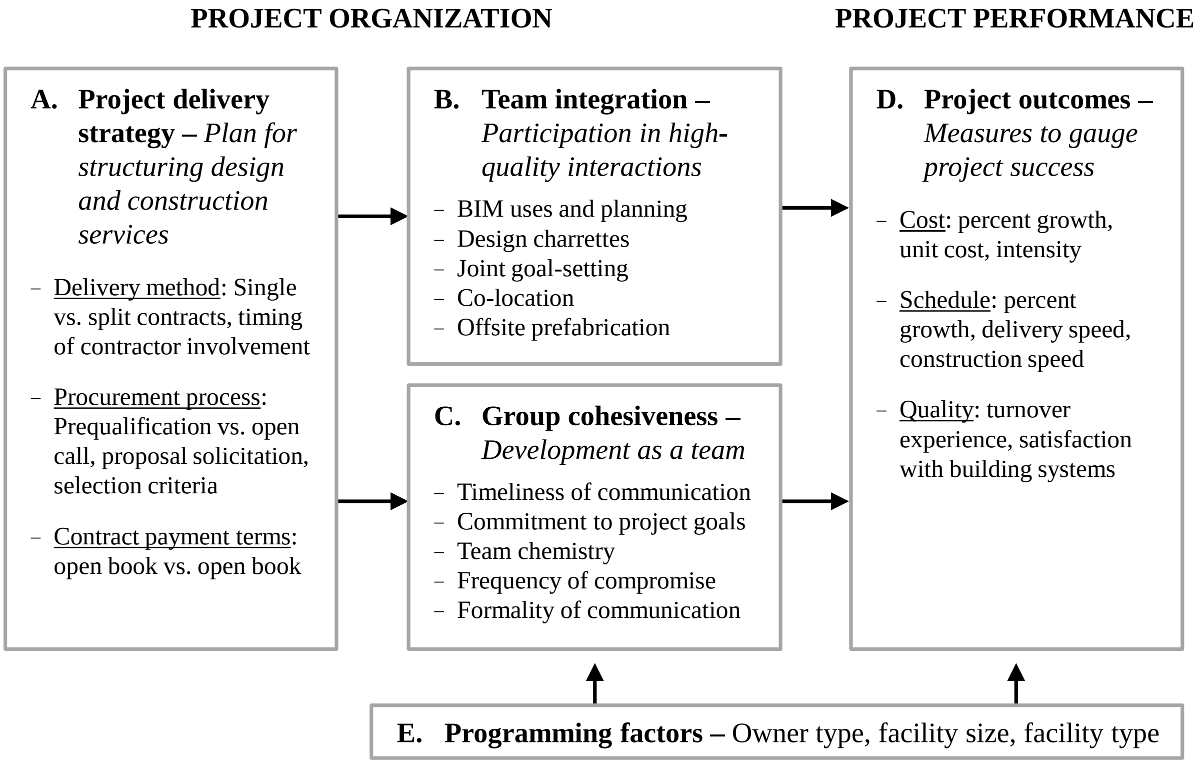


Figure 3-1: Theoretical model of research variables

3.2 Project Delivery Strategy

Although the terminology varies in literature, the main indicators of an owner's project delivery strategy include the (1) delivery method, (2) procurement process and (3) contract payment terms. Several studies have demonstrated a correlation between these indicators and measures of project performance, including cost growth, schedule growth and schedule intensity (Konchar and Sanvido 1998; Molenaar and Songer 1999; Ibbs et al. 2003; Bogus et al. 2010). While these findings have been widely circulated in industry, the relationships between project delivery strategies, team integration and group cohesiveness are less well defined. Therefore, this section documents the differences in common forms of delivery methods, procurement processes and contractual terms to examine each component's role in the overall project delivery strategy.

3.2.1 Delivery Method

The delivery method arranges the relationships among project team members, establishing a hierarchy that allocates responsibility and decision-making power. Design-bid-build (DBB), construction manager at risk (CMR) and design-build (DB) are the most common delivery methods in the U.S. for building construction projects. While there is little industry-wide consensus on the definitions of each delivery method, the following descriptions, adapted from the American Institute of Architects (AIA) and Associated General Contractors of America (AGC), are provided as a baseline for this research (AIA and AGC 2011):

> *Design-bid-build* is characterized by a distinct separation and linear progression of the design, procurement and construction phases of a project. The owner contracts a designer, typically led by an architect, to design the building, creating a completed set of drawings, specifications and supporting information suitable for obtaining competitive bids from contractors. Upon selection of a contractor, the owner awards a contract for the construction of the building. Construction work planning is based on the set of completed design documents and details of the finished building agreed upon by all parties before breaking ground.

> Frequently referred to as the ‘traditional’ approach, the separation of responsibilities of the architect and contractors in this delivery method are well-established and documented in common law.
>
> *Construction manager at risk* involves a construction manager during the design phase to provide pre-construction services, which may include cost estimation, consultation on design decisions and purchasing of long-lead items. There is no contractual relationship between the construction manager and architect. The designer, again typically architect led, is hired by the owner under a separate contract and may be involved with the selection of a construction management firm. The construction manager typically transitions to overseeing the construction process and is then responsible for negotiating and holding the trade subcontracts, becoming ‘at risk’ for construction of the project. The design and construction phases are typically overlapping and design ‘packages’ for contained areas of work, such as foundations or structural steel, may be issued by the designer prior to a completed building design, so construction work planning often proceeds when the full design is not yet completed.
>
> *Design-build* approaches create a single source of responsibility for the design and construction of a project. The owner contracts with a single entity, which may be represented by a design-build firm with in-house design and construction teams, a joint-venture designer and contractor (JV-DB), a designer with a subcontracted contractor (designer-led DB) or a contractor with a subcontracted design team (contractor-led DB). As a single point of responsibility, the design-build entity typically engages in overall project planning and scheduling to manage the overlap between design and construction phases.

Based on these descriptions, the key differentiators in delivery method can be summarized in the (1) number of contracts held by the owner for design and construction services, (2) level of design completed prior to hiring the primary contractor, construction manager and specialty trades, and (3) allocation of responsibility (‘who does what’) and by extension, risk among the architect, owner and primary contractor or construction manager. Responsibility, individual risk and the level of involvement in decision-making have been correlated with team performance in social science research (Steward and Barrick 2000; Kerr and Tindale 2004), suggesting that the delivery method of AEC project teams has a role in inter-organizational relationships.

3.2.2 Procurement Process

The procurement process describes how proposals are solicited from the designer and contractor, and the criteria for awarding the contract. Common distinctions for a procurement process include (1) low bid, (2) best value and (3) sole source. Similar to the difficulty experienced in defining delivery methods, the industry had developed several variations and combinations of procurement types. Therefore, the following definitions will describe the owner’s process for *selecting* project team members, with emphasis on the primary contractor:

> *Low bid* selection awards a contract for the lowest cost of work proposal in a competitive bidding process. The cost proposals are typically prepared based on a completed, or nearly completed, set of drawings and specifications for the project. The pool of bidders may be open to all interested parties or restricted to a smaller set of ‘prequalified’ parties.
>
> *Best value* selection awards a contract based on the consideration of cost and non-cost factors. The proposal that brings the greatest value to the owner is determined using criteria evaluation methods, often on a weighted basis, to aggregate cost and non-cost factors. Cost of work is often a criterion, but during early stages of design, project costs may be replaced by contractor fees and general conditions. Proposals may be solicited with or without prequalification of interested parties, and negotiation may still occur after submitting the proposal to determine the final contract value.

> *Sole source* selection awards a contract based exclusively on non-cost of work factors, including past performance, technical capabilities and established relationships through prior projects. The contract value is typically negotiated directly between the owner and team, so direct price competition is minimal.

Based on these descriptions, the main differentiators in team selection methods are (1) the openness to competition and (2) criteria considered by the owner for awarding the contract. In practice, the manner in which a team is selected may impact the team's ability to perform on the project. Prior experience working as team (Huckman et al. 2009) and specific personality characteristics (Morgeson et al. 2005) are cited in organizational literature as being correlated with task performance.

3.2.3 Contractual Terms

The contractual terms outline the compensation method for work performed by the designer, construction manager, primary contractor or design-builder. Common commercial terms for architects and contractors include lump sum (LS), cost plus a fee (CPF), with either a fixed or variable fee, and cost plus a fee with a guaranteed maximum price (GMP).

> *Lump sum* contract terms stipulate a firm, fixed price for a specified scope of work. The owner is not responsible for any cost overruns incurred by the contracted party (designer, contractor or design-builder) beyond the agreed upon lump sum, but also does not benefit from any cost savings generated during the design and construction process. The payments are made according to a schedule of values agreed upon by the parties in alignment with the activities in the project schedule, and the actual construction costs are not shared with the owner.

> *Cost plus a fee* is a form of reimbursable contract terms, wherein the owner agrees to reimburse the contracted party for actual costs of work plus a fee, which may be either a fixed value or percentage-based fee. There is typically no maximum for reimbursements, so the owner accepts the majority of the risk for cost overruns on the project. The contract is open book to the owner and payments usually require detailed documentation of the actual incurred costs for the designer and contractor.
>
> *Guaranteed maximum price* commercial terms establish a 'not to exceed' price from the contracted party for an established scope of work. Similar to cost plus arrangements, the contract is open book and the owner will reimburse actual costs, but only up to the guaranteed maximum price. Cost overruns are not the responsibility of the owner and any cost savings are typically either refunded to the owner, or may include shared incentives among the project team.

The common differentiators in these compensation methods are (1) the allocation of financial risk to specific members of the project team and (2) the transparency of open book accounting, which have been shown to impact the behavior of individuals and organizations. For example, lump sum and cost plus terms can have adverse effects on communication between the owner and construction manager (Müller and Turner 2005). Conversely, guaranteed maximum price terms may be more conducive to improving working relationships and encouraging cost savings (Chan et al. 2007). Research in this area is limited, but these studies indicate that contractual terms influence the environment in which the team interacts.

3.3 Team Integration

From an organizational perspective, team integration is the degree to which design and construction team members were brought together for a common purpose. A highly integrated team will leverage the expertise of individual team members to improve the project delivery process. Six measures were used to evaluate team integration. These measures were obtained from a two-day industry workshop held for the Advisory Board. A diverse group of owners, contractors and designers were in attendance and each had at least ten years of working experience in the construction industry. Many attendees were active members in least one large professional organization. These industry members were not intended to represent the voice of an entire industry, but rather as a group interested in understanding and improving the project delivery process. Summarized by Esmaeili et al. (2013), the workshop identified several integrated practices believed to improve project performance. These practices were adapted into metrics that consider high-quality interactions that are inherently inter-organizational and reflective of a high level of team integration.

The *number of BIM uses* is the sum of BIM applications on the project from a predefined list that included architectural design, engineered system design, MEP coordination and clash detection, 4D scheduling and facility management. Since BIM applications often involve information exchanges between multiple team members, more uses are indicative of frequent and richer inter-organizational information exchange.

Participation in BIM planning is the proportion of the project team that was involved in developing a BIM execution plan. Execution planning is the process of documenting an implementation strategy for incorporating BIM into the design, construction and operation phases of a facility (CIC 2010).   This includes the identification of project-specific BIM goals and objectives, modeling standards and team member responsibilities. The proportion was calculated according to Equation 3-1, where the denominator represents the five basic team members: owner, designer, primary contractor or construction manager, mechanical and electrical trade contractors and structural trade contractors. Respondents indicated which of these organizations had at least one representative participating in the BIM planning process. If BIM was conveyed only through contract requirements and no execution planning document was generated, the proportion was listed as zero.

$$Participation\ proportion\ = \frac{Number\ of\ participating\ organizations}{5} \qquad (3\text{-}1)$$

Participation in design charrettes is the proportion of the project team attending design charrettes, as part of a collaborative design and planning process. Charrettes are a form of interdisciplinary problem solving, typically performed during early stages of design, to draw on the expertise and diversity of project stakeholders. The proportion was obtained using Equation 3-1, with the number of team members attending the design charrettes as the numerator. If design charrettes were not used on the project, the proportion was listed as zero.

Participation in joint goal-setting is the proportion of the project team involved in creating the goals for the project. This measure investigates whether the goal setting process was top down or more interactive. A top down approach implies that project goals were established either solely by the owner or with consultation from the designer, and then passed down to the primary contractor and specialty trades. Interactive goal setting is a process that involves team members from different levels of the project organization in the discussion of operational goals. Similar to previous measures, the proportion was calculated using Equation 3-1, with the number of organizations assisting with goal setting as the numerator.

Participation in co-location is the proportion of the project team that was co-located during the construction phase of the project. Co-location was defined as two or more team members sharing a common office or workspace. Team members that were onsite concurrently, but housed in separate offices were not considered co-located. This measure does not consider the duration of co-location. Equation 3-1 was used to calculate the proportion and the numerator was the sum of organizations co-located onsite during construction. If co-location was not used, the proportion was listed as zero.

Offsite prefabrication is the perceived extent to which building systems were fabricated or modularized offsite and assembled onsite. This was evaluated on a semantic differential scale with extremes of ‘entirely built onsite’ and ‘entirely built offsite.’

3.4 Group Cohesiveness

Development of group cohesion is the stage where newly formed groups begin transitioning to an efficient team. Group cohesion has historically been considered the most important variable in studying small groups (Carron and Brawley 2000). As a construct, group cohesiveness is often measured by interpersonal attraction, group pride and task commitment; although evidence of a cohesive group may also be reflected in measures related to communication and agreement. All measures of group cohesiveness were collected on a six-point semantic differential scale. This allowed respondents to provide both the directionality and intensity of their attitudes on individual measures. Each measure was bipolar, having two extreme options listed at the terminal ends of the scale and four options in between. A list of the measures used to evaluate group cohesiveness is provided in Table 3-1.

Table 3-1: Semantic differential adjectives used to evaluate group cohesiveness

Measure	**Extremes**		
Timeliness of communication	Never on time	-	Always on time
Commitment to project goals	Very weakly	-	Very strongly
Team chemistry	Poor	-	Excellent
Frequency of compromise	Never	-	Frequently
Formality of communication	Informal	-	Formal

Timeliness of communication is the perception that information provided by other team members was received when needed. The scale for timeliness of communication ranged from ‘never on time’ to ‘always on time’. This measure arises from the concept of information latency, the lag between when a team member requests information and receives a useful response. Lower latency is associated with higher team satisfaction and reduced schedule durations on projects using an integrated design process (Chachere et al. 2008).

Commitment to project goals is the perceived extent to which all team members were committed to the same project goals, evaluated on a scale between ‘very weakly’ and ‘very strongly’. Goal commitment is directly analogous to task commitment as a measure of group cohesiveness (Zaccaro and McCoy 1988). Commitment is influenced by the team’s belief in the importance of project outcomes and that the goals are realistically attainable (Locke and Latham 2002).

Team chemistry is the perception of compatibility among team members, arising from differences in personalities and past and present relationships. This measure originated in prior project delivery research (Konchar 1997), and the scale of team chemistry ranged from ‘poor’ to ‘excellent’. Conceptually, team chemistry closely aligns with intrapersonal attraction (Festinger et al. 1950) and group pride (Bollen and Hoyle 1990) in group cohesiveness literature.

Frequency of compromise is the perceived prevalence of compromises being made within the project team, evaluated on a scale between ‘never’ and ‘frequently’. To compromise, the project team must collaborate to find a mutually acceptable solution that satisfies all parties. This measure is new to construction research, although the concept of compromise and the balance between cooperation and competition are studied in the field of game theory.

Formality of communication is the perceived extent to which the project team engages in brief, impromptu interaction or more structured, prescribed channels. The scale for formality of communication ranged from ‘informal’ to ‘formal.’ Informal communication is viewed as an important mechanism for team members to exchange information interactively and without being scheduled (Kraut et al. 2002). Conversely, formal communication is typically one-way and follows a preset agenda with a planned list of participants. Both forms of communication have a role on construction projects, but informal interactions are believed to be more supportive of inter-organizational relationships.

3.5 Project Performance

Every owner views project performance relative to their own project goals. An owner on a new data center project with aggressive time to market expectations may place greater emphasis on delivery speed, regardless of the extra cost needed for overtime or tenant revisions made near project completion. Therefore, there is no single measure of performance that is applicable for all building owners. Eight metrics were selected to represent cost, schedule and quality performance in this research. The data used to formulate these metrics was collected after project completion.

3.5.1 Cost Metrics

Costs were defined from the owner's perspective and were representative of the contractual commitments made for design and construction services. All costs were reported in U.S. dollars and did not include the value of land, permitting fees or furniture, fixtures and equipment. Cost data was used to create three performance metrics, including unit cost, cost growth and intensity.

Unit cost is the cost of a building, relative to its size. Unit cost is expressed in dollars per square foot and was calculated by Equation 3-2. Final project cost was the sum of design and construction contracts at the completion of the project and facility size was the gross square foot area of the building, including both occupied and unoccupied space. The location factor was necessary to compare projects built in different cities throughout the U.S., each with regionally varying labor and material costs. Location factors were obtained from the 2014 RSMeans guidebook and were used to adjust each project's costs to the nationwide average. A time modifier was needed to compare projects built in different years, under varying economic conditions. The Building Cost Index (BCI), published each month by the Engineering News Record (ENR), was used to translate completed project costs to current dollars. The time modifier is a dimensionless measure represented Equation 3-2a. BCI June 2014 was the most recent BCI published at the time of data cleaning and preparation. BCI Construction start was the historical BCI for the month and year when construction began on each project in the data set. The resulting time modifier adjusts for material and labor cost inflation between the time of construction and present, allowing unit costs to be compared fairly across projects.

$$Unit\ cost\ = \frac{Final\ project\ cost}{Facility\ size} \times Location\ factor\ \times Time\ modifier \qquad (3\text{-}2)$$

$$Time\ modifier = \frac{BCI_{June\ 2014}}{BCI_{Construction\ start}} \qquad (3\text{-}2a)$$

The second cost metric, *cost growth*, is the percent change in design and construction costs over the duration of the project. Cost growth is expressed as a percentage and was calculated with Equation 3-3. Actual project costs are the final design and construction costs reported at the completion of the project. Planned project costs are the initial or starting values of the contracts for design and construction services. Since cost growth is dimensionless, no location or time adjustments were performed.

$$Cost\ growth\ = \frac{Actual\ project\ cost - \ Planned\ project\ cost}{Planned\ project\ cost} \times 100 \qquad (3\text{-}3)$$

Lastly, *intensity* is a hybrid cost and schedule metric that examines the unit cost installed per month of project duration. Intensity is expressed in dollars per square foot per month and was calculated by Equation 3-4. Unit cost was calculated as explained above, including adjustments for time and location. Project duration is the number of fractional calendar months between the actual start of design and the substantial completion of construction activities.

$$Intensity = \frac{Unit\ cost}{Project\ duration} \tag{3-4}$$

3.5.2 Schedule Metrics

Project durations were calculated from planned and actual schedule dates on each project. The durations were expressed in calendar days and informed three measures of schedule performance, including schedule growth, delivery speed and construction speed.

Schedule growth is the percent change in duration of the project from design start to construction completion. Schedule growth is expressed as a percentage and was calculated using the Equation 3-5. Actual duration is the number of calendar days between the actual design start date and as-built substantial completion date. Planned duration is the number of calendar days between the planned design start date and planned construction end date.

$$Schedule\ growth = \frac{Actual\ duration - Planned\ duration}{Planned\ duration} \times 100 \tag{3-5}$$

The second schedule metric, *delivery speed*, represents the rate that the project team designed and constructed the building. Delivery speed is in units of square feet per month of project duration and was defined by Equation 3-6. Consistent with the previously defined cost metrics, facility size refers to the gross square footage of the building and project duration is the number of fractional calendar months between the actual start of design and substantial completion.

$$Delivery\ speed\ = \frac{Facility\ size}{Project\ duration} \tag{3-6}$$

Construction speed is rate that the building was constructed, as square feet per month of construction duration. The method for calculating construction speed is provided in Equation 3-7. Construction duration is the number of calendar months between the actual start of construction and the construction substantial completion date.

$$Construction\ speed\ = \frac{Facility\ size}{Construction\ duration} \tag{3-7}$$

3.5.3 Quality Metrics

Quality measures were obtained by asking the owner to rate, relative to their expectations, aspects of the facility turnover experience and quality of installed building systems. The measures related to the *facility turnover experience* included difficulty of facility start-up, number and magnitude of call backs and operation and maintenance (O&M) costs. *Building system* measures included the quality of envelope and structure, interior finishes, environmental systems, the exterior aesthetic and interior environment. Similar to the assessment of group cohesiveness, these quality measures were collected on six-point semantic differential scale with extreme values of ‘Low’ and ‘High’. This method of measuring project quality is subjective and does not assess the quality of work directly; instead it reflects the owner’s satisfaction with a project that either met or failed to meet expectations. There are no widely accepted equations for aggregating quality measures, so this research uses an exploratory factor analysis to determine if latent constructs of turnover experience and system quality may be represented by their respective rating measures.

3.6 Programming Factors

Construction projects are delivered according to a scope of work or ‘program’ made during the pre-design phases of the project. This program will outline the primary uses of the building and targeted square footage of occupied space, as well as any special requirements from the owner. These decisions made during programming persist throughout design and construction, and are likely to influence the quality of inter-organizational relationships and project performance. For example, a larger facility is likely to require more coordination between trade contractors than a smaller building. A public owner using government funding may institute stricter reporting policies for the project team and create an additional administrative burden. Three programming factors are identified in the theoretical framework, although only two are considered in the analysis: owner type, facility size and facility type.

3.6.1 Owner Type

The owner type is categorized as either public or private, depending on the funding source of the project. Publically funded projects are delivered by owners within or receiving funding from local, state and federal government agencies. They are often constrained by jurisdictional procurement laws when selecting project team members. For example, projects receiving public funding may be required to select contractors based solely on cost of work in response to greater financial scrutiny.

3.6.2 Facility Size

The size of a facility is the gross square foot area, which includes both occupied and unoccupied space. Larger projects may benefit from improved productivity due to reaching the plateau on the learning curve, and transitioning that experience to the next floor or wing of the building. Larger projects also distribute fixed costs over a greater number of units, resulting in economies of scale and reduced unit costs for building systems. However, large projects are often more technically and organizationally complex, and require more frequent team interaction to manage the additional complexity.

3.6.3 Facility Type

The facility type is a categorization that describes the predominant use of the building. Project complexity is often related to facility type. For instance, hospitals are more technically complex than simple offices, with environmental systems that are more challenging to design and construct. In this research, specific building uses were reduced to a list of nine facility types, adapted from the U.S. Census Bureau's classification of non-residential buildings (U.S. Census Bureau 2014). As shown in Table 3-2, *commercial* facilities included all retail and wholesale buildings, department stores and service centers. *Lodging* included hotels, motels, resort lodging, military barracks and dormitories. *Offices* represented administrative and professional buildings, as well as banks. *Correctional* facilities included prisons and jails. *Educational* included K-12 schools, university classrooms and research labs, museums and libraries. *Manufacturing* contained facilities for food processing, factory work and fabrication. *Sports and recreation* included movie theaters, stadiums, community centers, convention center and casinos. *Transportation* was composed of airport and bus terminals, and *healthcare* included hospitals, clinics, medical offices, medical labs and nursing homes. While facility type is explicitly mentioned in the theoretical framework, these classifications are not modeled in the statistical analysis. A very large sample size would be needed to observe significant differences in performance between nine facility types.

Table 3-2: Facility type classifications

Facility type	Uses
Commercial	Retail and wholesale buildings, department stores, service centers
Lodging	Hotels, motels, resort lodging, military barracks, dormitories
Office	Offices, administrative buildings, professional buildings, banks
Correctional	Prisons, jails
Educational	K-12 schools, university classrooms and research labs, museums, libraries
Manufacturing	Food processing plants, factories, fabrication facilities
Sports and recreation	Movie theaters, stadiums, community centers, convention centers, casinos
Transportation	Airports, bus terminals
Healthcare	Hospitals, clinics, medical offices, medical labs, nursing homes

3.7 Data Collection Tool

A survey questionnaire was developed to collect project data for each of the metrics and variables needed to assess the role of team integration and group cohesiveness in project performance. A copy of the questionnaire is found in Appendix A, which is separated into eleven sections. The questionnaire was developed in cooperation with the Advisory Board, and not all data requested from the respondent was used in this study. Sections one and two provide data to identify the project characteristics and qualitatively describe the organization of the core team members. Sections three through seven collect the primary quantitative data in this study that is used to calculate performance metrics. Section eight describes the procurement process, selection criteria and payment terms.

Sections nine and ten include questions related to the team's development and use of high-quality interactions, respectively. Lastly, section eleven allowed the respondent to comment on any lessons learned from the project and describe any unique features that may have influenced its performance.

3.7.1 Pilot Testing

The survey questionnaire underwent both internal and external pilot testing prior to distribution. The purpose of these tests was to (1) verify the availability of information being requested in the questionnaire and (2) identify potential misunderstandings in the wording of specific questions. The first draft of the questionnaire included approximately 275 questions, or nearly three times the data points of similar project delivery studies. Several redundant and onerous questions with little analytical value were eliminated to reduce the likelihood of respondent fatigue lowering the quality of data. The internal pilot included four projects, where a paper-based version of the questionnaire was completed by contacting the project owner via phone and conducting a survey-style interview. The external pilot was a test of both the survey distribution methodology and an electronic, web-based version of the questionnaire. A letter of introduction to the study and a web-link for the questionnaire were distributed via email to a small sampling of industry contacts. The external pilot produced twelve responses for ten unique projects. The most common feedback from participating owners and contractors addressed the length of the questionnaire, which was universally viewed as too time consuming. In response to this concern, a list of required 'key project information' was added to the introductory letter, allowing respondents to search for and obtain specific cost or schedule data prior to starting the questionnaire. Additionally, the external pilot revealed the need for a verification step after receiving a completed questionnaire. For example, the data for 'total project cost' was initially inconsistent, despite explicitly stating in the question statement to exclude all property, process and manufacturing equipment and furnishings costs. This verification was performed with a follow-up phone call between the respondent and a member of the research team.

3.7.2 Section 1: Project Characteristics

Project identifier information, including the project name, location and respondent's contact details were collected in Section one. This data was kept confidential within the research team. The project name was only used for reference during follow-up conversations with the respondent and to avoid duplicating project entries in the database. Respondents classified the owner as either public or private, and provided a brief description of the intended use of the facility. Physical characteristics of the building, including size, number of floors, foundation type and the percentage of new and renovation work were also requested.

3.7.3 Section 2: Project Organization

Sections two asked the respondent to select the delivery method that most resembled the delivery of their project. The possible selections included design-bid-build, construction manager at risk, design-build and integrated project delivery. Additionally, the timing of contract for each core team member was requested as a percentage of overall design completion.

3.7.4 Section 3: Project Cost

Total project costs and construction only costs at contract award and final completion were collected in Section three. The total project costs included both the design and construction contract commitments, without the value of land, permitting fees or furniture, fixtures and equipment. Costs at contract award represent the agreed upon price from the designer or contractor for the initial scope of work. Costs at final completion capture any changes or modifications to the contract values occurring during the project. In cases where questionnaires were returned by contractors or construction managers, the project owner was contacted to validate total project costs.

3.7.5 Section 4: Project Schedule

In Section four, respondents were asked to provide the planned and actual schedule dates for the start of design, start of construction and substantial completion. A complete date included the month, day and year. In cases where the respondent only provided a month and year, the midpoint of the given month was used in duration calculations.

3.7.6 Section 5: Project Quality

Section five was only answered by the project owner. If the questionnaire was returned by a designer or contractor, the name and phone number or email address of the owner was requested. The owner was then contracted during the verification process to complete this section. Measurements of quality were split into two subsections. The first asked the owner to rate the facility turnover and operation, with respect to difficulty of start-up, magnitude of call backs and operation and maintenance costs. The second section asked the owner to evaluate quality of facility's systems, including the structure and envelope, interior finishes, environmental systems, exterior aesthetic and interior environment.

3.7.7 Section 6: Project Safety

Section six was only answered by the primary contractor. If the questionnaire was returned by a designer or owner, the name and phone number or email address of the primary contractor was requested. This section asked the contractor to provide the total number of recordable injuries and lost time injuries on the job, with an estimate of the total labor hour for onsite construction activities. Section six data was collected, but not analyzed in this phase of research.

3.7.8 Section 7: Sustainability

Section seven collected data on any green or sustainable rating system used on the project. If a level of certification was obtained, respondents were asked to specify the level planned during design and the level awarded after construction. Section seven data was collected, but not analyzed in this phase of research.

3.7.9 Section 8: Team Procurement and Contracts

Information on how proposals were solicited for each team member, the selection criteria for making the contract award and the resulting contract payment terms was collected in Section 8. The options for proposal solicitation included open bid, prequalified bid, single-stage request for proposal (RFP), 2-stage RFP and sole source. Selection criteria were presented as a multiple select question, allowing the respondent to indicate any combination of cost of work, cost of fees and general conditions, technical proposal, design concept, similar project experience and interview performance. Lastly, payment terms were indicated as lump sum, guaranteed maximum price (GMP) or cost plus a fee.

3.7.10 Section 9: Team Characteristics and Behavior

Section nine asked the respondent to assess the level of team development on the project, with specific emphasis on group cohesion. Several theorized indicators of group cohesiveness were rated on a semantic differential scale, including chemistry, formality and timeliness of communication, frequency of compromise and goal commitment. This section also included data on co-location, the use of a shared design and construction contingency and the team members participating in joint goal setting.

3.7.11 Section 10: Process and Technology

Details on the types of inter-organizational activities engaged in by the project team were collected in Section ten. These included the number of design charrettes held, types of BIM applications and the specific team members that were invited to participate. Participation was presented as a series of multiple select questions, allowing the respondent to indicate any combination of participating organizations from a list of the owner, designer, construction manager or general contractor, MEP trades and structural trades. A multiple select was also used to indicate the number of BIM application on the project from a list of architectural design, engineered system design, MEP coordination, 4D scheduling and facility management. An evaluation for the level offsite prefabrication was also included in this section.

3.7.12 Section 11: Lessons Learned

The last section allowed respondents to list specific suggestions for how the project could have been delivered more successfully. Respondents were also asked to describe any unique features or conditions that may have influenced the final cost, schedule or quality performance.

3.8 Chapter Summary

A theoretical framework for studying inter-organizational relationships on construction projects was developed using literature, related studies and industry feedback. The framework informed a data collection instrument and provided the structure for a statistical analysis of the data set. The specific methodologies of data collection, verification and analysis are described in Chapter 4.

Chapter 4

DATA COLLECTION AND ANALYSIS METHODS

The purpose of this research was to explore relationships among team integration, group cohesiveness and project performance within the context of project organizations. To collect a broad range of quantitative project data, a survey questionnaire was distributed to owners and contractors in the construction industry. Once responses were received, they were checked for accuracy using a verification process and the data was screened prior to analysis. Multivariate statistical methods, including latent class analysis and structural equation modeling, were used to analyze the sample data set. This chapter describes the data collection process and summarizes the analysis techniques used in fulfillment of the research purpose.

4.1 Data Collection Methods

This research used a structured survey questionnaire to collect project information directly from the project participants. As mentioned previously, the data collection effort was performed in collaboration with the University of Colorado Boulder. Questionnaires were distributed by postal mail and email to professional organizations in the architecture, engineering and construction (AEC) industry. Because not all respondents have the same knowledge of the project, a verification procedure was followed to confirm key data with the project owner. Once verified by a member of the Penn State or University of Colorado research team, project data was entered into an electronic database and later screened to ensure a meaningful analysis. These steps in the data collection methodology, which will be discussed in subsequent sections, are summarized in Table 4-1.

Table 4-1: Summary of data collection methodology

Data Collection Method	Description
1. Survey distribution	• PDF form for email distribution • Double-sided paper version for postal distribution • Surveys reached the following groups: – Construction Owners Association of American (COAA) – Design-Build Institute of American (DBIA) – Construction Management Association of America (CMAA) – Penn State University, AE Dept. Alumni (1976-2012) – Penn State University, PACE (2012-2013)
2. Data recording and verification	• Data recorded into single database • Completed surveys reviewed and annotated for verification • Verification performed by research assistants at Penn State University and the University of Colorado Boulder
3. Data screening	• Combined multiple responses into single database entry • Removed projects outside the study scope • Removed unverified projects • Check data assumptions for statistical analysis

4.1.1 Survey Distribution

After developing and piloting the survey questionnaire, the document was distributed to the study's targeted population of project participants. Since a truly simple random sample of recently completed construction projects was not feasible, this research sought a large-scale convenience sample. Mailing lists from professional, alumni and academic organizations were used to reach a diverse group of project participants. Respondents were asked to complete the survey for their most recently completed project. The survey was intended primarily for owners, as the party with the most complete knowledge of the project; however contractors, construction managers and designers were not discouraged from participating. Surveys were sent as a PDF form for email distributions and as a double-sided paper version for postal mailings. Both forms of distribution were accompanied by a cover letter and list of frequently asked questions (FAQs) that explained the purpose of the study and listed definitions for several key terms.

Respondents that received the PDF form had the option of printing the survey and answering by hand, or completing the form electronically.

Approximately 2,500 surveys were sent via postal mail to alumni of the Architectural Engineering Department at Penn State and 41 were returned, representing a 1.6% response rate. Nearly 6,000 surveys were distributed by email to mailing lists for the Construction Owners Association of American (COAA), Design-Build Institute of American (DBIA), Construction Management Association of America (CMAA) and the Partnership for Achieving Construction Excellence (PACE) at Penn State. The research team received 290 returned surveys from the email distribution, representing a 4.8% response rate. When combined, a total of 331 surveys were received for this study, resulting in a 3.9% overall response rate.

4.1.2 Data Recording and Verification

A Microsoft Access® database was developed to enter and store completed survey responses. Forms were created with pull down menus, multiple select boxes and rating scales that automatically coded the data into tables. This reduced the likelihood of human error when manually entering data. Before each survey response was added to the database, the project was assigned a unique identification number that included the respondent's role in the project and the initials of the research assistant tasked with data verification. While research assistants were initially allowed to enter data directly into concurrent versions of databases, access was later centralized into a single database and restricted to senior researchers only.

The following procedures were used to verify the project information in returned surveys. First, returned surveys were reviewed for missing and inconsistent data. If necessary, annotations with clarifying questions or lines of further inquiry were attached to the survey. Special scrutiny was given to contract values and schedule dates to improve the accuracy of outcome data. This screening and annotation process ensured that interactions with survey respondents were consistent and professional. Data verification was conducted with follow-up phone calls and emails made by research assistants at Penn State and the University of Colorado Boulder. Each assistant was familiarized with the objectives of the research and made aware of the terminology used in the survey. Assistants were trained in verification procedures by observing and participating in several follow-up calls made by a senior researcher. In cases where the survey respondent was not the project owner, the owner was contacted to obtain quality measures and verify cost and schedule data.

4.1.3 Data Screening

Data screening was performed to prepare the sample data for analysis. First, the database tables were exported directly to a Microsoft Excel® spreadsheet. Cells with missing data were coded as -99999 to alert analysis programs to exclude those values. Projects with over 30% missing data across the study variables were removed. Columns were added and calculated for performance metrics using the verified costs and schedule dates. Projects that were outside the scope of this research were removed from the spreadsheet. These included renovation project with less than 50% new construction by cost, international projects, civil and highway work, uncompleted projects, facilities less than 5,000 gross square feet and projects completed prior to 2008. Additionally, several projects were not validated with the owner due to non-response from the point of contact.

Projects with more than one respondent (e.g. an owner and contractor submitting a survey for the same project) were combined into a single case. A multi-step procedure was followed for resolving discrepancies among respondent (Table 4-2). For quantitative data, including contract values and schedule dates, the first action is a follow-up discussion with the respondents to verify the data source or confirm that the question was fully understood by the respondent. If a follow-up was not possible or unsuccessful in resolving the conflict, then values marked as ‘Actual’ by a single respondent or the more precise value from multiple respondents was entered. For qualitative data with nominal categories, the study definitions were used to re-classify conflicting responses, after verifying that each term was understood by the respondents. For qualitative data derived from ordinal scales, the mean rating of all project respondents was used, with the exception of quality ratings. All quality rating reflected only the opinions of the project owner.

Table 4-2: Actions for resolving multiple response discrepancies

Data Type	**Research Actions**		
	Step 1	*Step 2*	*Step 3*
Quantitative	Verify source data with respondent	Preference to data denoted as 'Actual'	Preference to precise data, otherwise use mean
Qualitative *(Nominal)*	Verify terms were understood by respondent	Re-classify response using study definitions	---
Qualitative *(Ordinal)*	Preference to owner (e.g. Quality ratings)	Enter mean rating across all respondents	---

Lastly, the data screening process examined descriptive statistics for each observed variable. Specifically, the means, medians, minimums and maximums were reviewed for any out-of-range values as well as potential data entry errors. Additionally, the distributions of continuous and ordered categorical variables were considered. Most continuous variables were found to have some degree of skewness and kurtosis, and did not follow a normal distribution. A procedure for transforming non-normal data is discussed alongside the data analysis methods. Several ordered categorical variables were collapsed to consolidate response options with a low number of observations. Since analyses involving categorical variables proceed from a frequency or cross-tabulation table, response options with zero or few observations can lead to difficulty in estimation (Bentler and Chou 1987). Therefore, the measurement scales of group cohesiveness measures were collapsed from six points to either four or five points. In all cases, collapsing response options eliminated a positive or negative tail in the distributions toward one of the extremes. The lower extremes of the scales for timeliness of communication, commitment to project goals and team chemistry were collapsed to produce a new four point scale. Conversely, the upper extremes of the scales for frequency of compromise and formality of communication were collapsed, resulting in a five point scale.

4.2 Data Analysis Methods

This research used a combination of multivariate modeling techniques to analyze the sample data set. First, a latent class analysis was performed to identify underlying categorical groups that corresponded to patterns in procurement and contracting variables. Projects were given group assignments to represent their project delivery strategy in later stages of analysis. The measurement models for team integration and group cohesiveness were validated using confirmatory and exploratory factor analyses. Lastly, structural equation models were calculated and compared based on model fit and explained variance. All statistical analyses were performed with MPlus Version 7.2 and pairwise deletion of missing data. Pairwise deletion uses all available data and produces unbiased parameters when the data is missing completely at random (Muthén et al. 1987). These steps in the data analysis methodology, which will be discussed in subsequent sections, are summarized in Table 4-3.

Table 4-3: Summary of data analysis methodology

Data Analysis Method	**Description**
1. Latent class formation	• Identified a set of indicator variables • Performed an exploratory LCA to remove weak class differentiators • Chose most appropriate class model • Assigned most likely class membership to each project
2. Structural equation modeling	• Checked validity of latent constructs • Performed transformation on non-linear variables • Performed robust weighted least square path analysis • Compared alternate models

4.2.1 Latent Class Formation

Latent class analysis (LCA) uses a clustering algorithm to identify underlying, categorical subgroups or ‘classes’ in a sample. Classes are defined by the presence or absence of indicators, expressed as a probability, that differentiate one class from another. The purpose of this analysis was to better represent the construction project as an organization, using variables known to impact the structure of project team. Unordered categorical variables for procurement and contracting were reduced to binary indicators. Multiple class models were formed and based on fit and selection indices, the appropriate number of classes was chosen to represent the data. Lastly, each project was assigned to the class with its highest probability of belonging.

4.2.2 Structural Equation Modeling

Several estimation methods may be used with structural equation modeling (SEM) to obtain coefficients, standard errors and fit indices. As with most statistical techniques, SEM makes assumptions that should be satisfied before trusting the results of an analysis. For the most common types of estimators, maximum likelihood (ML) and generalized least square (GLS), the following assumptions are made regarding the sample data (Kline 2011):

1. The observations are independent and unstandardized;
2. The joint distribution of observed variables is multivariate normal, implying that the observed variables are also continuous; and
3. The independent variables are measured without error.

For this research, the assumption of multivariate normality was not satisfied. Specifically, measures accounting for variations in facility size were positively skewed with very high kurtosis. This included facility size, unit cost, delivery speed, construction speed and intensity. Since the sample included facility sizes over many orders of magnitude, ranging from 5,000 square feet to over 1-million, these measures were transformed with a base 10 logarithm. The transformed metrics followed a normal distribution with both skewness and kurtosis falling between -1 and 1. Additionally, this research used ordered categorical data in the same model as continuous data. Ordered categorical data is discrete in nature and cannot be normally distributed, failing to satisfy the multivariate normality assumption. Using this type of data in maximum likelihood estimation has documented effects in SEM, including (1) underestimation of fit indices suggesting that a correctly specified model does not fit the data (Hutchinson and Olmos 1998) and (2) a negative bias in regression parameters with increased standard errors (Babakus et al. 1987; Muthén and Kaplan 1985). Since the sample data did not satisfy the model assumptions needed for ML or GLS estimation, this research employed a mean and variance adjusted weighted least square estimator (WLSMV).

WLSMV estimation incorporates extra non-negative constants, or ‘weights’, for each parameter during the fitting process. Of the estimators suitable for analyzing non-normal categorical data, WLSMV was found to perform the best in SEM applications (Brown 2006). The weights are derived from the diagonals of the covariance matrix of parameter estimates. In other words, parameters that are more precise (i.e. having a lower variance) are given more weight, and those with less precision are given less weight. The result is a robust regression methodology that, when applied to correctly specified models, provides unbiased parameter estimates for ordered categorical and non-normal data (Muthén and Kaplan 1985).

Several structural models were developed to best arrange the study’s latent constructs in relation to performance outcomes. These models were calculated with and without control variables. Two indices were selected to assess model fit: the root mean square error of approximation (RMSEA) and comparative fit index (CFI). RMSEA is a measure of model misspecification that considers the number of variables in the model, and ranges from values of 0 to 1. Well-fitting models have RMSEA less than .08 (Hooper et al. 2008). The CFI compares the specified model against a baseline model that assumes no correlation among observed variables. The resulting index is a value between 0 and 1, with values at .95 and above indicating a good fit (Hu and Bentler 1999). Additionally, as a measure of variance explained in dependent variables, R^2 was considered alongside fit indices when choosing between alternate models. This additional criterion was implemented to avoid situations where the best fit model would be selected over a good fit model with better predictive ability.

4.3 Sources of Bias

Potential sources of bias in this research included the self-selection of projects by the respondent and non-response from individuals declining to return the survey or the implicit exclusion of projects not associated with individuals or organizations on the selected mailing lists

4.3.1 Self-Selection Bias

Self-selection bias occurs if respondents demonstrated a preference for completing the questionnaire with only poor or only favorable project experiences. Two measures were taken to reduce this type of response bias. First, the instructions distributed with the questionnaire explicitly requested a wide array of projects, both typical and challenging to inform respondents that the study is not targeting a specific type of project or performance outcome. Secondly, respondents were asked to rate the overall success of the project. Self-section bias may also occur if a large number of projects are submitted by a single respondent or organization (e.g. design-build projects from members of the Design-Build Institute of America). To limit this type of bias, the total number of projects submitted by any individual or organizational was limited to 10% of the total sample size.

4.3.2 Non-Response Bias

Using a mailing list to distribute the questionnaire implicitly excludes those projects without a team member represented in the mailing list. Therefore, the instructions also include a request that respondents share the questionnaire with other individuals, both inside and outside of their own company. This encouraged snowball or referral sampling, which allowed respondents to recruit new groups of participants that may not have received the initial distribution of the questionnaire.

4.4 Chapter Summary

A survey questionnaire was used to collect data from project participants. To ensure the accuracy of data, a verification procedure was followed by the research team to follow-up with each respondent. The data was screened for out-of-range values and the distributions were checked for normality violations prior to analysis. The applicability of multivariate analysis techniques, including latent class formation and SEM, were discussed. Lastly, sources of self-selection and non-response bias were identified.

Chapter 5

LATENT CLASS MODEL OF DELIVERY

Chapter 5 begins with a discussion of latent class analysis and describes how the procedure was used to identify underlying groups or “classes” of project delivery strategies. Indicator variables of delivery strategies are then reviewed and narrowed according to their strength as differentiators of latent classes. Multiple-class models are compared using fit indices to select a single model that best represents the underlying project delivery strategies found in the data set. Lastly, individual projects were assigned to the class with the highest posterior probability, or likelihood of belonging.

5.1 Preparing for Latent Class Analysis

Latent class analysis (LCA) is a statistical method of identifying discrete subgroups within multivariate response data. LCA posits that an underlying, categorical latent variable is responsible for the variation in two or more observed variables. Similar in concept to factor analysis, LCA is methodologically more akin to clustering analysis. Whereas factor analysis is concerned with the structure of observed variables as correlational, LCA is concerned with the structure of cases as taxonomical. Given a sample of cases (respondents, projects, etc.) with several observed variables, LCA determines if there is a clear separation of cases into a smaller number of subgroups. These subgroups are referred to as “classes” and within each latent class, each observed variable is assumed to be statistically independent of every other variable. Thus, the latent class is assumed to account for *all* of the association between observed variables.

In this study, LCA is used to extract a small number of project delivery strategies from patterns of organizational, procurement and contracting variables in the data set.

The primary goal for this stage of the research was to identify granularity in the broader classification of project delivery methods that reflects real practices in the industry. The secondary goal was to investigate a statistical method of data reduction to assist in the identification of a structural path analysis. The steps in building a latent class model for this research include:

1. Identify and code a set of indicator variables that may differentiate between classes of project delivery strategies.
2. Perform an exploratory LCA to identify and remove weak indicator variables.
3. Choose the most appropriate model, with the least number of latent classes using goodness-of-fit statistics (χ^2, G^2) and lowest information loss (AIC, BIC).
4. Use posterior probabilities to assign a class number to each response case.

5.1.1 Coding of Indicator Variables

Prior to performing the LCA, dichotomous indicator variables were identified from several observed variables in the data set. The relevant observed variables were categorical and described the organization, procurement and contracting of the project team. Table 5-1 summarizes the classification of these nominal variables into dichotomous, “Yes” or “No” indicators. For example, when the owner held a single contract for design and construction services, as in design-build (DB) and integrated project delivery (IPD), indicator D1 was coded as a “Yes” response. D1 was coded as “No” when the contract arrangement was split, as found in design-bid-build (DBB) or CM at risk (CMR). The remaining indicators D2-D13 were similarly coded to differentiate between delivery strategies and meet the assumption of conditional independence for LCA. Interviewing the primary contractor prior to selection (D10) and the use of a shared design and construction contingency (D11) were already dichotomous responses in the data set, and therefore not re-coded.

Table 5-1: Dichotomous classifications of delivery strategy indicators

Delivery strategy indicator		Dichotomous classification
D1	Owner held a single contract for design and construction	Yes = DB, IPD; No = DBB, CMR
D2	Primary builder was hired during schematic design or earlier	Yes = SD or earlier No = DD or later
D3	Trade contractors were hired during schematic design or earlier	
D4	Primary builder was prequalified	Yes = PQB, 2-Stage RFP, SS No = OB, 1-Stage RFP
D5	Trade contractors were prequalified	
D6	Primary contractor was selected based on cost of work	Yes = Cost of work No = Fee and/or qualifications
D7	Trade contractors were selected based on cost of work	
D8	Primary contractor had an open book contract	Yes = GMP, CPF No = LS
D9	Trade contractors had open book contracts	
D10	Primary contractor was interviewed prior to selection	N/A
D11	Project used a shared design and construction contingency	N/A
D12	Owner had a prior relationship with the designer	Yes = Repeat No = First time
D13	Owner had a prior relationship with the primary contractor	

A summary of the re-coded indicator variables is provided in Table 5-2, which lists the frequencies of "Yes", "No" and "Missing" responses for the sample (*N*=204). Prequalification of the primary contractor (D4) and trade contractors (D5) were the most common indicators at frequencies of 72% and 70%, respectively. Trade contractors having an open book contract (D9) was the least common, with an occurrence of only 13% across all cases. There was very little missing data in these indicator variables. The use of shared design and construction contingency (D11) had the highest frequency of non-response at 6% across all cases. Taken in isolation, these item-response frequencies are useful descriptors of the sample data set. However, further analysis using LCA is used to identify common patterns of indicators that would more accurately capture project delivery strategies in practice.

Table 5-2: Item-response frequencies for delivery strategy indicators

		Frequency (*N*=204)		
Delivery strategy indicator		*Yes*	*No*	*Missing*
D1	Owner held a single contract for design and construction	.41	.59	.00
D2	Primary builder was hired during SD or earlier	.67	.33	.00
D3	Trade contractors were hired during SD or earlier	.64	.36	.00
D4	Primary builder was prequalified	.72	.27	.00
D5	Trade contractors were prequalified	.70	.29	.00
D6	Primary contractor was selected based on cost of work	.60	.39	.01
D7	Trade contractors were selected based on cost of work	.71	.26	.03
D8	Primary contractor had an open book contract	.54	.46	.00
D9	Trade contractors had open book contracts	.13	.87	.00
D10	Primary contractor was interviewed prior to selection	.55	.45	.00
D11	Project used a shared design and construction contingency	.28	.66	.06
D12	Owner had a prior relationship with the designer	.57	.39	.04
D13	Owner had a prior relationship with the primary contractor	.56	.42	.01

5.1.2 Identifying Poor Differentiators

When using the complete list of delivery indicators (D1-D13) in exploratory three, four and five-class models, several indicators were identified as poor differentiators of latent class. The presence of open book contracts at the trade contractor level (D9) and use of a shared design and construction contingency (D11) had probabilities less than 0.3 across all class models. This suggests that neither indicator occurs frequently on projects and cannot serve as differentiator of delivery strategies. Similarly, the owner having a prior working relationship with the designer (D12) and primary contractor (D13) had probabilities between 0.4 and 0.6 across all class models. A probability around 0.5 suggests that these indicators may be independent of delivery strategy, since they occur with nearly equal likelihood or unlikelihood within all classes. Lastly, the primary contractor being interviewed prior to selection (D10) was redundant with the primary contractor being selected based on cost of work (D6). This redundancy was evident in each model, where classes with high probabilities of cost of work selection had consistently low probabilities of contractor interviews. Therefore, the weak indicators D9-D13 were removed from the LCA, and the class models were recalculated using only the remaining, strong indicators D1-D8.

5.2 Comparing LCA Models

The LCA models were calculated using robust maximum likelihood estimation (MLR) and were re-run a minimum of three times with varying random start values to avoid local maxima solutions. All calculations were performed using the MPlus Version 7.2 statistical software package with the mixture model add-on. The outputs for an analysis of a user-specified number of latent classes include: (1) model fit and selection statistics, (2) conditional probabilities of a “Yes” response for each indicator in each latent class, (3) posterior probabilities of class membership for each case, and (4) class assignment for each case based on the highest posterior probability. The model fit statistics compare observed and expected response patterns using chi-square (χ^2) and likelihood ratio tests (G^2). These statistics test the null hypothesis that the observed response frequency is equal to the expected frequency. Therefore, a low p-value and rejection of the null hypothesis indicates a poor fitting latent class model. Selection statistics combine goodness-of-fit with model complexity, using the maximized log-likelihood to calculate Akaike Information Criterion (AIC) and Bayesian Information Criterion (BIC). Chi-square tests are reasonable in assessing model fit for a LCA where the sample size is large and the number of indicators is small. Similar to all cross-tabulations, when there are too many sparse response patterns with low or zero frequencies, the chi-square and likelihood ratio tests are not valid. Therefore, the best-fit latent class model typically has the lowest AIC or BIC value of all the models considered.

Using the reduced indicator list (D1-D8), separate LCA models were created iteratively for up to six classes. A summary of the fit indices, selection criterion and ratio testing for each latent class solution are provided in Table 5-3. The one, two and three-class solutions have significant χ^2 and G^2 statistics, which indicates a poor fit between the response pattern of the indicator variables and those expected under the model. Additionally, the Vuong-Lo-Mendell-Rubin (VLMR) likelihood ratio test was significant in the one, two and three-class models. The VLMR test assesses the null hypothesis (H_0) that a lower number of classes, $k - 1$, are a better fit than the current number of classes, k. Therefore, rejecting the null hypothesis for the one, two and three-class models, while failing to reject the four and five-class models, suggests that the four-class solution is an adequate fit. The AIC and sample-size adjusted BIC decrease as the number of latent classes increases, but the rate of decline begins to taper off after the four-class model. Based on these comparisons, the four and five-class solutions appear to strike the best balance between model fit and complexity.

Table 5-3: Fit indices, selection criterion and ratio test for latent class solutions

No. of Classes (k)	**Model fit indices**			**Model selection criterion**			**Ratio test**
	LL	χ^2	G^2	*AIC*	*BIC*	*SSABIC*	*VLMR*
1	-1036	833*	462*	2088	2114	2089	N/A
2	-948	458*	291*	1929	1986	1932	176 (1)*
3	-907	362*	208	1867	1953	1871	81 (2)*
4	-880	190	155	1831	1947	1836	54 (3)*
5	-868	146	131	1824	1970	1831	25 (4)
6	-856	89	107	1818	1994	1826	24 (5)

Notes: LL = Log-likelihood, *AIC* = Akaike information criterion, *BIC* = Bayesian information criterion, *SSABIC* = Sample-size adjusted Bayesian information criterion, *VLMR* = Vuong-Lo-Mendell-Rubin likelihood ratio test for $k - 1$ (H_0) vs. k Classes; * $p < .05$

5.3 Selecting the Best-Fit LCA Model

The five-class model was as selected as the optimal solution, since the resulting classification of project delivery strategies was more interpretable, and maintained very high average posterior probabilities (>0.90). To select between the four and five-class solutions, the item-response probabilities for each model were examined in greater detail. Table 5-4 illustrates the probability of seeing a “Yes” response to each indicator variable by identified latent class. Ideally in dichotomous LCA, these probabilities would be very close to zero or one, signifying perfect homogeneity within classes. In practice, perfect homogeneity is rare and the typical thresholds for dichotomous LCA are (1) a probability of .3 or less to signify the absence of an indicator and (2) a probability of .7 or greater for the presence of an indicator.

A shown in Table 5-4, there are several instances in the four-class model where item-responses probabilities fall between these upper and lower thresholds, mostly in indicators of contractor prequalification. Additionally, prequalification of the primary contractor (D4) and trades contractors (D5) were not distinctive indicators and were present in all four classes of delivery strategy. The prevalence of these latent classes in the sample data set ranges from a minimum of 19% for Class IV to a maximum of 28% for Class I. Overall, the four-class model fits the data well, but struggles to differentiate any group of projects without contractor prequalification.

Table 5-4: Item-response probabilities for the four-class solution

		Latent class			
		I	**II**	**III**	**IV**
Latent class prevalence in data set		.28	.26	.26	.19
Item-response probabilities		Probability of a Yes response			
D1	Owner held a single contract for design and construction	.09	.09	.89	.69
D2	Primary builder was hired during SD or earlier	.00	.80	1.0	1.0
D3	Trade contractors were hired during SD or earlier	.00	.07	.70	.84
D4	Primary builder was prequalified	.64	.69	.84	.73
D5	Trade contractors were prequalified	.62	.78	.76	.64
D6	Primary contractor was selected based on cost of work	.93	.27	.90	.18
D7	Trade contractors were selected based on cost of work	.76	.87	1.0	.10
D8	Primary contractor had an open book contract	.23	1.0	.29	.70
Average posterior probability for classification		.93	.96	.91	.96

Notes: Probabilities greater than .60 are highlighted to aid in interpretation. The probability of a “No” response can be calculated by subtracting the item-response probabilities shown above from 1.

However, when considering the five-class solution, there is a clear class of projects without contractor prequalification. By expanding the model by an additional class, Class I from the four-class model was split into two groups in the five-class model shown in Table 5-5: Class I without any prequalification, and Class II with both primary contractor (D4) and trade contractor prequalification (D5). While the comparison of fit statistics suggested that the four-class solution was adequate in grouping project delivery strategies, the five-class solution better aligns with literature on prequalification. Prior studies consistently highlight the importance of examining contractor qualifications prior to soliciting a proposal or bid (Russell et al. 1992; Palaneeswaran and Kumaraswamy 2001). Additionally, the five-class solution has more homogenous classes, with fewer item-response probabilities falling in between the upper (.7) and lower (.3) thresholds. In the sample data set, the prevalence of these classes ranges from a minimum of 9% for Class I to a maximum of 27% for Class IV. Although the low representation of Class I in the sample data set is not desirable, the recognition of prequalification as a class differentiator makes the five-class model more reflective of practices in the construction industry.

Table 5-5: Item-response probabilities for the five-class solution

	Latent class				
	I	**II**	**III**	**IV**	**V**
Latent class prevalence in data set	.09	.19	.26	.27	.18
Item-response probabilities	Probability of a Yes response				
D1 Owner held a single contract for design and construction	.00	.13	.09	.90	.69
D2 Primary builder was hired during SD or earlier	.00	.03	.80	1.0	1.0
D3 Trade contractors were hired during SD or earlier	.00	.00	.07	.71	.84
D4 Primary builder was prequalified	.03	1.0	.67	.84	.73
D5 Trade contractors were prequalified	.32	.79	.78	.76	.64
D6 Primary contractor was selected based on cost of work	.95	.92	.27	.90	.18
D7 Trade contractors were selected based on cost of work	.85	.71	.88	1.0	.10
D8 Primary contractor had an open book contract	.00	.34	1.0	.29	.70
Average posterior probability for classification	.91	.96	.91	.94	1.0

Notes: Probabilities greater than .60 are highlighted to aid in interpretation. The probability of a "No" response can be calculated by subtracting the item-response probabilities shown above from 1.

5.4 A Five-Class Model of Project Delivery Strategies

Each of the five classes is described in Figure 5-1, using the estimated probabilities of encountering each indicator variable on projects within a given class. The nomenclature adopted for these classes reflects the combination of indicators with estimated probabilities greater than 0.65 found in each class:

Class I: Projects in this class universally reported split design and construction contracts (0.00 probability of a single contract), no early primary contractor (0.00) and trade (0.00) involvement, a small probability of primary contractor prequalification (0.03), a small probability of trade prequalification (0.32), very high probabilities of primary contractor (0.95) and trades (0.85) being selected based on cost of work, and no use of open book contracts (0.00). The prevalence of this class in the data set was 9% (*n*=19).

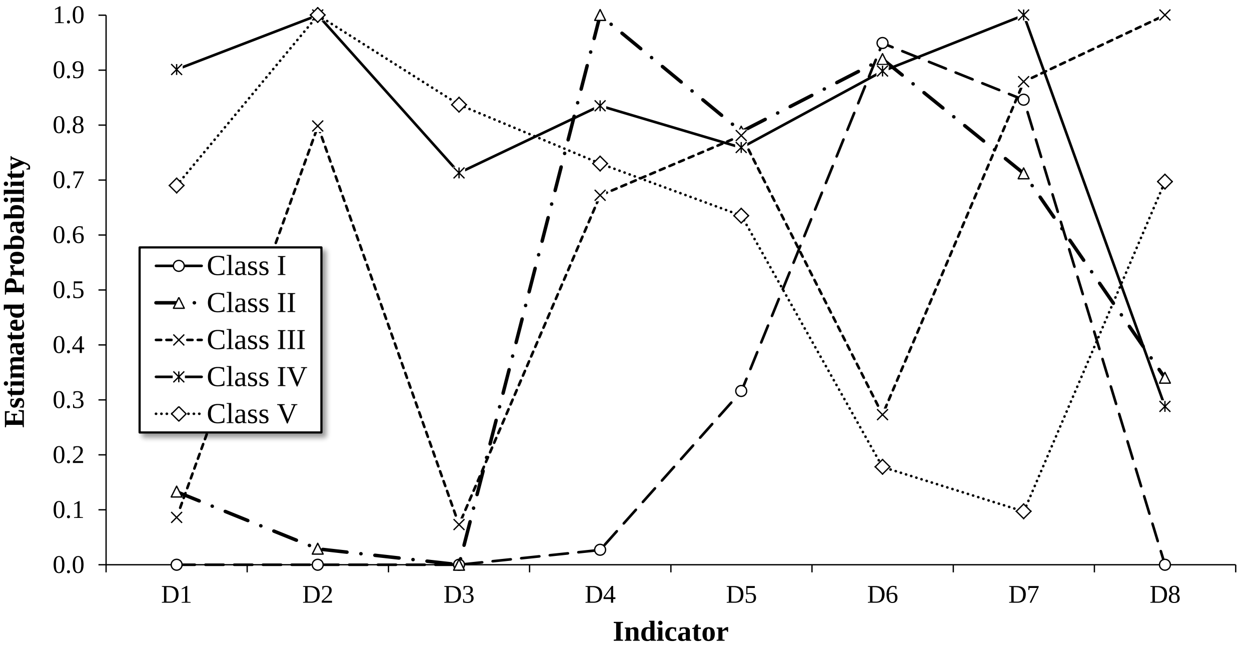


Figure 5-1: Probabilities of having each indicator variable for the five latent classes

Class II: These projects reported a small probability of a single design and construction contract (0.13), very small probabilities of early primary contractor (0.03) and trade (0.00) involvement, universal prequalification of the primary contractor (1.00), high probability of trade prequalification (0.79), very high probabilities of primary contractor (0.92) and trades (0.71) being selected based on cost of work, and a small probability of an open book contract with the primary contractor (0.34). The prevalence of this class in the data set was 19% (*n*=39).

Class III: Projects in this class reported a small probability of a single design and construction contract (0.09), very high probability of early primary contractor involvement (0.80), very small probability of early trade involvement (0.07), high probability of prequalification for the primary contractor (0.67) and trades (0.78), small probability of the primary contractor being selected based on cost of work (0.27), very high probability of trades being selected based on cost of work (0.88), and universal use of an open book contract (1.00). The prevalence of this class in the data set was 26% (*n*=54).

Class IV: This class was characterized by near universal use of a single design and construction contract (0.90), universal early primary contractor involvement (1.00), very high probability of early trade involvement (0.71), very high probability of primary contractor (0.84) and trade (0.76) prequalification, near universal consideration of cost of work when selecting the primary contractor (0.90) and trades (1.00), and small probability of an open book contract (0.29). The prevalence of this class in the data set was 27% (*n*=56).

Class V: These projects reported a high probability of a single design and construction (0.69), universal early primary contractor involvement (1.00), very high probability of early trade involvement (0.84), high probability of primary contractor (0.73) and trade (0.64) prequalification, small probabilities of selecting the primary contractor (0.18) and trades (0.10) based on cost of work, and very high probability of an open book contract (0.70). The prevalence of this class in the data set was 18% (*n*=36).

5.4.1 Class Assignment using Posterior Probabilities

Calculated alongside the LCA, posterior probabilities are used to assign class membership to projects in the data set. Posterior probabilities reflect the likelihood of a given case belonging to each latent class, based on the case’s response pattern on the indicator variables. For example, a sample case with posterior probabilities of 0.05 on

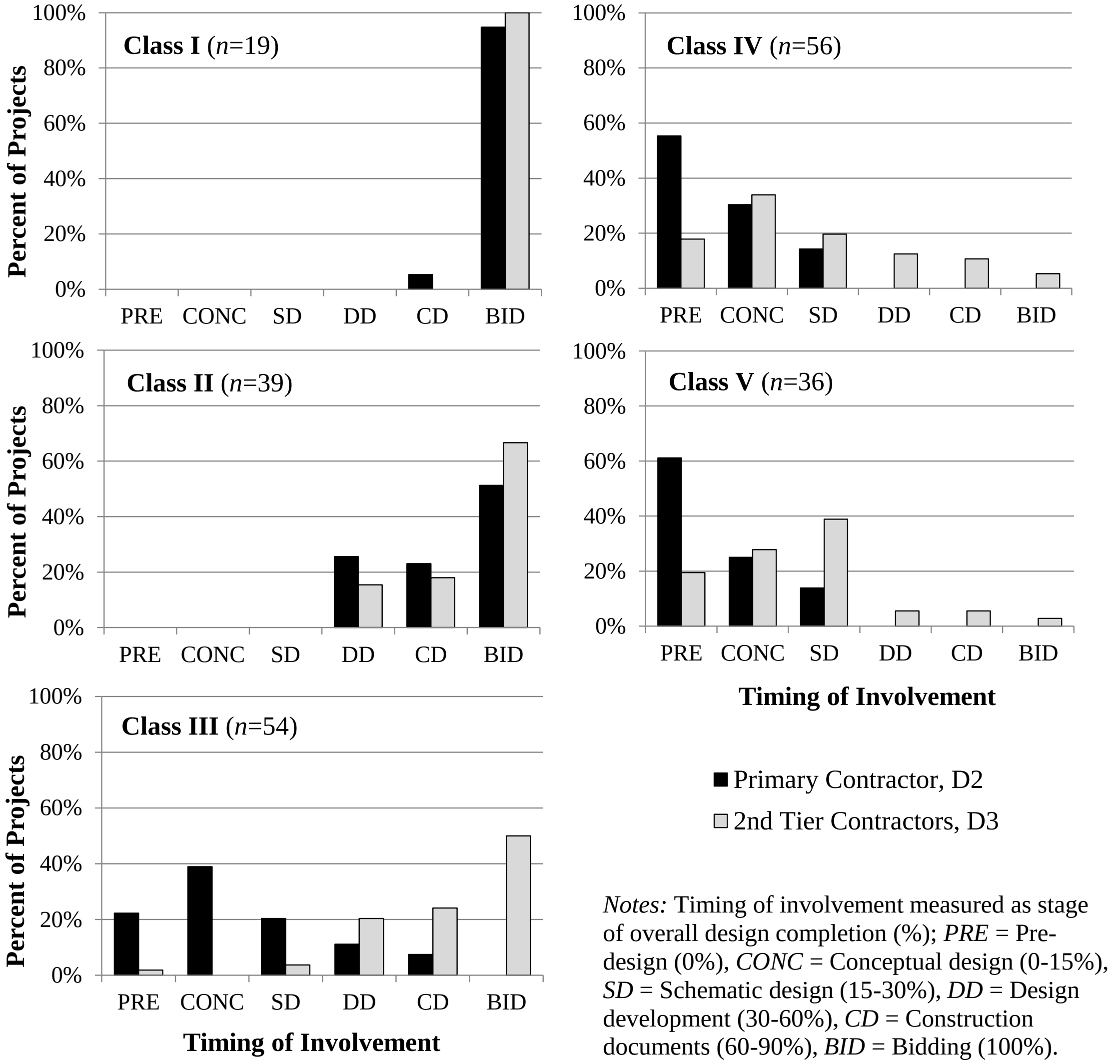
Class I, 0.00 on *Class II*, 0.92 on *Class III*, 0.03 on *Class IV* and 0.00 on *Class V* almost certainly belongs in *Class III*, with a very small possibility of being part of *Class I* and *Class IV*. In this manner, class assignments were made for all cases in the sample data set (N=204) according to their highest posterior probability in the five-class solution. This method of class assignment, which removes the uncertainty in classification, does introduce a small amount of measurement error into future analyses.

One method of examining how well cases have been classified in the latent class analysis is to examine the model's entropy (Celeuz and Soromenho 1996). Entropy is calculated according to Equation 5-1, where $\hat{p}_{ik}$ is the estimated posterior probability for case i in class k. The function scales this summation for the sample size of n and a total number of classes, K. Entropy is bounded between zero and one, with a value of one indicating that all cases were perfectly classified. The entropy of the five-class model in this research was .88, which indicates strong delineation between classes. In simulation studies, latent class models with entropy greater than .80 were found to have low levels of assignment error.

$$Entropy = \frac{\sum_i \sum_k (-\hat{p}_{ik} \ln \hat{p}_{ik})}{n \ln K} \tag{5-1}$$

5.4.2 Detailed Description of Classes

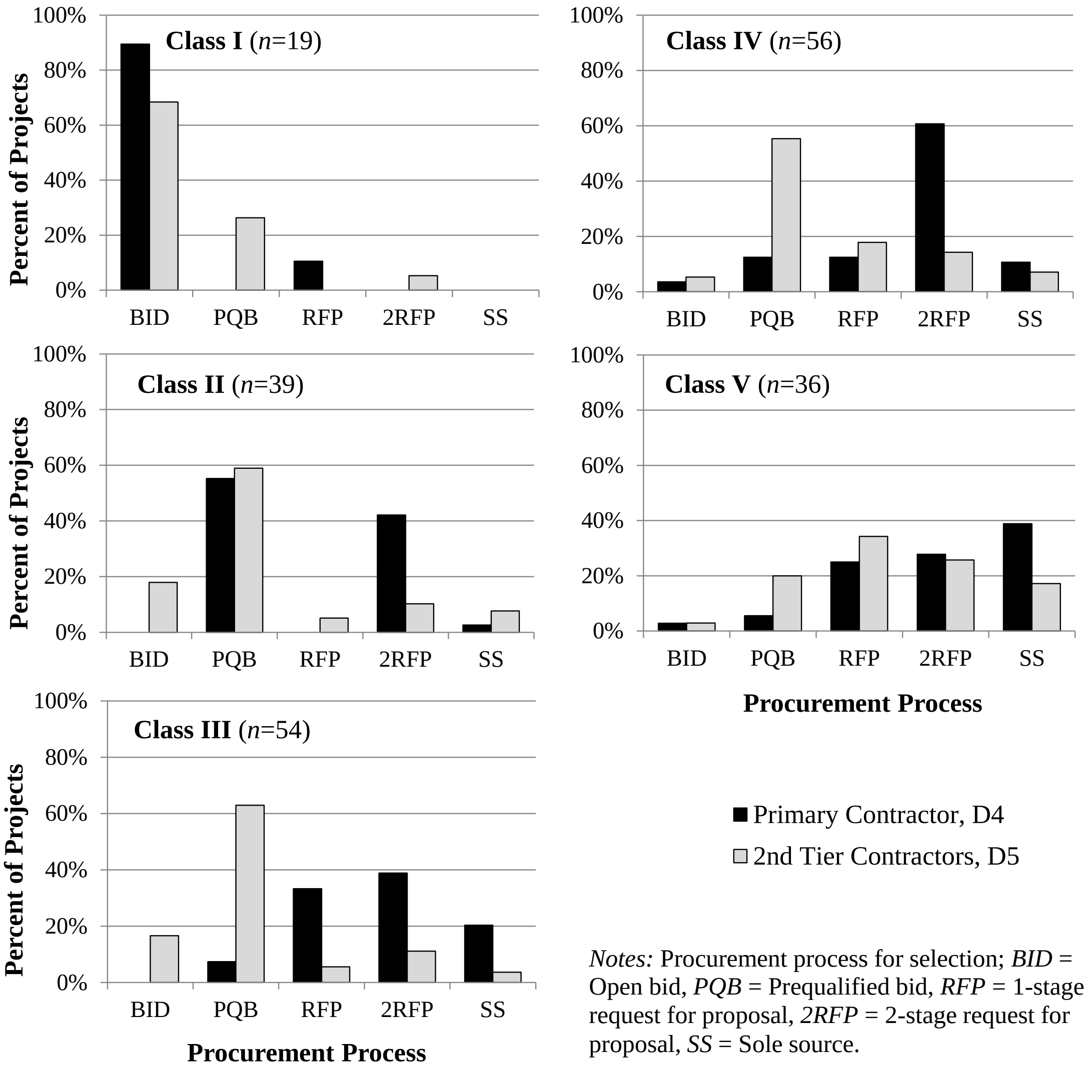
The creation of dichotomous indicators from observed variables was needed to obtain an interpretable latent class model. However, once cases in the data set are assigned to their most likely class, the observed variables may be re-examined to better understand the types of projects grouped within each class. Figure 5-2 summarizes the distribution of timing of involvement, represented by the stages of building design, for the primary contractor (D2) and trade contractors (D3). There is a clear progression of primary contractor involvement, which transitions from the bidding phase in *Class I* (95% of cases in class) to conceptual design and earlier in *Class IV* (86%) and *Class V* (86%). The *Class II* group has no primary contractor involvement prior to design development, whereas *Class III* has less than 20% of cases with the primary contractor involved after schematic design. At the 2nd tier contractor level, which includes MEP and structural trades, involvement during the bidding phase was common in *Class I* (100%), *Class II* (67%) and *Class III* (50%) projects. Trades were involved earliest in *Class IV*, with 52% hired during conceptual design or earlier, and *Class V*, with 86% hired in schematic design or earlier.



Notes: Timing of involvement measured as stage of overall design completion (%); *PRE* = Pre-design (0%), *CONC* = Conceptual design (0-15%), *SD* = Schematic design (15-30%), *DD* = Design development (30-60%), *CD* = Construction documents (60-90%), *BID* = Bidding (100%).

Figure 5-2: Involvement for contractors based on posterior class assignments

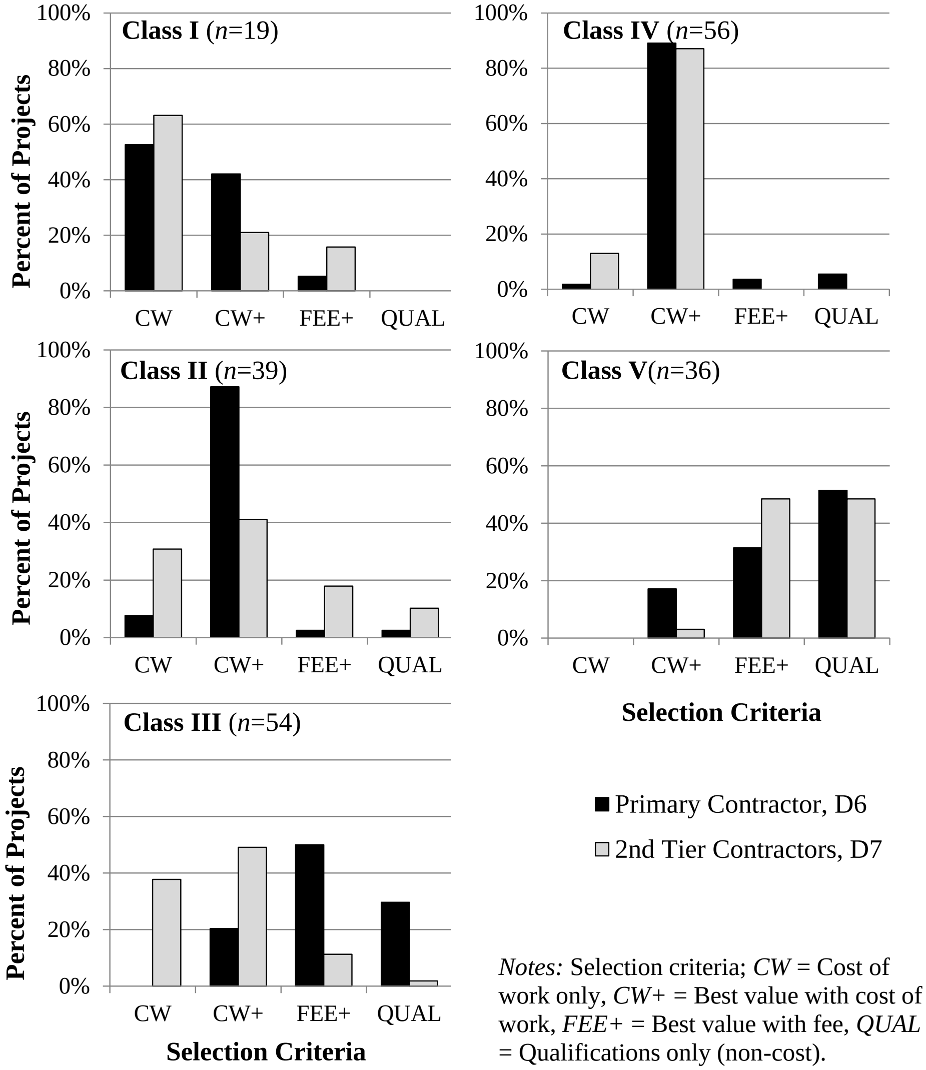
The distribution of procurement processes that was included in the LCA as a prequalification step for the primary contractor (D4) and 2nd tier contractors (D5) is shown in Figure 5-3. The horizontal axis is oriented from no prequalification on the left (Open bid) to full qualification-based procurement on the right (Sole source). *Class I* is entirely composed of projects with no prequalification of the primary contractor, who was procured via open bid (89% of cases in class) or single-stage RFP (11%). *Class II* has a nearly equal representation of prequalified bid (55%) and two-stage RFP (42%) procurement of the primary contractor, while *Class III* is split between single-stage RFP (33%) and two-stage RFP (39%). *Class IV* is highly represented by two-stage RFP (61%) procurement and *Class V* is largely comprised of projects using two-stage RFP (28%) and sole source (39%). Trade contractors were primary procured via open bid in *Class I* (68%), prequalified bid in *Class II* (59%), *Class III* (53%) and *Class IV* (55%), but were more evenly distributed across other methods in *Class V*.



Notes: Procurement process for selection; *BID* = Open bid, *PQB* = Prequalified bid, *RFP* = 1-stage request for proposal, *2RFP* = 2-stage request for proposal, *SS* = Sole source.

Figure 5-3: Procurement process for contractors based on posterior class assignments

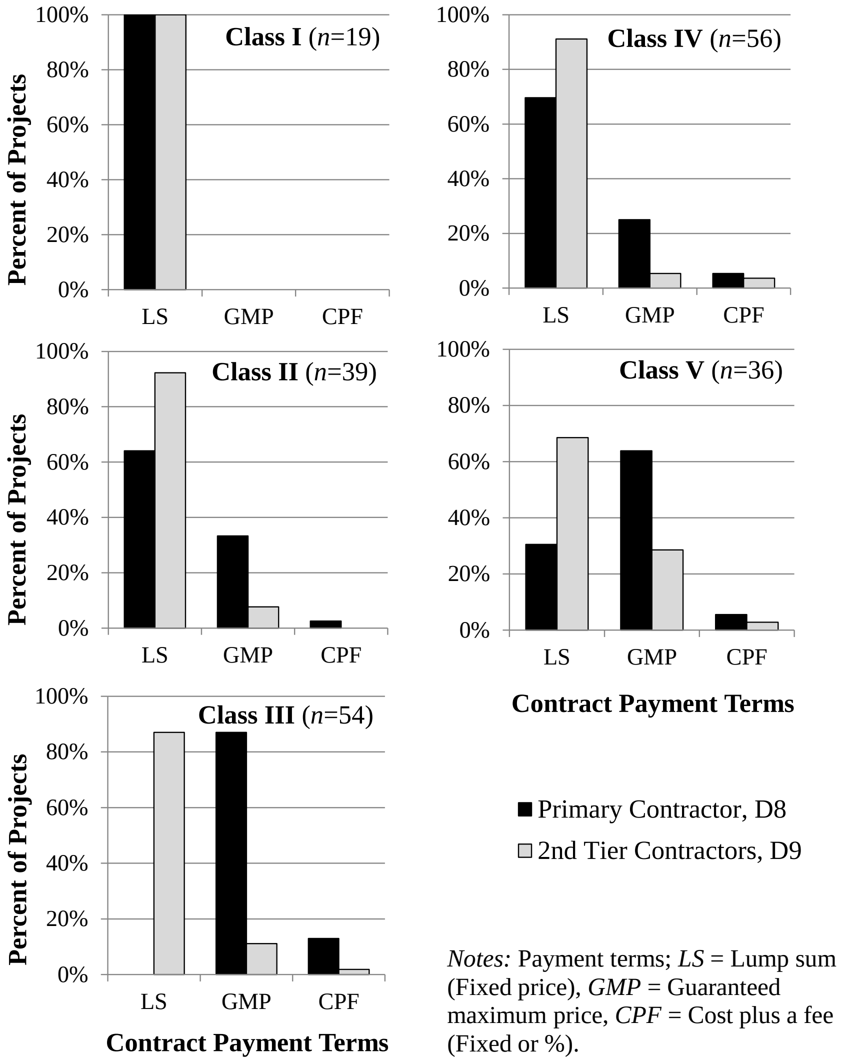
Figure 5-4 illustrates the differences in selection criteria by class for the primary contractor (D6) and 2nd tier trade contractors (D7). Projects classified as *Class I* predominantly selected the primary contractor based on the cost of work (95% of cases in class), either considering cost of work only (53%) or alongside other factors in a best value comparison (42%). *Class II* cases were typically a best value selection focused on the total cost of construction (87%). *Class III* begins to shift away from cost-based selection for the primary contractor and places greater emphasis on best value with fees (50%) and non-cost qualifications (30%). Best value with cost of work was the preferred criteria on *Class IV* (89%) cases, whereas non-cost qualifications were used most frequently in *Class V* (51%). Generally, the 2nd tier trade contractors have similar selection criteria as the primary contractor. The exception was *Class III*, where the trades were selected based on cost of work (38%) or best value with cost of work (49%).



Notes: Selection criteria; *CW* = Cost of work only, *CW+* = Best value with cost of work, *FEE+* = Best value with fee, *QUAL* = Qualifications only (non-cost).

Figure 5-4: Selection criteria for contractors based on posterior class assignments

The distribution of contract payment terms for each class, represented in the LCA as open book or closed book, is illustrated in Figure 5-5. The payment terms for 2nd tier contractors are included in Figure 5-5 for completeness, although the indicator for open book contracts at the trade level (D9) was removed from the LCA. Cost plus a fee payment terms were not common in any class, having a representation of 0% in *Class I*, 3% in *Class II*, 13% in *Class III*, 5% in *Class IV* and 6% in *Class V*. Lump sum terms were most common in *Class I* (100% of cases in class), *Class II* (64%) and *Class IV* (70%). Conversely, 87% of project in *Class II* and 64% in *Class V* had guaranteed maximum price contract terms for the primary contractor.



Notes: Payment terms; *LS* = Lump sum (Fixed price), *GMP* = Guaranteed maximum price, *CPF* = Cost plus a fee (Fixed or %).

Figure 5-5: Payment terms for contractors based on posterior class assignments

5.5 Chapter Summary

The latent class analysis performed for this research revealed five clearly delineated groups that represent different project delivery strategies used by owners. Although several indicators were removed from the analysis for not being strong differentiators of latent class, these indicators may still have a role in project delivery. The latent class approach recognizes that delivery methods, procurement processes and contractual terms are not used independently. In practice, common combinations exist to assist owners in structuring their project organizations. The most common observed variables in each class were organized in Appendix B. The class assignments made during this analysis were used to represent project delivery strategies in the structural model.

Chapter 6

STRUCTURAL MODELING RESULTS

This chapter uses structural equation modeling to describe the relationships among team integration, group cohesiveness and performance outcomes, when controlling for the project delivery strategy, facility size and owner type. A descriptive overview of projects included in the sample data set is presented. The results of the structural modeling process are separated into two sections. First, measurement variables for the latent constructs of *team integration* and *group cohesiveness* are validated using factor analysis techniques. Next, the structural model results for the full project survey data set are reported. Significant path relationships are discussed relative to primary predictors of cost, schedule and quality outcomes, and secondary predictors of team integration and group cohesiveness.

6.1 Data Demographics

Of the 204 verified projects in the data set, 62% were publicly funded and 38% were private. Facilities were classified into one of nine types describing their intended purpose, including: commercial, lodging, office, correctional, educational, manufacturing, sports and recreation, transportation and health care. The most represented facility type was educational, at 27% of the sample, and the least represented was transportation at only 1%. The prevalence of each facility type, roughly ordered from low to high complexity and expressed as a percentage of the total sample, is provided in Figure 6-1. Public owners were most common in educational facilities and least common in health care.

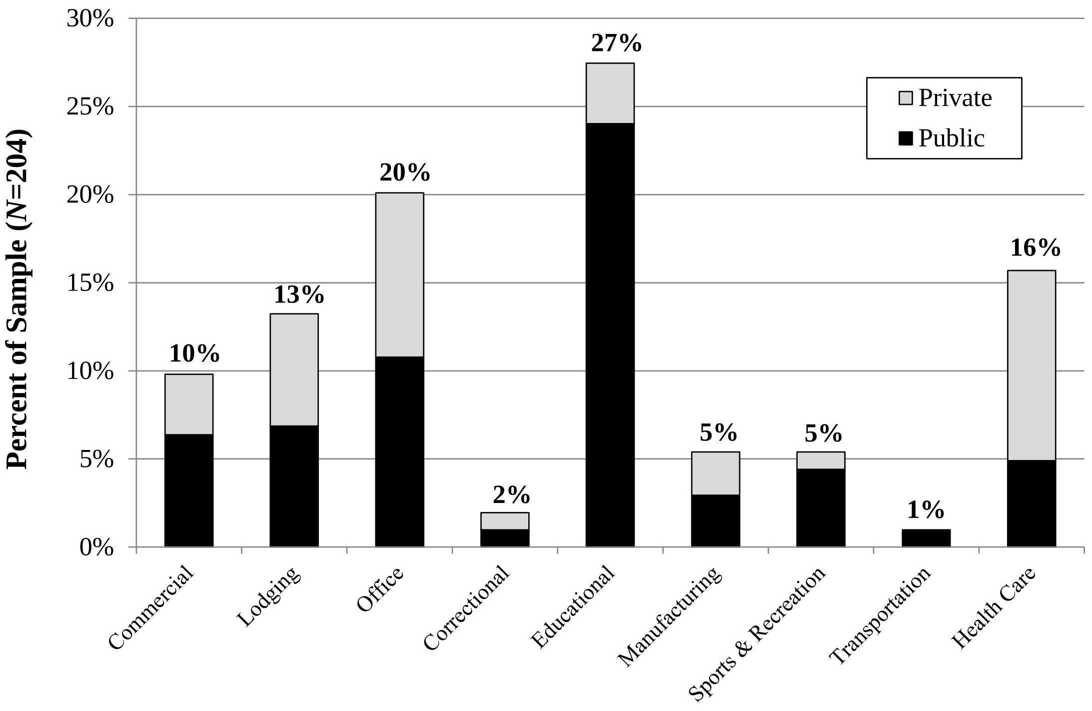


Figure 6-1: Distribution of projects by facility type

Figure 6-2 separates facility types by class of project delivery strategy. Class I delivery is roughly 50% publically funded educational facilities, with lower representation of commercial (16%), health care (16%) and manufacturing (11%). Class II and Class III share a similar distribution of facility types, although Class III has a higher proportion of private owners. The most represented type was educational, at 36% for Class II and 35% for Class III. Educational facilities were less common in Class IV (14%) and Class V (17%) delivery strategies. The Class IV is predominantly office (23%) and lodging (19%) facilities, while the Class V is mainly health care (25%) and office (22%). Class III and Class V had the lowest proportion of public owners.

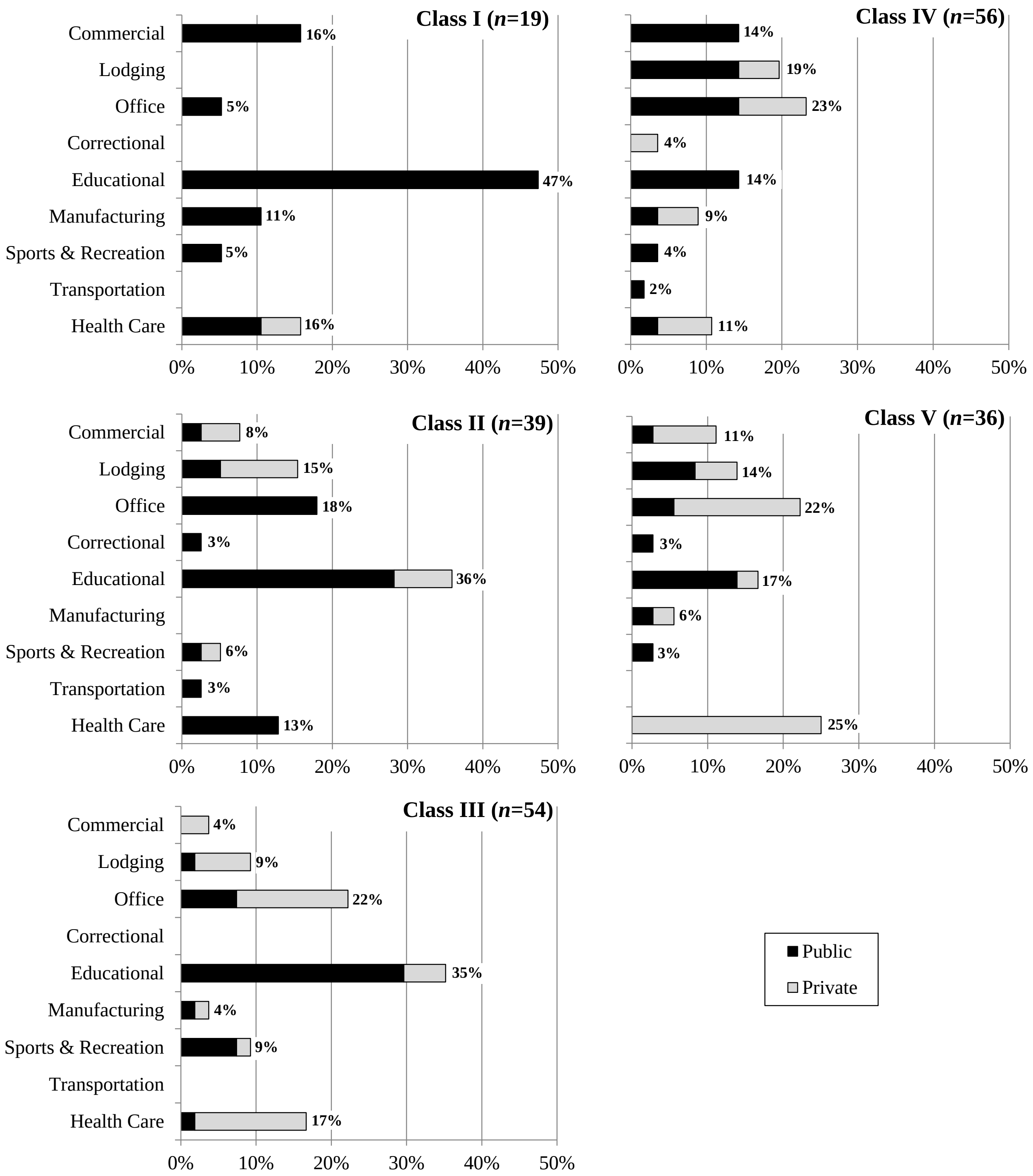


Figure 6-2: Distribution of facility type by class of project delivery strategy

Projects ranged in size from 5,000 square feet to over 1-million, although approximately 60% were less than 200,000 square feet. The distribution of facility size by funding source is shown in Figure 6-3. With the exception of the first and last categories, the facility size is grouped in 100,000 square foot increments. The first category identifies small projects, less than 50,000 square feet, and represents 27% of the sample. The last category captures the 2% of the sample and represents very large projects with over 1-million square feet. Compared against the sample proportion of owner types, public owners were less common on small (55%) and very large projects (43%) and more common on projects between 150,000 (70%) and 350,000 (71%) square feet. Since this distribution ranges over several orders of magnitude and is positively skewed, logarithmic transformations of base 10 were performed prior to structural modeling.

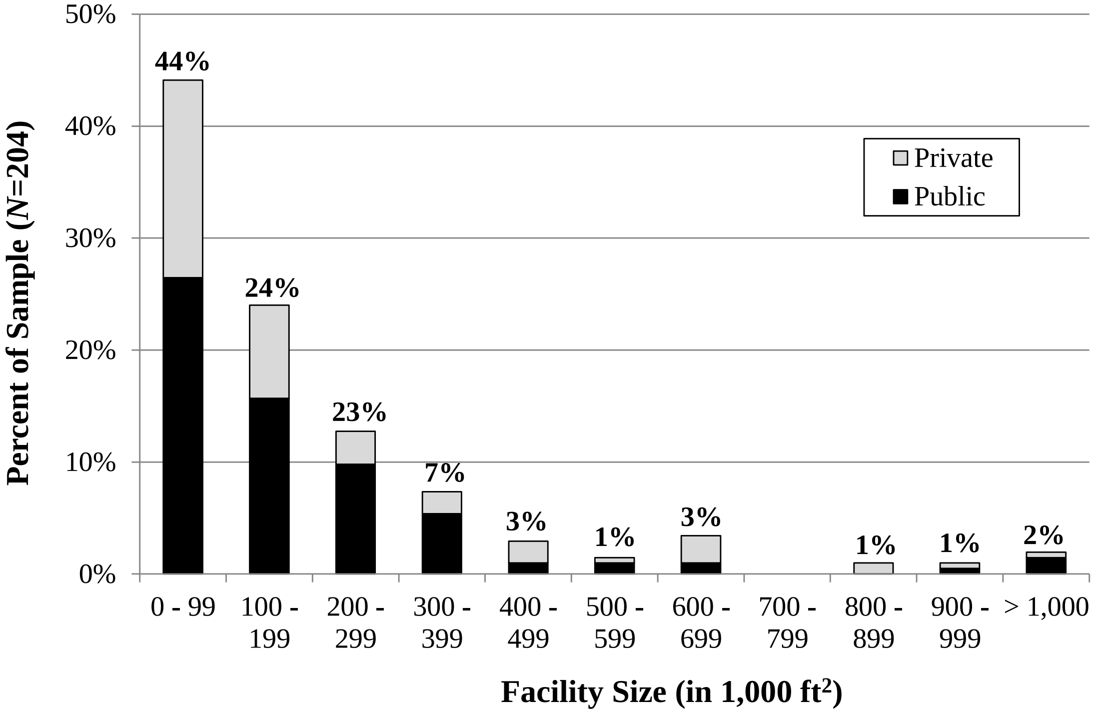


Figure 6-3: Distribution of project size by square footage

Projects were distributed across the continental United States. As shown in Figure 6-4, the largest percentages of projects were located Pennsylvania, Colorado and California. There was strong coverage in the Midwest and South Central regions, but very few surveys were returned with projects from the North Central states. The sample was geographically broad and not focused on any single region in the United States.

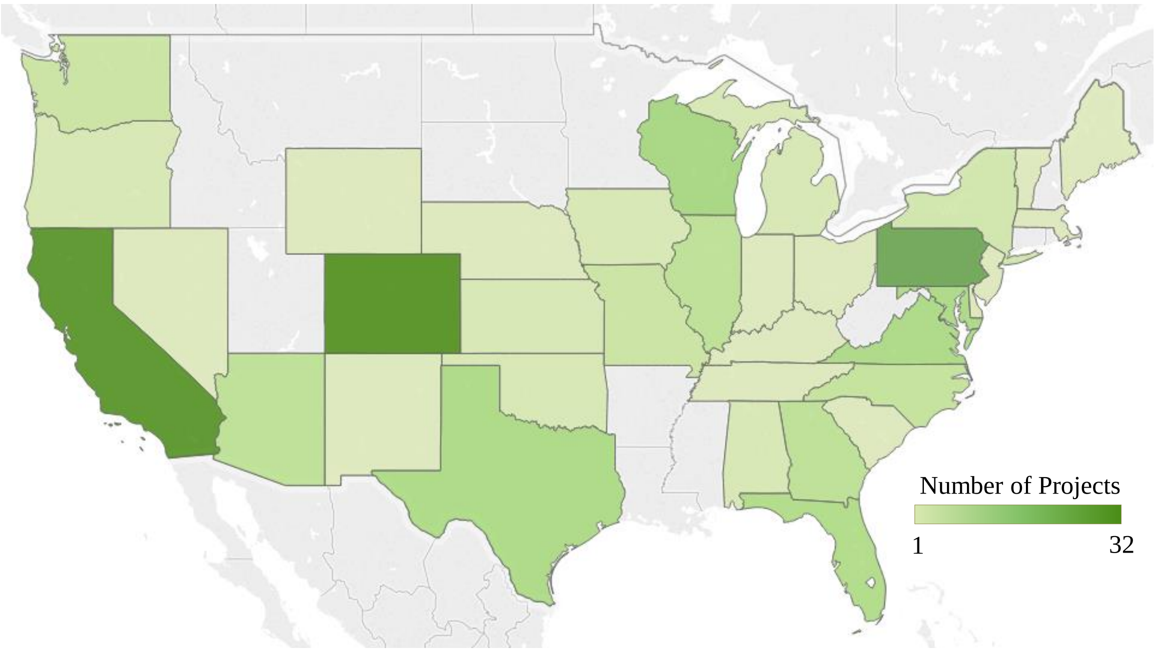


Figure 6-4: Distribution of sample projects across the United States

The unit cost of projects ranged from $50 per square foot to over $1,200, with 55% reporting less than $400 per square foot. All unit costs were adjusted for time and location. Using the historical Building Cost Index (BCI) reported monthly by the Engineering News Record (ENR), all project costs were adjusted for material and labor price fluctuations between their start of construction and June 2014. Location factors provided by RSMeans 2014 guidebooks were used to adjust for differences in regional design and construction costs. Figure 6-5 illustrates the unit cost distribution, with categories in $100 per square foot increments. Only 3% had unit costs less than $100 per square foot and were split evenly between public and private ownership. However, the 9% of projects with unit costs exceeding $800 per square foot were predominantly public (89%). Private funding was most common in projects costing less than $300 per square foot, but was present in all ranges of unit price. Since unit cost is a function of facility size and the distribution is similarly positively skewed, unit cost values were transformed using a base 10 logarithm prior to analysis. Descriptive statistics of the mean, median and range of each performance measure is provided in Appendix C.

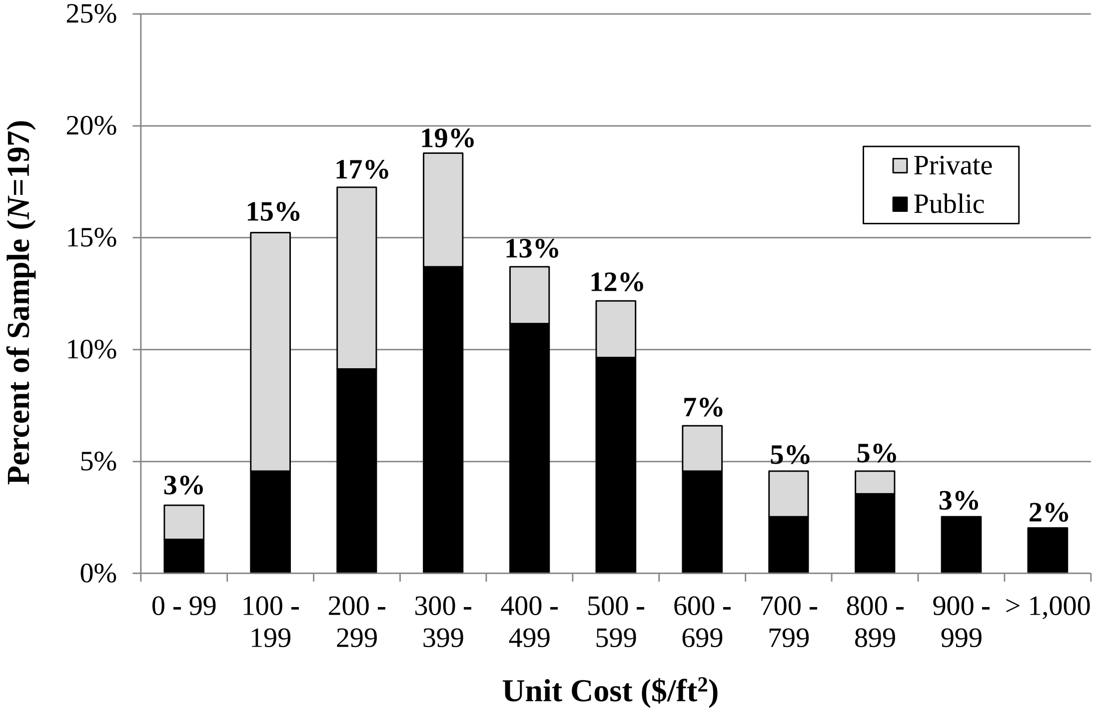


Figure 6-5: Distribution of project unit cost in dollars per square foot

6.2 Construct Validity of Latent Factors

As discussed in Chapter 3, the conceptual model for this research posits two latent constructs for the project team that contribute to project performance outcomes. *Group cohesiveness* represents the level of development attained by the team while delivering of the facility. This construct was measured by ratings of timeliness of communication, commitment to project goals, team chemistry, frequency of compromise and formality of communication. *Team integration* represents the team’s involvement in high-quality, collaborative interactions and was measured by the number of BIM uses on the project, level of offsite prefabrication and proportion of the team participating in: BIM planning, joint goal setting, design charrettes and construction-phase co-location. This section assesses the validity of these measurement variables in reflecting the underlying latent construct by:

1) Reviewing a correlation matrix for expected inter-correlations of measurement variables within each latent construct;
2) Assessing the initial model fit of measurement variables on the theorized 2-factor model with a confirmatory factor analysis (CFA);
3) Using exploratory factor analysis (EFA) to identify poorly fitting variables that are not reflective of the desired latent constructs; and
4) Re-visiting the 2-factor CFA with a validated list of measurement variables.

6.2.1 Measurement Variable Correlations

Correlations among variables are of primary interest in factor analysis, which groups highly inter-correlated variables into fewer number unobserved, latent factors. Polychoric correlations were calculated to avoid attenuation, since this data consisted of ordinal rating scales and proportions. Separated by theorized latent constructs, the correlation matrix for the measurement variables in this study is shown in Table 6-1. Cohen's (2013) guidelines are used for interpreting the effect size of correlations. A correlation coefficient of .10 is a weak or small association, .30 is considered moderate and greater than .50 is a strong or large correlation. There are strong correlations among timeliness of commitment (TE1), commitment to project goals (TE2) and team chemistry (TE3). However, frequency of compromise (TE4) and formality of communication (TE5) do not appear related with other measures of *group cohesiveness*. For *team integration*, the number of BIM uses (TI2) and participation in BIM planning (TI1), goal setting (TI3), design charrettes (TI4) and co-location (TI5) are moderately inter-correlated. The level of offsite prefabrication (TI6) is unrelated to team participation in design charrettes and co-location. Lastly, there are weak to moderate correlations between variables across the *group cohesiveness* and *team integration* constructs.

Table 6-1: Correlation coefficients for team measures

Measure	**TE1**	**TE2**	**TE3**	**TE5**	**TE5**	**TI1**	**TI2**	**TI3**	**TI4**	**TI5**	**TI6**
Group cohesiveness											
TE1. Timeliness of communication	1										
TE2. Commitment to project goals	**.64**	1									
TE3. Team chemistry	**.62**	**.64**	1								
TE4. Frequency of compromise	**.25**	.12	.23	1							
TE5. Formality of communication	.09	.03	.02	.01	1						
Team integration											
TI1. Participation in BIM planning	.09	**.22**	.16	.05	-.04	1					
TI2. Number of BIM uses	**.19**	**.20**	**.28**	.10	.00	**.64**	1				
TI3. Participation in goal setting	.13	**.22**	**.20**	**.24**	-.16	**.34**	**.35**	1			
TI4. Participation in design charrettes	.13	**.21**	**.19**	.01	-.13	**.23**	**.35**	**.30**	1		
TI5. Participation in co-location	.09	.11	**.18**	.01	-.11	**.28**	**.26**	**.28**	**.24**	1	
TI6. Offsite prefabrication	.06	.14	**.26**	.04	-.05	**.26**	**.22**	.14	.13	**.15**	1

Notes: Polychoric correlations using robust weighted least squares (WLSMV) estimation with pairwise deletion of missing values; Bolded correlations are significant, *p*<.05.

6.2.2 Initial Confirmatory Factor Analysis

Confirmatory factor analysis (CFA) tests whether the measurement variables of a construct or “factor” are consistent with a hypothesized model. In this research, CFA is used to assess a model that considers variables TE1-TE5 as measures of the *group cohesiveness* and TI1-TI6 as measures of the *team integration*. Two fit indices were selected to test whether the CFA model represents the data set: the root mean square error of approximation (RMSEA) and comparative fit index (CFI). RMSEA is a measure of model misspecification that considers the number of variables in the model. Well-fitting models have RMSEA less than .08 (Hooper, Coughlan and Muller 2008). The CFI compares the specified model against a baseline model that assumes no correlation among observed variables. The resulting index is a value between 0 and 1, with values at .95 and above indicating a good fit (Hu and Bentler 1999). For this research, the fit indices for an initial 2-factor confirmatory model exceeded the required levels of fit

(CFI=.97, RMSEA=.03), but closer inspection revealed that several variables are not reflective of the proposed latent constructs. Specifically, low standardized regression coefficients were found for frequency of compromise (.27), formality of communication (.01) and offsite prefabrication (.35). When considered alongside similar observations in the correlation matrix, there is evidence of these three variables having poor association with their theorized factors.

6.2.3 Exploratory Factor Analysis

Evidence of poor association in a CFA suggests that either (1) some measurement variables are not reflective of the theorized latent factor, or (2) the variables are better represented by a different number of underlying factors. Exploratory factor analysis (EFA) is used to determine the minimum number of latent factors that adequately describe correlations in a set of measurement variables. Unlike CFA, no preset structure is imposed that forces variables to group with a specific factor. This EFA was conducted using robust weighted least squares (WLSMV) estimation and Geomin oblique rotation for 1-, 2-, and 3-factor solutions. An oblique rotation was selected to allow the extracted factors to correlate, which is expected in the theoretical model being tested. The 1-factor solution is a poor fit (CFI=.77, RMSEA=.10) and the 3-factor solution offers only a small improvement (ΔCFI=.01, ΔRMSEA=.03) over the 2-factor at the cost of added model complexity. This comparison confirms that the set of measurement variables (TE1-TE5, TI1-TI6) are adequately represented by a 2-factor latent model.

The 2-factor EFA solution identifies three poorly fitting variables across both latent constructs. For a sample size of 200, variables should achieve a rotated loading of at least .40 to be considered reflective of the underlying factor (Stevens 2012). As shown in Table 6-2, the frequency of compromise (TE5) and level offsite prefabrication (TI6) have rotated loadings below .30 on Factor #1 and Factor #2, respectively. Formality of communication (TE5) has weak loadings across both factors, at .14 on Factor #1 and -.20 on Factor #2. Therefore, these three measurement variables do not appear to reflect the same latent factors as TE1-TE3 and TI1-TI5, and should be removed to improve the validity of the constructs.

Table 6-2: Rotated loadings for 2-factor EFA of team measures

		Factor	
Theorized Factor	**Components**	1	2
Group cohesiveness	TE1. Timeliness of communication	.87	-.16
	TE2. Commitment to project goals	.80	.01
	TE3. Team chemistry	.77	.05
	TE4. Frequency of compromise	.24	.05
	TE5. Formality of communication	.14	-.20
Team integration	TI1. Participation in BIM planning	-.07	.67
	TI2. Number of BIM uses	.02	.66
	TI3. Participation in goal setting	.01	.58
	TI4. Participation in design charrettes	.02	.47
	TI5. Participation in co-location	-.05	.47
	TI6. Offsite prefabrication	.06	.29

Notes: Goodness-of-fit summary: CFI=.98, RMSEA=.04; EFA with robust weighted least squares (WLSMV) estimation and oblique rotation. Loadings greater than .40 are highlighted to aid in interpretation.

6.2.4 Poorly Fitting Measurement Variables

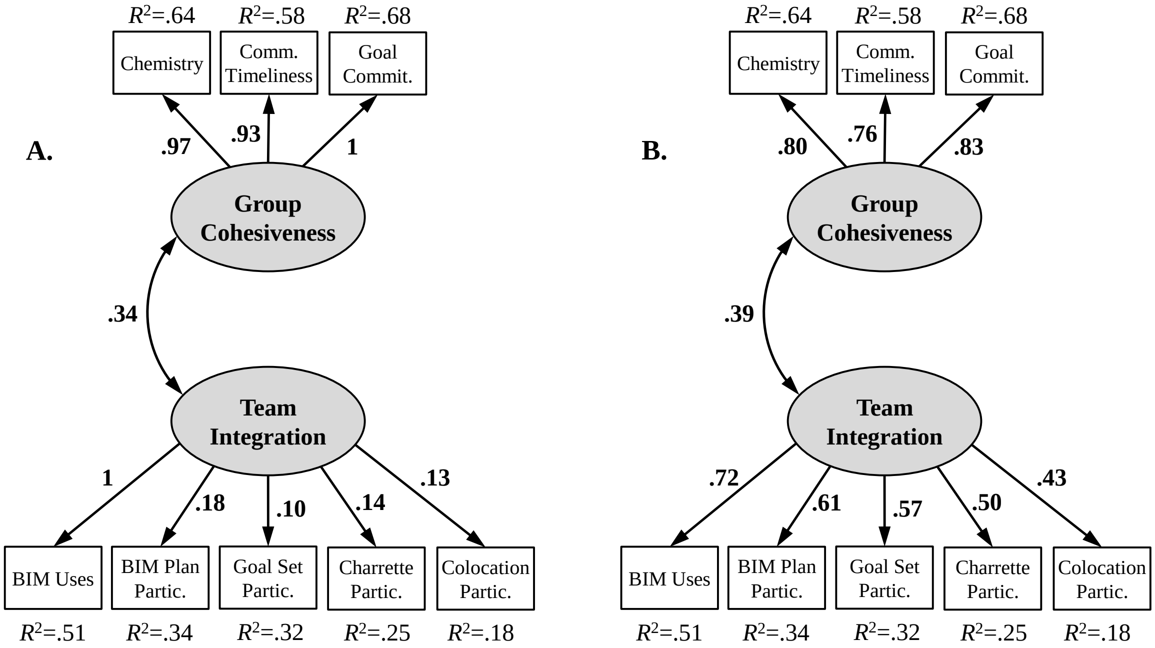
Poorly fitting variables in a factor analysis are unreliable in providing information about the underlying latent construct. However, removing the variables for frequency of compromise (TE4), formality of communication (TE5) and offsite prefabrication (TI6) from their respective latent constructs does *not* suggest that theories supporting the inclusion of these variables are invalid. Compromise and formality of interactions have reasonable, theoretical justification in literature for being considered a product of the group cohesiveness. Likewise, offsite prefabrication and modularization of building systems often benefit from more integrated teams.

In this research, the lack of measurement reliability in TE4, TE5 and TI6 was likely the result of unclear survey questions. For example, respondent ratings to the question “How often did the project team compromise on project issues?” are biased by whether they perceive compromise as a positive or negative influence. Taking a positive perspective, compromise allows the team to move forward with design options or construction plans that strike a balance between the competing interests of each participant. Alternately, compromise may be viewed negatively, as a sub-optimal solution where no one is satisfied and the project suffers as a result. Since no definition of comprise was provided with the survey, both perspectives are represented in the data set, leading to inconsistent measurements. A similar susceptibility to respondent bias can be observed in evaluating communication formality. Without a strict definition for “formal” and “informal”, the question lacked objectivity and was too open to respondent interpretation. Lastly, responses from owners may lack the perspective to provide an accurate assessment on the level of offsite prefabrication on their project. Unless the specification explicitly calls for prefabricated or modularized systems, the decision to use offsite resources often lies with the primary contractor and specialty trades. Therefore, the question regarding offsite prefabrication was likely inappropriate for owners as the targeted survey response group.

6.2.5 Revised Confirmatory Factor Analysis

After removing poorly fitting variables, a second CFA was conducted to verify the final factor structure. Illustrated in Figure 6-6, with both standardized and unstandardized coefficients, the 2-factor model of *group cohesiveness* and *team integration* is well representative of the data (CFI=1.0, RMSEA=.00). The large standardized regression coefficients on the measurement variables for *group cohesiveness* construct indicate that team chemistry (.80), timeliness of communication (.76) and goal commitment (.83) are reflective of the same underlying latent variable. Similarly, the CFA produced moderate to large coefficients for variables measuring *team integration*, including the number of BIM uses (.72), participation in BIM planning (.61), goal setting

(.57), design charrettes (.50) and co-location (.43). Lastly, as expected from the theoretical model, the latent constructs are positively correlated.



Notes: Goodness-of-fit summary: $\chi^2_{(204)}$/df=16.6, *p*=.62, CFI=1.0, RMSEA=.00

Figure 6-6: Revised CFA with unstandardized (A) and standardized (B) estimates

6.3 Factoring Performance Outcomes

Although not explicitly theorized, the correlations among performance outcomes were examined for the presence of underlying latent factors. A correlation matrix for cost and schedule metrics, as well as facility quality ratings is provided in Table 6-3. Since these measures are a combination of continuous and ordinal data, polychoric correlation coefficients were calculated and interpreted similarly to previous discussions of correlation. There are strong correlations between unit cost and intensity (.59), and between delivery speed and construction speed (.95). Both relationships are expected, since intensity is a function of unit cost and the construction duration is a subset of the project duration. While each pair of correlated metrics could be reduced to a single factor, there is little improvement to model interpretability when introducing additional factors with only two measurement variables. However, the pattern of correlations among quality ratings suggests the influence of one or more latent factors. The moderate to strong inter-correlations among ratings for difficulty of start-up, magnitude of call backs and operation costs (.48 to .68) seem to reflect the owner's *turnover experience*. And the large correlations among ratings for the quality of structure and envelope, interior finishes and environmental systems (.56 to .62) are indicative of the facility's *system quality*.

Table 6-3: Correlation coefficients for project performance variables

Measure	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Project performance												
1. Unit cost (Log)	1											
2. Intensity (Log)	**.59**	1										
3. Project cost growth	.03	-.13	1									
4. Delivery speed (Log)	-.26	-.14	-.06	1								
5. Construction speed (Log)	-.26	-.28	-.04	**.95**	1							
6. Project schedule growth	.09	-.15	**.19**	-.16	-.15	1						
Facility quality												
7. Difficulty of start-up	-.27	-.07	-.24	.02	-.03	-.11	1					
8. Magnitude of call backs	-.22	-.02	-.29	.05	.01	-.21	**.68**	1				
9. Operation costs	-.16	-.10	-.21	-.01	-.05	-.11	**.48**	**.60**	1			
10. Structure and envelope	.04	-.11	-.14	**.26**	**.27**	-.08	.17	.17	**.26**	1		
11. Interior finishes	**.15**	-.17	.12	.13	**.17**	.04	.02	.08	**.26**	**.58**	1	
12. Environmental systems	.04	-.09	-.14	.17	**.18**	-.13	.13	**.34**	**.38**	**.62**	**.56**	1

Notes: Polychoric correlations using robust weighted least squares (WLSMV) estimation with pairwise deletion of missing values; Bolded coefficients are significant, *p*<.05

An EFA was performed on the six quality measures to determine if the inter-correlations may be explained by one or more latent factors. The 1-factor model was a very poor fit (CFI=.78, RMSEA=.31), but the 2-factor solution was adequate (CFI=.99, RMSEA=.07). Shown in Table 6-4, difficulty of start-up (Q1), magnitude of call backs (Q2) and operation costs (Q3) have rotated loadings of .60 or greater in Factor #1 and the quality of structure and envelope (Q4), interior finishes (Q5) and environmental systems (Q6) have rotated loadings on .75 of greater in Factor #2. This is reasonable evidence to support the use of two continuous latent factors, *turnover experience* and *facility quality*, as representative of quality performance outcomes.

Table 6-4: Rotated loadings for 2-factor EFA of quality ratings

		Factor	
Theorized Factor	**Components**	1	2
Turnover experience	Q1. Difficulty of start-up	.76	-.06
	Q2. Magnitude of call backs	.92	.00
	Q3. Operation costs	.60	.23
Facility quality	Q4. Structure and envelope	.00	.78
	Q5. Interior finishes	-.11	.77
	Q6. Environmental systems	.12	.75

Notes: Goodness-of-fit summary: CFI=.99, RMSEA=.07; EFA with robust weighted least squares (WLSMV) estimation and oblique rotation. Loadings greater than .40 are highlighted to aid in interpretation.

6.4 Specifying the Structural Model

Due to the flexibility of structural model specification, a variety of models can be conceived. As discussed in Chapter 4, the framework for this research contained three focal blocks: (1) the project delivery strategy, (2) the quality of inter-organizational relationships, as represented by constructs of team integration and group cohesiveness, and (3) the project's performance. Programming factors, including owner type and facility size, were seen as control variables. Several structural models, assembled from two or more of these focal blocks, were explored for both model fit and predictive capability. The specification of these model alternatives is shown in Figure 6-7.

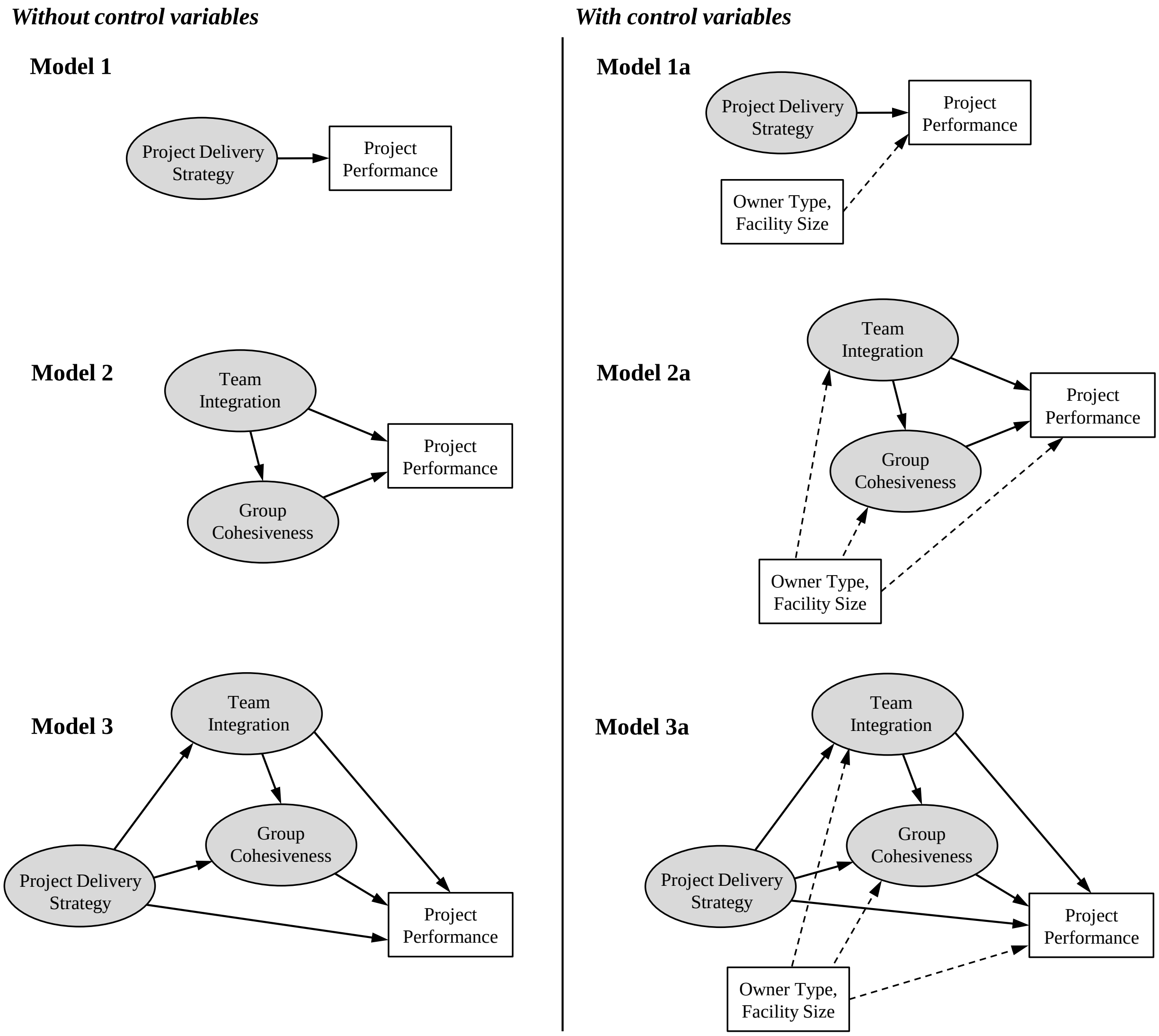


Figure 6-7: Specification of structural model alternatives

The model alternatives were separated into two groups, one including control variables (Models 1a, 2a, 3a) and the other without (Models 1, 2, 3). Models 1 and 1a approximate the relationships often tested in project delivery literature, where project performance is seen to vary by delivery method. Models 2 and 2a suggest that project performance is dependent on team integration and group cohesiveness, without accounting for differences in project delivery strategy. Lastly, Models 3 and 3a are holistic representations that combine all three focal blocks from the theoretical framework. Fit indices and measures of the predictive capability for each dependent variable (R^2) were calculated for each model configuration.

The goodness-of-fit indices for these model alternatives are provided in Table 6-5. All model alternatives achieved the minimum fit criteria for this study. Model 2 was the overall best fit (CFI=.99, RMSEA=.01), and Models 1 (CFI=.96, RMSEA=.05) and 1a (CFI=.97, RMSEA=.06) were comparatively the weakest. Model 3a, with the most variables and path relationships, was in the middle of the range for fit indices (CFI=.99, RMSEA=.03). The addition of control variables improved the CFI for all models. The RMSEA, which favors parsimony and fewer estimated parameters in the model, was slightly worsened with addition of control variables. These goodness-of-fit indices reflect the specified model's ability account for the sample covariance. However, structural models may have a strong fit to the data without having much predictive capability on the dependent variables.

Table 6-5: Fit indices of structural model alternatives

	Fit Indices			
Model Specification	χ^2	df	CFI	RMSEA
Models without control variables				
Model 1: Project delivery strategy	68.6	48	.96	.05
Model 2: Team integration, group cohesiveness	134.2	131	.99	.01
Model 3: Project delivery strategy, team integration, group cohesiveness	180.4	171	.99	.02
Models with control variables				
Model 1a: Project delivery strategy, *controls*	96.4	56	.97	.06
Model 2a: Team integration, group cohesiveness, *controls*	164.5	151	.99	.02
Model 3a: Project delivery strategy, team integration, group cohesiveness, *controls*	218.2	191	.99	.03

For each model alternative, the percent of variance explained for each dependent variable (R^2) is summarized in Table 6-6. Although Model 2 had the best overall fit, its usefulness as a predictor of project performance was very low, explaining only 6% of the variance in cost growth and 5% in schedule growth. The addition of control variables into the model greatly improved the prediction of delivery and construction speeds, improving their respective R^2 from 8% to 84% in the most extreme case. Team integration and group cohesiveness were most influential in predicting cost growth, schedule growth, system quality and turnover experience. Model 3a consistently explained a larger percent of variance than the alternative models, and when considered alongside strong fit indices, was the model specification used in this research.

Table 6-6: Predictive capability of structural model alternatives

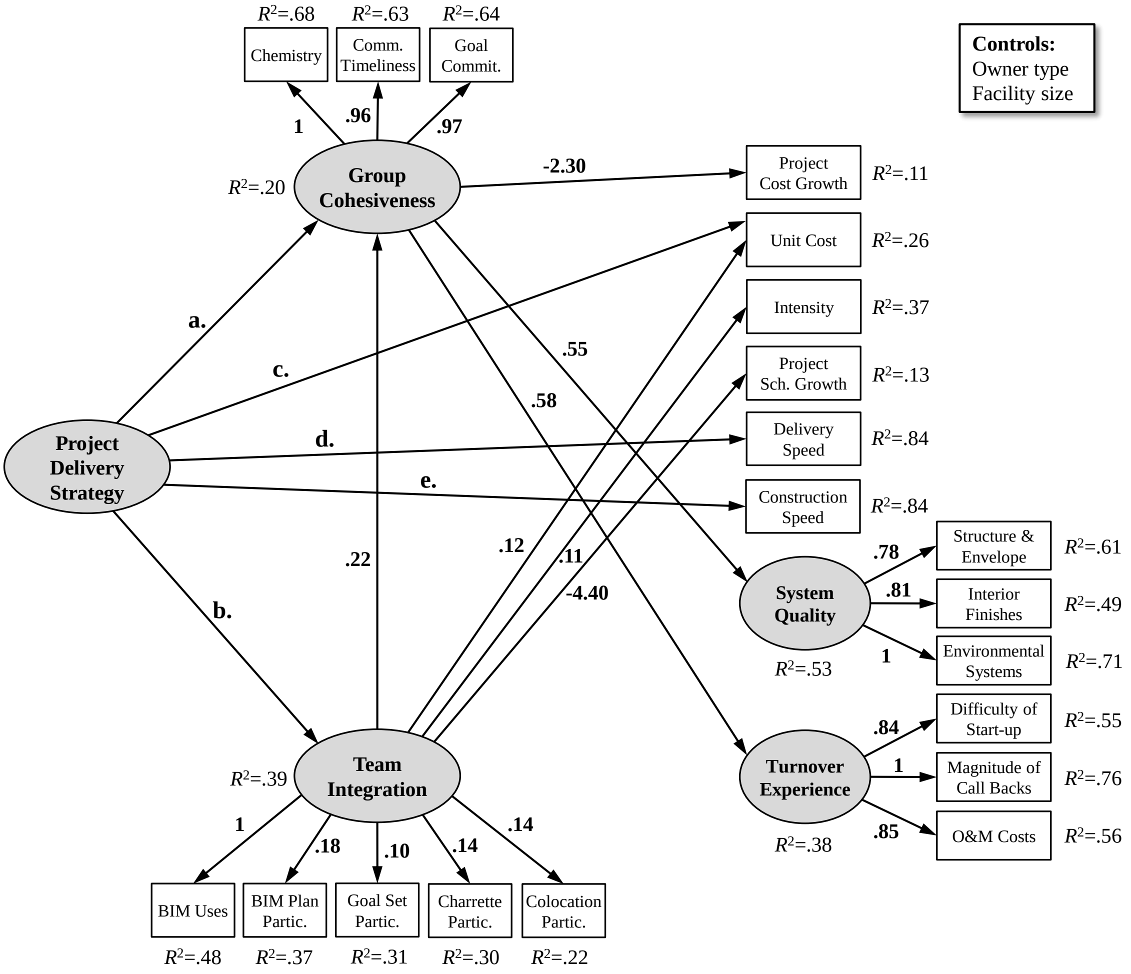
	Predictive Capability (R^2)					
	Without control variables			*With control variables*		
Model Variable	**Model 1**	**Model 2**	**Model 3**	**Model 1a**	**Model 2a**	**Model 3a**
Team integration	--	--	.28	--	.16	.46
Group cohesiveness	--	.15	.19	--	.15	.20
Project cost growth	.03	.06	.09	.05	.08	.11
Unit cost	.02	.07	.15	.12	.20	.25
Intensity	.09	.05	.11	.26	.33	.25
Project schedule growth	.01	.05	.08	.04	.08	.14
Delivery speed	.13	.19	.20	.84	.79	.84
Construction speed	.08	.14	.15	.84	.83	.84
System quality	.12	.42	.53	.21	.44	.51
Turnover experience	.07	.26	.29	.12	.35	.38

6.5 Primary Structural Model Results

The presentation and discussion of structural model results is separated into two sections. First, primary results will examine predictors of cost, schedule and quality performance within the context of the structural model. Then, secondary results will consider the predictors of *team integration* and *group cohesiveness* as intermediate outcomes. The structural model was calculated using MPlus Version 7.2 statistical software with robust weighted least square (WLSMV) estimation of regression paths. The discrete classes of project delivery strategies from Chapter 5 were split into five dummy coded variables, with Class I delivery serving as the baseline for comparison.

Logarithmic transformations were used for variables that were a function of the gross square-footage of the facility, such as unit cost or delivery speed. These variables tended to have non-constant variance that increased with facility size. Prior to interpreting the results of transformed regression coefficients, the coefficients were back-transformed as the percent change in a dependent variable, given a one unit change in the independent variable.

The calculated structural model diagram is presented in Figure 6-8, with unstandardized coefficients, and Figure 6-9, with standardized values. For simplicity, only significant paths are shown in these diagrams ($p<.05$) and the classes of project delivery strategy are represented by a single categorical latent variable. For primary or secondary outcomes that varied by project delivery strategy, path coefficients and significance tests are provided in the table below the model diagram. All latent constructs and outcome variables were controlled for by owner type and facility size. A complete diagram of the structural model that includes insignificant paths, control variable paths and dummy coded variables is provided in Appendix D. All discussion of model results will use the unstandardized coefficients from Figure 6-8 to facilitate direct interpretation.



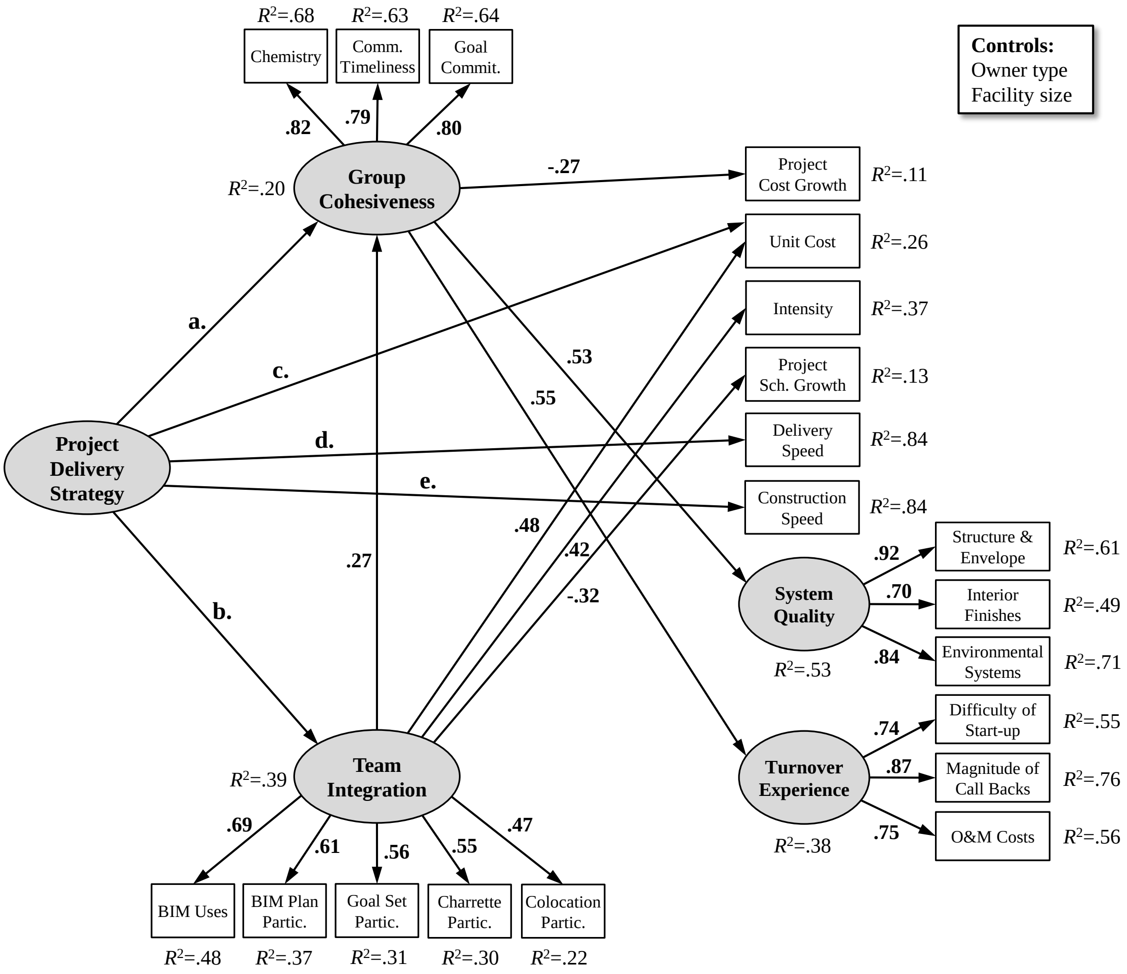
Notes: (→) denotes a significant path, $p<.05$; Goodness-of-fit summary: $\chi^2_{(204)}$/df=218.2, p=.09, CFI=.98, RMSEA=.03

Standardized estimates by latent class of Project Delivery Strategy (paths marked **a.** - **e.**) are summarized in the table below.

Regression Path	Estimate	S.E.	*p*-value
a. *Group Cohesiveness* ON			
Class II	.40	.28	.15
Class III	.59	.31	.06
Class IV	.49	.31	.11
Class V	.78	.32	.01
Facility size (Log)	.12	.15	.43
Public owner	.08	.15	.59
b. *Team Integration* ON			
Class II	.59	.36	.10
Class III	1.35	.38	.00
Class IV	1.65	.39	.00
Class V	1.53	.41	.00
Facility size (Log)	.67	.16	.00
Public owner	.34	.18	.05

Regression Path	Estimate	S.E.	*p*-value
c. *Unit Cost (Log)* ON			
Class II	-.05	.09	.61
Class III	-.13	.09	.17
Class IV	-.23	.09	.01
Class V	-.18	.10	.06
Facility size (Log)	-.10	.04	.01
Public owner	.15	.04	.00
d. *Delivery Speed (Log)* ON			
Class II	.07	.06	.23
Class III	.14	.06	.01
Class IV	.33	.06	.00
Class V	.28	.06	.00
Facility size (Log)	.81	.03	.00
Public owner	-.07	.03	.01
e. *Construction Speed (Log)* ON			
Class II	.02	.05	.71
Class III	.08	.06	.20
Class IV	.17	.06	.00
Class V	.10	.05	.07
Facility size (Log)	.91	.02	.00
Public owner	-.11	.03	.00

Figure 6-8: Unstandardized estimates for structural model paths



Notes: (⟶) denotes a significant path, *p*<.05; Goodness-of-fit summary: $\chi^2_{(204)}$/df=218.2, *p*=.09, CFI=.98, RMSEA=.03

Standardized estimates by latent class of Project Delivery Strategy (paths marked **a.** - **e.**) are summarized in the table below.

Regression Path	Estimate	S.E.	*p*-value
a. *Group Cohesiveness* ON			
Class II	.18	.13	.15
Class III	.30	.15	.05
Class IV	.26	.16	.11
Class V	.34	.14	.01
Facility size (Log)	.07	.09	.43
Public owner	.04	.08	.59
b. *Team Integration* ON			
Class II	.22	.13	.09
Class III	.56	.14	.00
Class IV	.70	.13	.00
Class V	.55	.13	.00
Facility size (Log)	.32	.07	.00
Public owner	.16	.08	.04

Regression Path	Estimate	S.E.	*p*-value
c. *Unit Cost (Log)* ON			
Class II	-.07	.13	.61
Class III	-.21	.15	.17
Class IV	-.38	.15	.01
Class V	-.26	.14	.06
Facility size (Log)	-.18	.07	.01
Public owner	.26	.07	.00
d. *Delivery Speed (Log)* ON			
Class II	.06	.05	.23
Class III	.13	.05	.01
Class IV	.31	.06	.00
Class V	.23	.05	.00
Facility size (Log)	.87	.03	.00
Public owner	-.08	.03	.01
e. *Construction Speed (Log)* ON			
Class II	.02	.05	.71
Class III	.08	.06	.20
Class IV	.17	.06	.00
Class V	.10	.05	.07
Facility size (Log)	.91	.02	.00
Public owner	-.11	.03	.00

Figure 6-9: Structural model diagram and results with standardized estimates

6.5.1 Cost Performance

Cost performance was measured using three metrics: project cost growth, unit cost and intensity. These metrics were treated as separate dependent variables in the structural model and regressed on the latent constructs of project delivery strategy, team integration and group cohesiveness. The owner type and facility size were included in the model to control for funding source and project scale, respectively. In this manner, the significant effects of the latent constructs on cost performance were separated from the effects of other explanatory variables. A *p*-value of .05 was selected as the cut-off for determining statistical significance.

Project cost growth was defined as the percent difference between the actual and planned costs of design and construction services. Group cohesiveness was the only significant predictor of project cost growth (*p*=.00), when controlling for project delivery strategy, team integration, owner type and facility size. Improving the group cohesiveness by one unit, reduced the mean cost growth by 2.3%; although the overall variation explained was low (R^2=.11). In the context of this model, there was no significant difference in mean cost growth across the discrete classes of project delivery strategy ($.36 \leq p \leq .93$) and no significant linear relationship between cost growth and team integration (*p*=.79, owner type (*p*=.11) or facility size (*p*=.41).

Unit cost, or cost per square foot, was calculated as the actual design and construction costs divided by the gross square footage of the facility. The unit cost was adjusted for time and location using historical indices, and transformed using a base 10 logarithm. Both project delivery strategy and team integration were significant predictors of unit cost (*p*=.01), when controlling for group cohesiveness, owner type and facility size. These relationships explained a total of 26% of the variation in unit cost. The Class IV was the only project delivery strategy that showed significantly different unit costs when compared against Class I delivery, averaging 41% cheaper (*p*=.01) after accounting for differences in group cohesiveness, team integration, owner type and gross square footage of the facility. The Class V averaged 34% cheaper than Class I delivery, at a nearly significant level (*p*=.06). Within the context of this model, an increase of one unit in team integration was found to increase unit cost by 32% (*p*=.00), having a public owner resulted in 39% higher mean unit cost (*p*=.00) and increasing the facility size by 10% reduced the unit cost by approximately 1% (*p*=.01). There was no significant linear relationship between group cohesiveness and unit cost (*p*=.27).

Intensity was defined as the cost per square foot installed per month of project duration, using the actual design and construction costs and the duration from start of design until substantial completion. Intensity values were adjusted for time and location using historical indices, and transformed using a base 10 logarithm. Team integration was the only significant predictor of intensity (*p*=.00), when controlling for project delivery strategy, group cohesiveness, owner type and facility size. An increase of one unit in team integration resulted in 29% higher intensity (*p*=.00). Increasing the facility size by 10% reduced the overall intensity by 2.8% (*p*=.00) and having a public owner increased intensity by 20% (*p*=.03), explaining a moderate amount of variation (R^2=.37). There was no significant difference in mean intensity across the classes of project delivery strategy ($.27 \leq p \leq .86$) and no significant linear relationship between group cohesiveness and intensity (*p*=.16).

6.5.2 Schedule Performance

Schedule performance was measured with three metrics: project schedule growth, delivery speed and construction speed. These metrics were treated as separate dependent variables in the structural model and regressed on the latent constructs of project delivery strategy, team integration and group cohesiveness. The owner type, either public of private, and facility size, as the gross square foot area, were included in the model to control for funding source and project scale, respectively.

Project schedule growth was calculated as the percent difference between the planned and actual project duration, measured from the start of design to substantial completion. Team integration was the only significant predictor of schedule growth (*p*=.01), when controlling for project delivery strategy, group cohesiveness, owner type and facility size.

Public owners experienced a 7% higher mean schedule growth, at a nearly significant level (p=.06). An increase of one unit in team integration reduced the mean schedule growth by 4.4%; although the overall variation explained was low (R^2=.13). There was no significant difference in mean schedule growth across the classes of project delivery strategy ($.07 \leq p \leq .53$), and no significant linear relationship between group cohesiveness and schedule growth (p=.10) or between facility size and schedule growth (p=.37).

Delivery speed was defined as the gross square foot area of the facility divided by the actual project duration in months, from start of design to substantial completion. Similar to other metrics calculated using facility size, he delivery speed values were transformed using a base 10 logarithm. Project delivery strategy, owner type and facility size were significant predictors of delivery speed, when controlling for group cohesiveness and team integration. Within the classes of project delivery strategy, there was no significant difference in mean delivery speed between Class II and Class I delivery (p=.23). However, when compared against Class I delivery, the mean delivery speed for Class III was 38% faster (p=.01), Class IV was 111% faster (p=.00) and Class V was 91% faster (p=.00). Within the context of this model, having a public owner resulted in a 15% slower delivery speed (p=.01) and increasing the facility size by 10% increased the delivery speed by 8% (p=.00). Approximately 86% of the variation in delivery speed was accounted for in this model. There was no significant linear relationship between group cohesiveness and delivery speed (p=.97) or team integration and delivery speed (p=.53).

Construction speed was defined as the gross square footage of the facility divided by the actual construction duration, from groundbreaking to substantial completion. The construction speeds were transformed using a base 10 logarithm for analysis. Project delivery strategy, owner type and facility size were significant predictors of construction speed, when controlling for group cohesiveness and team integration; explaining a large portion of the variation in construction speed (R^2=.84). Within the classes of project delivery strategy, there was no significant difference in mean construction speed between Class II (p=.71) or Class III (p=.20) and Class I delivery. The Class IV was 45% faster during construction (p=.00), when compared against Class I delivery. Although not quite significant, the Class V had a 27% higher mean construction speed (*p*=.07) than Class I delivery. Within the context of the model, having a public owner resulted in 25% slower construction speed (*p*=.00) and increasing the facility size by 10% increased the construction speed by 7.5% (*p*=.00). There was no significant relationship between group cohesiveness and construction speed (*p*=.99) or team integration and construction speed (*p*=.25).

6.5.3 Quality Performance

Quality performance was represented by two latent constructs: *turnover experience* and overall *facility quality*. These latent constructs were treated as separate dependent variables in the structural model and regressed on the other latent constructs of project delivery strategy, team integration and group cohesiveness. The owner type, either public of private, and facility size, as the gross square foot area, were included in the model to control for funding source and project scale, respectively.

Turnover experience was measured by the owner's rating for difficulty of start-up, magnitude of call backs and operation and maintenance (O&M) costs. The rating scales were oriented such that higher scores of turnover experience signify easier start-up, fewer call backs and lower O&M costs. Group cohesiveness and facility size were significant predictors of turnover experience, when controlling for project delivery strategy, team integration and owner type. For a one unit increase in group cohesiveness, the turnover experience was improved by .58 units (*p*=.00). For projects with public owners, the mean turnover experience was .55 units less than private owners (*p*=.00). This model explains 38% of the variation in the turnover experience construct. There was no significant difference in turnover experience across the classes of project delivery strategy ($.16 \leq p \leq .99$) and no significant linear relationship between team integration and turnover experience (*p*=.54) or facility size and turnover experience (*p*=.30).

Overall facility quality was measured by the owner's rating of satisfaction with the structure and building envelope, interior finishes and environmental systems. The rating scales were oriented such that higher levels of overall facility quality signify greater satisfaction with the structure and envelope, interior finishes and environmental systems. Group cohesiveness was the only significant predictor of overall facility quality, when controlling for project delivery strategy, team integration, owner type and facility size. When group cohesiveness increases by one unit, the mean facility quality increases by .55 units (p=.00); explaining a moderate amount of variation (R^2=.53). Although not quite significant, an increase in one unit of team integration improved facility quality by .22 units (p=.06). There was no significant difference in facility quality across the classes of project delivery strategy ($.13 \leq p \leq .78$) or with owner type (p= .51) and facility size (p=.15).

6.5.4 Summary of Primary Results

Structural modeling provided a robust method of examining the simultaneous influence of group cohesiveness and team integration on project performance, within the context of a project delivery strategy, funding source and facility size. Facility type was not accounted for in the model. Table 6-7 provides a high level summary of significant linear relationships between predictors and outcomes. The directionality of each association is listed as either positive or negative. There were measurable differences in unit cost, delivery speed and construction speed across classes of project delivery strategy, when compared against Class I delivery. Team integration was a contributor to unit cost, intensity and schedule growth, while the group cohesiveness helped to predict cost growth, turnover experience and facility quality. Projects with higher team integration scores used BIM in design and coordination applications, and involved more of the team in BIM planning, goal setting, design charrettes and construction-phase co-location. Higher group cohesiveness scores resulted in better team chemistry, stronger commitment to project goals and more on-time communication.

Table 6-7: Summary of primary outcome relationships from structural model

	Cost			Schedule			Quality	
Predictor	Intensity	Unit cost	Cost growth	Construction speed	Delivery speed	Schedule growth	*Facility quality*	*Turnover experience*
Class II[1]								
Class III[1]					+			
Class IV[1]		(–)		+	+			
Class V[1]					+			
Public owner		+		(–)	(–)	+		(–)
Facility size		(–)		+	+			
Team integration	+	+				(–)		
Group cohesiveness			(–)				+	+
Variance explained:	37%	26%	11%	84%	84%	13%	53%	38%

Notes: [1] Project delivery strategies compared against Class I; (+) Significant positive relationship between predictor and outcome, *p*<.05; (–) Significant negative relationship. *p*<.05.

6.6 Secondary Structural Model Results

Whereas the discussion of primary results focused on predictors of cost, schedule and quality outcomes, this section reviews predictors of *team integration* and *group cohesiveness* as intermediate or secondary outcomes in the structural model. When primary outcomes are dependent on these latent team constructs, the model paths discussed in this section identify the explanatory variables that influence team integration and group cohesiveness.

6.6.1 Team Integration

The team integration construct was measured by the number of BIM uses selected by the respondent from a prescribed list and the proportion of the team participating in: BIM planning, goal setting, design charrettes and construction-phase co-location. The rating scales were oriented such that higher scores of team integration were reflective of a higher number BIM uses and greater proportions of team participation in collaborative interactions. In creating the proportions, a full team consisted of at least one representative from each of the five main players on the project: owner, designer, primary contractor, MEP trade contractor and structural trade contractor. Project delivery strategy, owner type and facility size were all significant predictors of team integration. Within the classes of project delivery strategy, there was no significant difference in mean team integration between Class II (p=.10) and Class I delivery. In order of increasing means of team integration, Class III (1.35), Class V (1.53) and Class IV (1.65) were all significantly different from Class I delivery (p=.00). Within the context of this model, having a public owner increased the mean team integration by .34 (p=.05) and a 10% increase in facility size increases team integration by .07 units (p=.00).

6.6.2 Group Cohesiveness

The group cohesiveness construct was measured by ratings of goal commitment, team chemistry and timeliness of communication. The rating scales were oriented such that higher scores of group cohesiveness were associated with stronger goal commitment, better team chemistry and more frequent on-time communication. The ratings were self-reported by the respondent and reflect their perception of the group cohesiveness after the completion of the project. Project delivery strategy and team integration were both significant predictors of group cohesiveness, when controlling for owner type and facility size. Within the classes of project delivery strategy, there was no significant difference in mean group cohesiveness between Class II (p=.15) or Class IV (p=.11) and Class I delivery. The Class V had a higher mean group cohesiveness score (p=.01), when compared against Class I delivery. Although not quite significant, Class III was also associated with a better group cohesiveness (p=.06) than Class I delivery. For an increase of one unit in team integration, the group cohesiveness improved by .22 units (p=.03). This model explained 20% of the variation in the group cohesiveness on projects in the sample data set. There was no significant linear relationship between owner type and group cohesiveness (p=.59) or facility size and group cohesiveness (p=.42).

6.6.3 Summary of Secondary Results

This section examined the latent constructs of *team integration* and *group cohesiveness* as intermediate, or secondary, outcomes dependent on the project delivery strategy, owner type and facility size. Facility type was not accounted for in the model. A summary of the significant linear relationships are found in Table 6-8, with directionality indicated as either positive or negative. Team integration was found to vary by class of project delivery strategy, achieving higher scores with the earlier primary contractor involvement found in Class III, Class IV and Class V, when compared against Class I delivery. Team integration was also higher in public projects and increased linearly with the logarithm of facility size. The group cohesiveness was improved using Class III and Class V delivery strategies, and on projects with higher team integration.

Table 6-8: Summary of secondary outcome relationships from structural model

Predictor	*Team integration*	*Group cohesiveness*
Class II[1]		
Class III[1]	+	+
Class IV[1]	+	
Class V[1]	+	+
Public owner	+	
Facility size	+	
Team integration		+
Variance explained:	20%	39%

Notes: [1] Project delivery strategies compared against Class I; (+) Significant positive relationship between predictor and outcome, p<.05.

6.7 Chapter Summary

The results presented in this chapter describe differences in project performance that can be attributed to the owner's choice of project delivery strategy, the depth of team integration and degree of group cohesiveness. The constructs of team integration and group cohesiveness were validated using both confirmatory and exploratory factor analyses. A structural equation model was specified to investigate relationships with project performance. The results were discussed in terms of primary outcomes, examining predictors of the eight project-level cost, schedule and quality metrics; and secondary outcomes, examining predictors of the team-level integration and cohesiveness. The combination of these perspectives enables practical interpretation of path in the structural model.

Chapter 7

SUMMARY AND CONCLUSIONS

This chapter summarizes the key findings, contributions and limitations of this research. First, the theoretical framework is reviewed and the latent constructs of project delivery strategy, team integration and group cohesiveness are discussed. Next, the significant findings from the structural equation model are summarized and limitations in the research methodology are acknowledged. Contributions are presented for both the academic community and industry practitioners. Lastly, specific conclusions are presented and areas of future work branching from this research are suggested.

7.1 Summary of Findings

To investigate the role of inter-organizational relationships in project performance, a theoretical framework was developed. This framework summarized variables and relationships found in literature, related studies and industry workshops. Inter-organizational relationships were studied using latent constructs to represent team integration and group cohesiveness. Team integration, as measured by the team's participation in high-quality interactions, refers to the extent that design and construction team members worked together in a systematic manner across disciplines. Group cohesiveness refers to the extent that design and construction team members as individuals have developed into an effective team. This research used data from 204 completed building projects to assess the influence that differing levels of integrated and cohesive teams have on cost, schedule and quality performance. The context for these relationships was provided by five classes of project delivery strategies. The five classes, derived from a latent class analysis, were clustered according to differentiators of contract structure, payment terms and procurement processes. The five underlying project delivery strategies in this research were labeled as Class I, Class II, Class III, Class IV and Class V.

Project data was first used to confirm the theorized latent constructs of team integration and group cohesiveness. Five of the six measurement variables thought to be reflective of team integration were statistically significant. A higher number of BIM uses and larger proportion of the team participating in BIM execution planning, joint goal-setting, design charrettes and construction phase co-location were found in more integrated project teams. The perceived amount of offsite prefabrication was not correlated to team integration. Three of the five measurement variables chosen to reflect group cohesiveness were statistically significant. Higher ratings of goal commitment, team chemistry and timeliness of communication were found in more cohesive project teams. Formality of communication and the frequency of compromise were not related to group cohesion. Lastly, there was a significant positive correlation between the latent constructs, suggesting that higher team integration can improve group cohesiveness on building construction projects.

Using the theoretical framework in Figure 3-1 as a guide, a structural equation model was created to place measures of team integration and group cohesiveness within the context of project delivery strategies. This model identified several significant paths that demonstrate the importance of inter-organizational relationships in cost, schedule and quality performance.

1) Predictors of cost performance:

   Project cost growth was reduced by 2.3% per unit of increase in group cohesiveness, although the overall variation explained was low (R^2=.11). There was no significant difference in cost growth across the classes of project delivery strategy and team integration, owner type and facility size were not significant predictors of cost growth when included in the model with team cohesiveness.

Intensity increased by 29% per unit of increase in team integration, explaining a moderate amount of variance (R^2=.37) when considered alongside smaller contributions from owner type and facility size. Intensity did not significantly vary across the classes of project delivery strategy, and group cohesiveness was not a significant predictor of intensity when included in the model with team integration.

2) Predictors of schedule performance:

   Project schedule growth was reduced by 4.4% per unit of increase in team integration, although the overall variation explained was low (R^2=.13). There was no significant difference in schedule growth across the classes of project delivery strategy and group cohesiveness, owner type and facility size were not significant predictors of schedule growth when included in the model with team integration.

   The mean difference in *delivery speed* was 38% faster than a Class I delivery strategy for Class III, 111% faster for Class IV and 91% faster for Class V. The structural model explained 86% of the variation in delivery speed and included significant contributions for owner type and facility size. Team integration and group cohesiveness were not significant predictors of delivery speed, when included in the model with project delivery strategies, owner type and facility size.

   The mean difference in *construction speed* was 45% faster for Class IV projects and 27% faster for Class V, when compared to a Class I delivery strategy. The structural model explained 86% of the variation in construction speed and included significant contributions for owner type and facility size. Team integration and group cohesiveness were not significant predictors of construction speed, when included in the model with project delivery strategies, owner type and facility size.

3) Predictors of quality performance:

   The owner's *turnover experience* was improved by .58 units per unit of increase in group cohesiveness, explaining a moderate amount of variation (R^2=.38) with contributions for owner type. Turnover experience did not significantly vary across the classes of project delivery strategy, and team integration and facility size were not significant predictors of turnover experience when included in the model with group cohesiveness.

   The building's *system quality* was improved by .55 units per unit of increase in group cohesiveness. The structural model explained 53% of the variation in system quality, which did not significantly vary across the classes of project delivery strategy or by degree of team integration. Owner type and facility size were not significant predictors of system quality when included in the model with group cohesiveness.

This research demonstrates that many differences in cost, schedule and quality outcomes are attributable to the strength of inter-organizational relationships. Projects with a greater depth of team integration, observable by their participation in high-quality interactions, generally saw reduced schedule growth and increased intensity. Design and construction teams that were highly cohesive reported lower cost growth, with a better turnover experience for the owner and higher perceived system quality. These findings strongly suggest that team integration and group cohesiveness are desirable attributes in effective project teams.

The structural model was also used to investigate the impact that project delivery strategies have on team integration and group cohesiveness. As the primary determinant of project organizational boundaries in this research, delivery strategies provide the structure for inter-organizational relationships. This model identified several significant paths that demonstrate how project delivery strategies differ in their levels of team integration and group cohesiveness:

4) Predictors of team integration:

    The mean difference in *team integration* was greater for Class III (1.35), Class V (1.53) and Class IV (1.65), when compared against the Class I delivery strategy. The mean team integration in Class II (.59) delivery was not significantly different from Class I. The structural model explained 39% of the variation in team integration, including contributions from owner type and facility size.

5) Predictors of group cohesiveness:

    Group cohesiveness was improved by .22 units per unit of increase in team integration. Additionally, the mean difference in group cohesiveness was greater for Class III (.59) and Class V (.78), when compared against the Class I delivery strategy. Owner type and facility size were not significant predictors of group cohesiveness when included in the model with team integration and project delivery strategies. The structural model explained 20% of the variation in group cohesiveness.

This research also demonstrates that the constructs of team integration and group cohesiveness are at least partially influenced by the structure of the project organization. Project delivery strategies that involved the primary contractor during the schematic design phase generally achieved higher levels of team integration. Strategies that used open book payment terms, such as guaranteed maximum price or cost plus a fee, achieved more cohesion among design and construction team members. These findings suggest that owners may be able to select a project delivery strategy leading to a more effective inter-organizational team that both directly and indirectly results in better cost, schedule and quality performance.

7.2 Research Contributions

This research made the following contributions to academic communities and industry practitioners:

1) *A theoretical framework was established for understanding the impact of inter-organizational relationships on project performance.*

   The idea that building construction projects resemble a temporary organization has been proposed by multiple researchers (Turner and Müller 2003). Under this view, the project is a production process, comprised of several specialty firms working to deliver a unique product—an operational building. The integration of these firms and their ability to form a cohesive team is vital to the success of complex projects. Prior studies have examined the determinants of project success from two, separate perspectives: as relating to the structure of project organization (Konchar and Sanvido 1998; Ibbs et al 2003; Bogus et al. 2010; Korkmaz et al. 2010) and as relating to the degree of integration or collaboration among the project team (Greenwood and Wu 2012; Franz et al. 2014). The theoretical framework developed for this research brings together these two streams of inquiry into a single model. The framework recognizes the construction project as a temporary organization, established according to a high-level delivery strategy. The group cohesion that develops within that organization and the depth of team integration are then indicators of project performance. This enables a more holistic understanding of the facility delivery process.

2. *Classes of project delivery strategy were proposed to better represent the organizational arrangement of design and construction teams.*

   Since the seminal efforts in project delivery studies conducted in the mid-1990s, the distinctions between design-bid-build, CM at risk and design-build have become increasingly blurred. Experienced owners are experimenting with hybrid deliveries that seem to fall between the typical definitions of delivery methods. For example, the United States Army Corps of Engineers (USACE) occasionally uses an integrated design-bid-build (IDBB) approach that selects the primary contractor early to provide construction management services during design. However, the primary contractor is not guaranteed the award of the construction scope and must submit a proposal alongside competitors when the design reaches 90% completion. Depending on who receives the contract award, this form of delivery may resemble either design-bid-build or CM at risk. This distinction is most felt within the project team. In one scenario, the established pairing of designer and primary contractor is allowed to carry their relationship forward into construction. In the other, the designer and newly selected primary contractor start the construction process as virtual strangers. Integrated project delivery (IPD) faces a similar challenge in delivery method categorization. IPD uses a multi-party agreement that combines elements from both early involvement CM at risk and qualifications-based design-build.

This research deconstructed the classifications of delivery methods, procurement processes and payment terms to identify key differentiators of the owner's underlying project delivery strategy. These differentiators were used to cluster each project in the 204 sample data set according to their most likely project delivery strategy. The resulting five classes are an attempt to recapture the boundaries of current delivery practices that have evolved to meet the needs of project owners. These classes are important in studying project performance because they represent the high-level strategy for forming the project organization, reflected in the team arrangement, timing of involvement, selection criteria and cost transparency.

3. *Structural equation modeling was used to investigate abstract concepts of team integration and group cohesion within the context of project delivery strategies.*

   The use of latent constructs is rarely seen in construction research. One potential reason is that latent constructs contribute more to the theory of the concept being studied, rather than its application in practice. For reflective constructs, a set of observed variables is used to infer the underlying latent variable responsible for their shared variance. The directionality of this relationship is important to interpretation. Using group cohesiveness as an example, project teams with a greater cohesion were observed to have higher chemistry, goal commitment and timely communication. A reflective construct does not suggest that having higher chemistry, goal commitment and timely communication resulted in greater team cohesion. The difference in conclusions is subtle, but the first statement tells us more about the concept of group cohesiveness. Since no a priori assumptions are made about how the observed variables may combine to form the latent variable, the construct represents the available data rather than a predefined model structure.

   Most project managers intuitively grasp the value of a positive team atmosphere, and would prefer that collaborative rather than adversarial relationships develop among team members. To begin exploring the role of team relationships in project performance, this research successfully modeled two reflective latent variables: team integration and group cohesiveness. Using measures of participation in inter-organizational activities, a continuous latent factor for team integration was inferred. Similarly, using measures of a collaborative team environment, a factor was derived for group cohesiveness. Both latent factors were found to vary by project delivery strategy and were statistically significant with several performance outcomes. This research demonstrated that latent constructs are a viable analysis technique for studying teams in construction research.

7.3 Industry Applications

To apply and disseminate the results of this study, the research team has developed an owner's guide to support project delivery strategy selection. Development of the guide began with a thorough review of existing project delivery selection tools to determine the approach that would be most effective in applying the unique empirical results from this study. The owner's guide is provided in Appendix F and a plan for disseminating the guide is provided in Appendix G.

7.3.1 Review of Existing Project Delivery Selection Tools

Due to the number of variables involved in the project delivery decision, researchers and practitioners have developed a number of selection techniques. Documented approaches ranged from non-complex flowcharts (Goldon, 1994) to more complex frameworks, such as multi-attribute utility and value theory (Oyetunji and Anderson, 2006) and the analytical hierarchical process (Alhazmi and McCaffer, 2000; Mahli and Alreshaid, 2005). Table 7-1 summarizes the notable research efforts on project delivery selection in the construction industry.

All of the tools ultimately compare the multiple decision variables involved in selecting a project delivery system. Non-complex tools have the advantage of being more transparent to the users and typically rely on owner judgment for the final selection. This reliance on owner judgment does carry the risk of introducing bias into the decision. These non-complex tools are often referred to as decision-support tools because they guide and support the owner through the decision, but to not provide a ranking or numerical output. Complex tools have the advantage of introducing more data-driven decisions. These typically have an analytical engine (e.g., multivariate formula, fuzzy logic system or simulation) that transforms owner inputs into a numerical scoring or ranked output. These tools are often called expert systems or decision models. Since they rely heavily on the numeric model, the tool is only as accurate as the model the drives it and the results are difficult for an owner to interpret because they do not always understand the process, often seen as a "black box", that produces the scoring or ranking.

Table 7-1: Summary of project delivery selection efforts in literature

Approaches	**Examples in Literature**
Evaluation of single delivery methods	Yates (1995); Songer and Molenaar (1996); Beard et al. (2001); Lam et al. (2008); Gransberg et al. (2006); Migliaccio et al. (2009)
Comparison of multiple delivery methods	Konchar and Sanvido (1998); CII (1997); Molenaar et al. (1999); Debella and Ries (2006); Ibbs et al. (2003); Rojas and Kell (2008); Hale et al. (2009); Shrestha et al. (2007); Tran et al. (2013)
Flowchart	Gordon (1994)
Multi-attribute utility and value theory	Molenaar and Songer (1998); Miller et al. (2000); CII (2003); Oyetunji and Anderson (2006); Mahdi and Alreshaid (2005); Skitmore and Marsden (1988); Love et al. (1998)
Analytical hierarchical process (AHP)	Al Khalil (2002); Alhazmi and McCaffer (2000)
Fuzzy logic model	Ng et al. (2002); Chan (2007)
Knowledge-based decision support	Kumaraswamy and Dissanayaka (2001)
Case-based, qualitative assessment	Luu et al. (2003; 2006); Warne (2005); Touran et al. (2011)

7.3.2 Owner's Guide Format

The research team ultimately took a non-complex, decision support approach to provide guidance on the project delivery strategies identified in this study. The tool infuses empirical evidence and lessons learned from survey participants into a transparent process that allows owners to select a project delivery strategy with the goal of maximizing team integration and cohesiveness. The tool is designed to meet unique project goals while working within each owner's legal, policy, cultural, functional and operational constraints. The research findings identify key decision points where owners can make decisions that influence the levels of team integration and group cohesion on their projects. These decision points are summarized in the tool as follows:

- Delivery method
    a. *Design responsibility* expressed as single or multiple contracts held by the owner for design and construction services.
    b. *Timing of involvement* related to when the builder and key specialty contractors were contracted for the project.
- Contractual payment terms
    a. *Cost transparency and risk for cost overruns* associated with open book and closed book contracting.
    b. *Risk for unknowns* managed with shared design and construction contingency or split owner and contractor contingency.
- Procurement process
    a. *Selection criteria* that considers price only or included non-price factors.
    b. *Prequalification* to create a shortlist of qualified contractors rather than pursuing open procurement.
    c. *Prior working experience* or relationships with owner from the perspective of the design and construction disciplines.
    d. *Interview process* used to assess the builder prior to selection.

The tool guides owners through these decision points in the following steps:

1. Define project goals and constraints
2. Organizational considerations
3. Contract payment considerations
4. Team assembly considerations
5. Design the project delivery strategy

In each of these steps, owners review the advantage and disadvantages for each path of the delivery strategy (e.g., open-book vs. closed-book contract terms). The discussion of advantages and disadvantages focuses on maximizing team integration and cohesiveness. The owner's guide provides evidence for these decisions from the data analysis, literature review and Advisory Board experience. At the end of the process, the owner has a defensible and transparent project delivery decision.

7.4 Limitations

This research acknowledges the following limitations:

1. *Other external factors, not captured in the theoretical framework, may also influence team integration, group cohesiveness and project performance.*

   Several external factors were not practical to collect for the scope of this study. For example, the structural equation model explained roughly 40% of the variation in team integration. The remaining unexplained variation may be attributed to the owner's corporate policies that were independent of their chosen project delivery strategy. If they could be reliably collected and categorized from owners, these policies, such as requiring certain BIM uses on all projects, would help explain variation in the team integration construct. Similarly, the model explained approximately 20% of the variation in group cohesiveness. Design and construction teams are made of individuals and the unexplained variation could result from differences in personalities, prior experiences and corporate cultures. The analysis was blind to whether an effective project manager was staffed to a poorly planned project or a careless project manager was assigned to an established, proactive project team. Construction teams are frequently fluid, yet there may be one or two exceptional individuals who drive the jobsite culture and encourage collaboration within an otherwise restrictive organizational structure. Data on these factors was not obtainable, given the format and scope of the questionnaire. Lastly, the research did not collect specific data on the reasons for contract modifications that may have resulted in cost or schedule growth. Ideally, the respondent would provide a detailed accounting for change orders, listing a brief explanation, the amount of approved contract revision and any time extensions. Tracking this type of data with a questionnaire is onerous for the respondent, which prohibited its use in this research.

2. *Facility type was not controlled for in the structural model.*

   Due to the complexity of the structural equation model, the moderate sample size of 204 projects did not allow for comparisons by facility type. Nine facility types were identified from the descriptions of the building uses provided by respondents. Descriptive results of facility types were provided for the overall sample and by class of project delivery strategy. With a larger sample size, the explanatory value of facility type in the model would have been to control for differences in building system complexity. For example, hospitals include both diagnostic and treatment spaces, with complex environmental systems. By comparison, office buildings are intentionally designed to be simple and flexible and accommodating to tenants. These differences in complexity are most obvious in the unit cost of the building and measures that are a function of unit cost, such as intensity. The findings of this research reflect relationships found across all sectors of industry, with the understanding that specific paths may be stronger or weaker depending on the facility type.

3. *The questionnaire had a low response rate and a non-response study was not conducted.*

   The availability of information on the internet, and the speed by which it spreads via social media and news outlets, has made building owners more guarded with their project information. This research experienced a response rate of approximately 4% for questionnaires distributed both by email and postal mail. The danger of a low response rate is potentially missing certain subgroups of the population that declined to participate. Some reasons for non-response were identified by this research during the data verification process, including (1) organizational policies that prohibit sharing of cost information to outside parties, (2) no recent projects within the scope of the study and (3) too little time to dedicate to the questionnaire. While a response rate of 4% is typically considered low for survey research, this rate is consistent with other large-scale project delivery studies. For example, the most directly comparable study performed by Konchar and Sanvido (1998) reported a 5.1% response rate. However, without a formal non-response study, care should be exercised when generalizing the findings of this research to the construction industry.

7.5 Future Research

The theoretical framework developed for this research was successfully used to explore the role of inter-organizational relationships in project performance. The model incorporated statistical techniques for representing abstract concepts, such as project delivery strategy, team integration and group cohesion. However, there are opportunities to expand the framework in future research:

1. *Explore greater delineation between classes of project delivery strategy.*

   Similar to the publication of the first periodic table, which had gaps that enabled the prediction of as-yet-unknown elements, this research may serve a similar function for project delivery strategies. Five strategies were identified in the sample data set, but not all projects were ideal fits within each class. To form the latent classifications in this research, several indicators were discarded for not being strong differentiators of class. These indicators may become important in a larger data set and assist in the identification of more classes of project delivery strategy.

2. *Develop a consistent methodology for comparing the final unit costs of projects.*

   The unit cost metric is frequently used by owners and developers to compare the cost of their projects against completed facilities of the same type. However, as demonstrated in this study, unit cost performance should not be considered in isolation. More so than cost growth or intensity, unit cost is heavily influenced by the scope and context of the project. The complexity of environmental systems, quality of interior finishes and constructability of the design may cause unit costs to vary widely among facilities that seem comparable on the surface. Until a consistent methodology for comparing unit costs is developed and tested, any statistical relationships with unit costs should be interpreted with caution. Future studies should focus on comparing the final unit cost of the project against the expected unit cost of a similarly scoped facility. The expected unit cost may be developed by averaging historical data or through an algorithm that accounts for differences in project scope.

3. *Investigate sustainability and safety performance with respect to team integration.*

   Data on the planned and actual LEED certification levels, as well as recordable and lost time safety incidents, were collected as part of this study. However, these outcomes were a secondary area of interest and much of this information remained unverified. Collecting accurate safety data after project completion is challenging. The construction manager may no longer have access to the total number of labor hours worked by each subcontractor. Or, the task of obtaining archived files may be too time consuming or otherwise onerous for the respondent. A study with the resources to dedicate exclusively towards collecting detailed safety data could leverage the project database created in this research and become the first step in institutionalizing this type of data collection with project owners.

7.6 Concluding Remarks

With the increasing fragmentation of design and construction services in the industry, the topic of team integration is gaining the attention of building owners. This research analyzed team integration as a latent construct in a statistical model. Integrated teams involved all tiers of the project organization, from designers to specialty trades, in high-quality interactions. These interactions were collaborative in nature and included design charrettes, goal setting and multidisciplinary BIM uses. The owner's project delivery strategy had a significant impact on team integration. Strategies that involved construction managers and specialty trades during schematic design achieved higher levels of integration and were more equipped to control project schedule growth.

More integrated teams are suspected to bring process improvements that lead to greater collaboration and improve the quality of complex building systems. This research analyzed group cohesiveness, a trait common in highly developed teams, as a latent construct in a statistical model. Cohesive teams reported higher chemistry, goal commitment and timeliness of communication. Project delivery strategies that required cost transparency with open book contracts generally resulted in a more cohesive teams and a lower average project cost growth. Additionally, the owner's perception of turnover and building system quality was consistently rated higher for cohesive teams.

The vision for this research was to begin studying construction projects as organizations. In practice, this means expanding our view of projects to include the culture and team dynamics that develop within the project organization. This research demonstrated practical techniques to measure those attributes using behaviors and attitudes of the project team.

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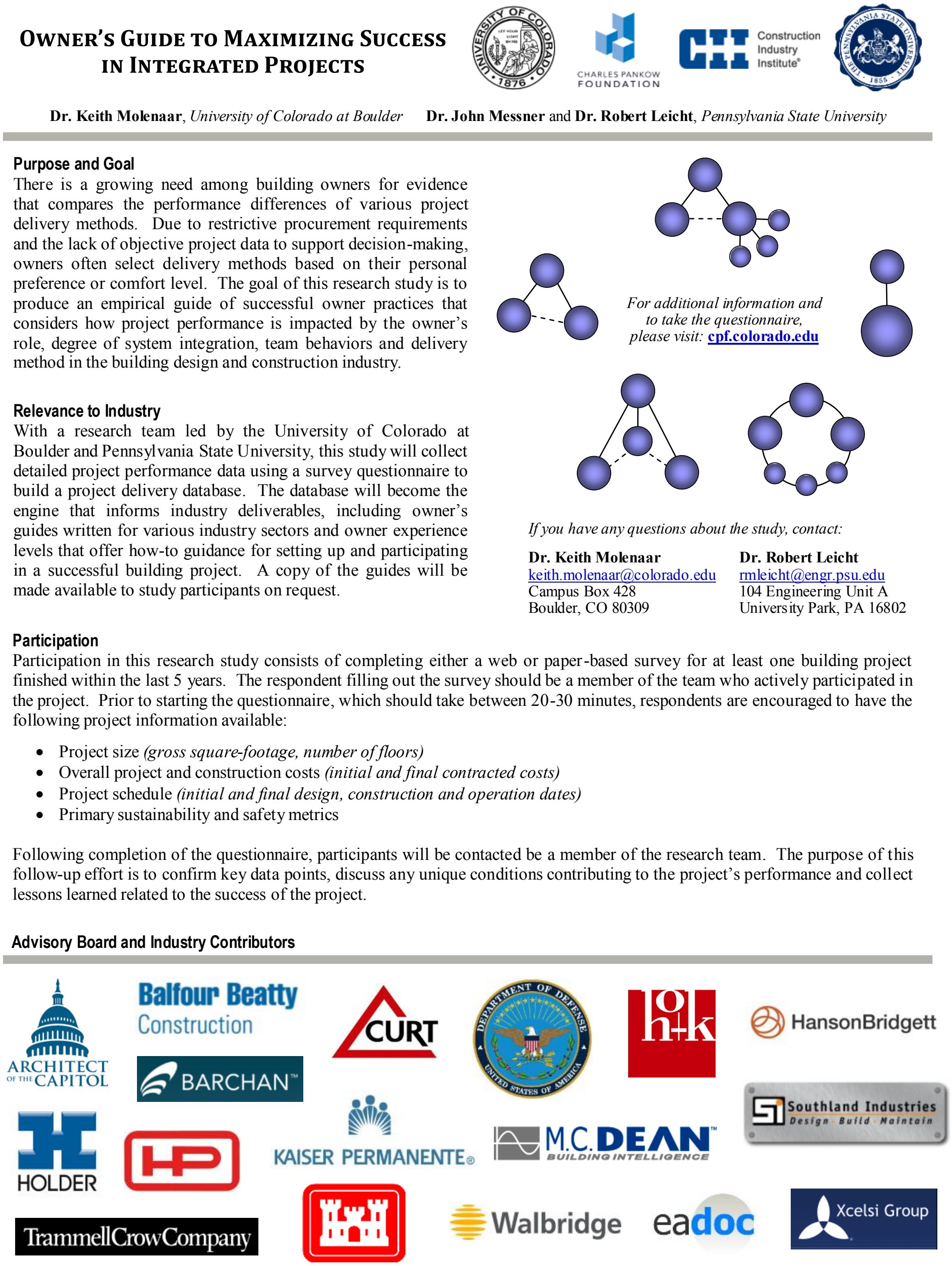
Appendix A: DATA COLLECTION TOOL



OWNER'S GUIDE TO MAXIMIZING SUCCESS IN INTEGRATED PROJECTS

Charles Pankow Foundation
Construction Industry Institute®

Dr. Keith Molenaar, *University of Colorado at Boulder* **Dr. John Messner** and **Dr. Robert Leicht**, *Pennsylvania State University*

Purpose and Goal

There is a growing need among building owners for evidence that compares the performance differences of various project delivery methods. Due to restrictive procurement requirements and the lack of objective project data to support decision-making, owners often select delivery methods based on their personal preference or comfort level. The goal of this research study is to produce an empirical guide of successful owner practices that considers how project performance is impacted by the owner's role, degree of system integration, team behaviors and delivery method in the building design and construction industry.

Relevance to Industry

With a research team led by the University of Colorado at Boulder and Pennsylvania State University, this study will collect detailed project performance data using a survey questionnaire to build a project delivery database. The database will become the engine that informs industry deliverables, including owner's guides written for various industry sectors and owner experience levels that offer how-to guidance for setting up and participating in a successful building project. A copy of the guides will be made available to study participants on request.

For additional information and to take the questionnaire, please visit: **cpf.colorado.edu**

If you have any questions about the study, contact:

Dr. Keith Molenaar
keith.molenaar@colorado.edu
Campus Box 428
Boulder, CO 80309

Dr. Robert Leicht
rmleicht@engr.psu.edu
104 Engineering Unit A
University Park, PA 16802

Participation

Participation in this research study consists of completing either a web or paper-based survey for at least one building project finished within the last 5 years. The respondent filling out the survey should be a member of the team who actively participated in the project. Prior to starting the questionnaire, which should take between 20-30 minutes, respondents are encouraged to have the following project information available:

- Project size *(gross square-footage, number of floors)*
- Overall project and construction costs *(initial and final contracted costs)*
- Project schedule *(initial and final design, construction and operation dates)*
- Primary sustainability and safety metrics

Following completion of the questionnaire, participants will be contacted be a member of the research team. The purpose of this follow-up effort is to confirm key data points, discuss any unique conditions contributing to the project's performance and collect lessons learned related to the success of the project.

Advisory Board and Industry Contributors

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FREQUENTLY ASKED QUESTIONS

SECTION 1: PROJECT CHARACTERISTICS

How does Integrated Project Delivery (IPD) differ from the other delivery methods? In an IPD organization, the primary parties enter into a single, multi-party contract agreement.

Should the building gross square-footage include the area of parking structures? No, please remove the area of all above grade, standalone parking structures from your building square-footage.

What effects the level of complexity? Contributors to project complexity include the type of building systems used and their interdependence, relative to other projects of similar type.

SECTION 2: PROJECT ORGANIZATION

What do SD, DD, and CD mean? During the Schematic Design (SD) phase, the spatial relationships, scale and form of building are developed based on the owner's requirements. The Design Development (DD) phase lays out the mechanical, electrical, plumbing, structural and architectural systems. The drawings and specifications for construction details are finalized during the Construction Document (CD) phase.

Where is Design-Builder in the list of project participants? Design-build firms, with in-house design and construction services, should use the row labeled 'GC, CM/GC or DB'. Designer-led, contractor-led and joint venture design-build deliveries should use both rows labeled 'Architect/Designer' and 'GC, CM/GC or DB' to represent the design-build team.

What is meant by administrative burden? Administrative burden includes the amount of paperwork, length and frequency of meetings and the management or oversight of team members.

SECTION 3: PROJECT COST

What is the difference between the Construction Cost and Total Project Cost? Construction costs include the field labor, materials, oversight, general conditions and fees incurred by contractors to build the project. Typically, the construction costs are equal to the value of the contracts held by the construction manager at risk or general contractor. Total project costs include both these construction costs ***and*** the services provided by the architect/ designer and outside consultants.

SECTION 4: PROJECT SCHEDULE

What's the difference between 'Planned' and 'Actual' dates? Planned dates are the initial contract commitments made between the owner and project team (e.g. the contract specifies a substantial completion on or before 11/5/2011). Actual dates represent when the commitment was achieved or 'as-built' by the project team (e.g. a Certificate of Occupancy was issued 11/3/2011).

SECTION 5: PROJECT QUALITY

This section contains questions based on your experience with the building ***after*** project completion. When assessing the quality of the facility and systems, please consider only the finished product.

SECTION 6: PROJECT SAFETY

What is the difference between a recordable and lost time incident? A recordable incident is a work-related injury or illness that results in death, days away from work, restricted work or transfer to another job, medical treatment beyond first aid or loss of consciousness. Lost time incidents are a specific subset of recordables that result in one or more days away from work.

SECTION 7: SUSTAINABILITY

What is the difference between 'Planned" and 'Awarded' level of certifications? Planned certification is the level of sustainability conveyed to the project team prior to or during schematic design. Awarded certification is the level of sustainability achieved and recognized by the rating system used for the project.

SECTION 8: TEAM PROCUREMENT & CONTRACTS

What is the difference between Price (Fee) and Price (Work)? Price (Fee) refers to selection based only on the project participant's proposed fees, or fees and general conditions. Price (Work) refers to selection based on the project participant's proposed price for their entire scope of work, including all fees, general conditions, labor, materials and equipment.

What is the difference between a 1-stage RFP and a 2-stage RFP? A 1-Stage Request for Proposal (RFP) announces a project program, asking respondents to provide a comprehensive proposal for the work. A 2-Stage RFP first asks respondents to submit documentation for an initial screening, followed by the preparation of a comprehensive proposal. If a member of your project team was solicited with more than 2 or more-Stages of RFP, please indicate "2 -Stage" on the questionnaire.

What is the difference between Cost Plus (Fixed Fee) and Cost Plus (% Fee)? Cost Plus (Fixed Fee) reimburses a project team member for the direct cost of work, plus a fixed fee that does not change with an increase in the cost of work. Cost Plus (% Fee) reimburses a project team member for the direct cost of work, plus a variable fee that is calculated as a percentage of the cost of work.

What would be considered operation and maintenance scope included in a contract? Operation and maintenance (O&M) scope may include preventative maintenance, repair of malfunctioning or deteriorated systems, and the process of using the building system equipment to accomplish their function. Contractual warranty and callback service should not be considered O&M scope for the purposes of this questionnaire.

SECTION 9: TEAM CHARACTERISTICS & BEHAVIOR

What is the difference between the end user and the owner? The end-user is the individual or group occupying the completed building and using it for the intended purpose (e.g. nurses and doctors in a hospital). The owner is the individual or group initiating and overseeing the project to fulfill a programmatic need (corporation building a new home office). In some cases, the owner and end-users can be the same.

What is co-location? Co-location is the practice of establishing a continuously shared workspace among project team members, for example sharing trailers on site. Working in separate trailers is not considered as co-location.

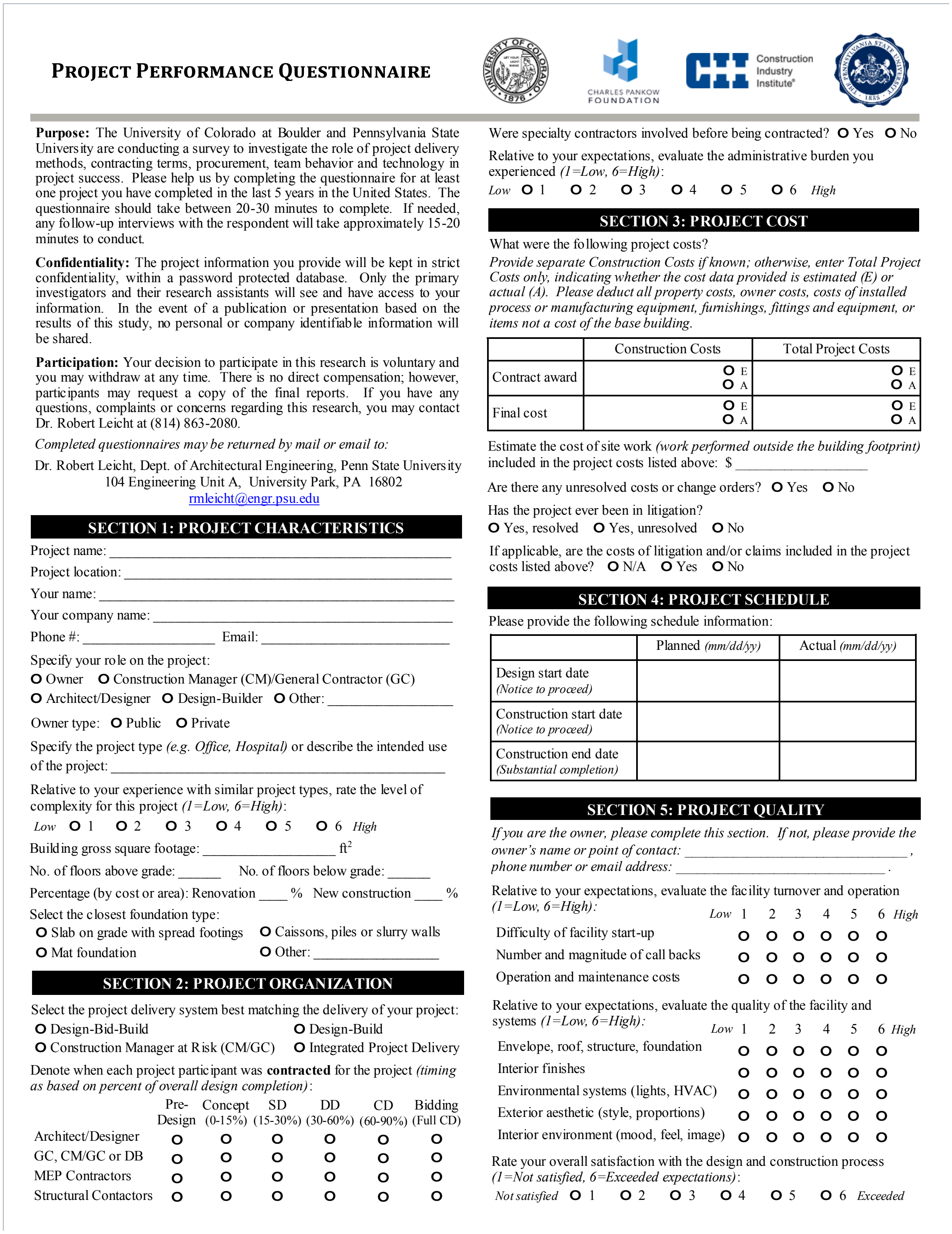
What is considered compromising on a project issue? Compromise is made through mutual concessions, where team members adjust their conflicting or opposing claims, principles and demands to reach an agreement on project issues.

SECTION 10: PROCESS AND TECHNOLOGY

What is multiple trade involvement in prefabricated or modularized systems? Multiple trade involvement refers to the practice of assembling a system or units of system with components from multiple disciplines on the project (e.g. racked MEP distribution with duct, pipe and conduit from different trades).

SECTION 11: LESSONS LEARNED

In this section, please provide any insights which may clarify or assist in our understanding of the project.



PROJECT PERFORMANCE QUESTIONNAIRE

Purpose: The University of Colorado at Boulder and Pennsylvania State University are conducting a survey to investigate the role of project delivery methods, contracting terms, procurement, team behavior and technology in project success. Please help us by completing the questionnaire for at least one project you have completed in the last 5 years in the United States. The questionnaire should take between 20-30 minutes to complete. If needed, any follow-up interviews with the respondent will take approximately 15-20 minutes to conduct.

Confidentiality: The project information you provide will be kept in strict confidentiality, within a password protected database. Only the primary investigators and their research assistants will see and have access to your information. In the event of a publication or presentation based on the results of this study, no personal or company identifiable information will be shared.

Participation: Your decision to participate in this research is voluntary and you may withdraw at any time. There is no direct compensation; however, participants may request a copy of the final reports. If you have any questions, complaints or concerns regarding this research, you may contact Dr. Robert Leicht at (814) 863-2080.

Completed questionnaires may be returned by mail or email to:

Dr. Robert Leicht, Dept. of Architectural Engineering, Penn State University
104 Engineering Unit A, University Park, PA 16802
rmleicht@engr.psu.edu

SECTION 1: PROJECT CHARACTERISTICS

Project name: ____

Project location: ______________________________________

Your name: ____

Your company name: ____________________________________

Phone #: __________________ Email: __________________________

Specify your role on the project:

○ Owner ○ Construction Manager (CM)/General Contractor (GC)

○ Architect/Designer ○ Design-Builder ○ Other: _________________

Owner type: ○ Public ○ Private

Specify the project type *(e.g. Office, Hospital)* or describe the intended use of the project: ____

Relative to your experience with similar project types, rate the level of complexity for this project *(1=Low, 6=High)*:

Low ○ 1 ○ 2 ○ 3 ○ 4 ○ 5 ○ 6 *High*

Building gross square footage: ________________ ft^2

No. of floors above grade: ______ No. of floors below grade: ______

Percentage (by cost or area): Renovation ____ % New construction ____ %

Select the closest foundation type:

○ Slab on grade with spread footings ○ Caissons, piles or slurry walls

○ Mat foundation ○ Other: _________________

SECTION 2: PROJECT ORGANIZATION

Select the project delivery system best matching the delivery of your project:

○ Design-Bid-Build ○ Design-Build

○ Construction Manager at Risk (CM/GC) ○ Integrated Project Delivery

Denote when each project participant was **contracted** for the project *(timing as based on percent of overall design completion)*:

	Pre-Design	Concept (0-15%)	SD (15-30%)	DD (30-60%)	CD (60-90%)	Bidding (Full CD)
Architect/Designer	○	○	○	○	○	○
GC, CM/GC or DB	○	○	○	○	○	○
MEP Contractors	○	○	○	○	○	○
Structural Contactors	○	○	○	○	○	○

Were specialty contractors involved before being contracted? ○ Yes ○ No

Relative to your expectations, evaluate the administrative burden you experienced *(1=Low, 6=High)*:

Low ○ 1 ○ 2 ○ 3 ○ 4 ○ 5 ○ 6 *High*

SECTION 3: PROJECT COST

What were the following project costs?

Provide separate Construction Costs if known; otherwise, enter Total Project Costs only, indicating whether the cost data provided is 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.

	Construction Costs	Total Project Costs
Contract award	○ E ○ A	○ E ○ A
Final cost	○ E ○ A	○ E ○ A

Estimate the cost of site work *(work performed outside the building footprint)* included in the project costs listed above: $ __________________

Are there any unresolved costs or change orders? ○ Yes ○ No

Has the project ever been in litigation?

○ Yes, resolved ○ Yes, unresolved ○ No

If applicable, are the costs of litigation and/or claims included in the project costs listed above? ○ N/A ○ Yes ○ No

SECTION 4: PROJECT SCHEDULE

Please provide the following schedule information:

	Planned *(mm/dd/yy)*	Actual *(mm/dd/yy)*
Design start date *(Notice to proceed)*		
Construction start date *(Notice to proceed)*		
Construction end date *(Substantial completion)*		

SECTION 5: PROJECT QUALITY

If you are the owner, please complete this section. If not, please provide the owner's name or point of contact: ______________________________ , phone number or email address: ______________________________ .

Relative to your expectations, evaluate the facility turnover and operation *(1=Low, 6=High)*:

	Low 1	2	3	4	5	6 *High*
Difficulty of facility start-up	○	○	○	○	○	○
Number and magnitude of call backs	○	○	○	○	○	○
Operation and maintenance costs	○	○	○	○	○	○

Relative to your expectations, evaluate the quality of the facility and systems *(1=Low, 6=High)*:

	Low 1	2	3	4	5	6 *High*
Envelope, roof, structure, foundation	○	○	○	○	○	○
Interior finishes	○	○	○	○	○	○
Environmental systems (lights, HVAC)	○	○	○	○	○	○
Exterior aesthetic (style, proportions)	○	○	○	○	○	○
Interior environment (mood, feel, image)	○	○	○	○	○	○

Rate your overall satisfaction with the design and construction process *(1=Not satisfied, 6=Exceeded expectations)*:

Not satisfied ○ 1 ○ 2 ○ 3 ○ 4 ○ 5 ○ 6 *Exceeded*

SECTION 6: PROJECT SAFETY

If you are the builder, please complete this section. If not, please provide the builder's name or point of contact: ________________________________ *, phone number or email address:* ______________________________ .

Number of recordable injuries: _____ Number of lost time injuries: _____

Work-hours for all onsite construction activities *(indicate (E) for estimated or (A) for actual):* __________________ E / A

SECTION 7: SUSTAINABILITY

Specify any green or sustainable rating system used on this project:

____

What level of certification was planned and awarded?

Planned: ___________________ Number of points/credits: ______

Awarded: __________________ Number of points/credits: ______

SECTION 8: TEAM PROCUREMENT & CONTRACTS

Indicate how proposals were solicited from each project participant:

	Open Bid	Pre-Qualified Bid	1-Stage RFP	2-Stage RFP	Sole Source
Architect/Designer	○	○	○	○	○
GC, CM/GC or DB	○	○	○	○	○
MEP Contractors	○	○	○	○	○
Structural Contactors	○	○	○	○	○

Which of the following factors were considered in the selection of each project participant *(check all that apply)*?

	Price (Fee)	Price (Work)	Tech. Proposal	Design Concept	Similar Project Experience	Interview Performance
Architect/Designer	☐	☐	☐	☐	☐	☐
GC, CM/GC or DB	☐	☐	☐	☐	☐	☐
MEP Contractors	☐	☐	☐	☐	☐	☐
Structural Contractors	☐	☐	☐	☐	☐	☐

Select the commercial terms used for the following project participants:

	Lump Sum	GMP	Unit Price	Cost Plus
Architect/Designer	○	○	○	○ Fixed Fee / ○ % Fee
GC, CM/GC or DB	○	○	○	○ Fixed Fee / ○ % Fee
MEP Contractors	○	○	○	○ Fixed Fee / ○ % Fee
Structural Contractors	○	○	○	○ Fixed Fee / ○ % Fee

Were performance-based incentives used in any contracts? ○ Yes ○ No

Was the operation and maintenance of the facility included in the contract scope of any team member or members? ○ Yes ○ No

Did the project team use a formal partnering agreement? ○ Yes ○ No

If Yes, please explain:

SECTION 9: TEAM CHARACTERISTICS & BEHAVIOR

Indicate the owner's type of relationship with the project team:

Architect/Designer ○ First Time ○ Repeat

GC, CM/GC or DB ○ First Time ○ Repeat

Evaluate each of the following attributes of your project team:

Team's prior experience as a unit *(1=Low, 6=High)*:

Low ○ 1 ○ 2 ○ 3 ○ 4 ○ 5 ○ 6 *High*

Team chemistry *(1=Poor, 6=Excellent)*:

Poor ○ 1 ○ 2 ○ 3 ○ 4 ○ 5 ○ 6 *Excellent*

Relative to your expectations, denote the frequency of staff turnover within the project team *(1=Low, 6=High)*:

Low ○ 1 ○ 2 ○ 3 ○ 4 ○ 5 ○ 6 *High*

When was end-user feedback provided to the project *(check all that apply)*?

☐ Inception ☐ Conceptual ☐ DD ☐ Construction

☐ Programming ☐ SD ☐ CD ☐ Operation

Specify when each project participant was **co-located** or sharing a workspace with other team members *(check all that apply)*:

	Owner	Architect/ Designer	CM/GC	MEP Contractors	Structural Contractors
Design Phase	☐	☐	☐	☐	☐
Construction Phase	☐	☐	☐	☐	☐

Evaluate the communication among the project team:

Formality of communication *(1=Informal, 6=Formal)*:

Informal ○ 1 ○ 2 ○ 3 ○ 4 ○ 5 ○ 6 *Formal*

Timeliness of communication *(1=Never on time, 6=Always on time)*:

Never ○ 1 ○ 2 ○ 3 ○ 4 ○ 5 ○ 6 *Always*

How often did the project team compromise on project issues *(1=Never, 6=Frequently)*?

Never ○ 1 ○ 2 ○ 3 ○ 4 ○ 5 ○ 6 *Frequently*

Did the project team manage a shared, internal contingency usable by both design and construction team members? ○ Yes ○ No

Who participated in setting goals for the project *(check all that apply)*?

☐ Owner ☐ Architect/Designer ☐ GC, CM/GC or DB

☐ MEP Contractors ☐ Structural Contractors ☐ Other: ____________

To what extent were **all** project team members committed to the same project goals *(1=Very Weakly, 6=Very Strongly)*:

Weakly ○ 1 ○ 2 ○ 3 ○ 4 ○ 5 ○ 6 *Strongly*

SECTION 10: PROCESS AND TECHNOLOGY

Number of design charrettes held by the project team: _________

Who was involved with the design charrettes *(check all that apply)*?

☐ Owner ☐ GC, CM/GC or DB ☐ Structural Contractors

☐ Architect/Designer ☐ MEP Contractors ☐ Other: _____________

How was Building Information Modeling (BIM) used *(check all that apply)*?

☐ BIM was not used ☐ MEP Coordination/Clash Detection

☐ Architectural Design ☐ 4D Scheduling

☐ Engineered Systems Design ☐ Facility Management

Who was involved in developing a BIM execution plan *(check all that apply)*?

☐ No BIM execution plan was developed for this project

☐ Owner ☐ GC, CM/GC or DB ☐ Structural Contractors

☐ Architect/Designer ☐ MEP Contractors ☐ Other: _____________

To what extent was electronic file and information sharing used by the project team *(1=Primarily paper-based, 6=All electronic)*?

Paper-based ○ 1 ○ 2 ○ 3 ○ 4 ○ 5 ○ 6 *Electronic*

List any lean tools or approaches consistently used by the project team:

Evaluate the level of offsite fabrication and modularization used on the project *(1=Entirely built onsite, 6=Entirely built offsite)*:

Onsite ○ 1 ○ 2 ○ 3 ○ 4 ○ 5 ○ 6 *Offsite*

Did any prefabricated or modularized system on the project involve multiple trades? ○ Yes ○ No

SECTION 11: LESSONS LEARNED

Rate the overall success of this project *(1=Poor, 6=Excellent)*:

Poor ○ 1 ○ 2 ○ 3 ○ 4 ○ 5 ○ 6 *Excellent*

How could this project have been delivered more successfully?

Describe any unique features of this project that may have influenced its cost, schedule, quality or sustainability:

Appendix B: LATENT CLASS DESCRIPTIONS

Table B-1: Summary of project delivery classes

	Project Delivery Strategy				
Delivery Indicator	*Class I*	*Class II*	*Class III*	*Class IV*	*Class V*
Contract structure with owner:	Split	Split	Split	Combined	Split / Combined
Primary contractor involvement:	Bidding	CD / Bidding	Conceptual	Pre-Design	Pre-Design
Trade contractor involvement:	Bidding	Bidding	CD / Bidding	Conceptual	Conceptual / Schematic
Primary contractor procurement:	Open Bid	Prequalified Bid / 2-Stage RFP	1-Stage RFP / 2-Stage RFP	2-Stage RFP	Sole Source / 2-Stage RFP
Trade contractor procurement:	Open Bid	Prequalified Bid	Prequalified Bid	Prequalified Bid	1-Stage RFP / 2-Stage RFP
Primary contractor selection criteria:	Cost of Work	Best Value (Cost of Work)	Cost of Work / Best Value (Cost of Work)	Best Value (Cost of Work)	Qualifications / Best Value (Fee)
Trade contractor selection criteria:	Cost of Work	Cost of Work / Best Value (Cost of Work)	Cost of Work / Best Value (Cost of Work)	Best Value (Cost of Work)	Qualifications / Best Value (Fee)
Primary contractor payment terms:	Lump Sum	Lump Sum / GMP	GMP	Lump Sum	GMP

Appendix C: DESCRIPTIVE STATISTICS

Table C-1: Descriptive statistics for group cohesiveness measures

Group Cohesiveness Measures		**Descriptive Statistics**				
		Mean	SD	Min.	Median	Max.
Timeliness of communication:	Class I	2.26	.93	1	2	4
	Class II	2.63	.75	1	2	4
	Class III	2.87	.73	1	3	4
	Class IV	2.92	.64	1	3	4
	Class V	2.97	.74	1	3	4
	Overall (*n*=203)	2.77	.75	1	3	4
Commitment to project goals:	Class I	2.58	1.07	1	2	4
	Class II	2.94	.95	1	3	4
	Class III	3.11	.91	1	3	4
	Class IV	3.13	.93	1	3	4
	Class V	3.30	.92	1	4	4
	Overall (*n*=195)	3.07	.93	1	3	4
Team chemistry:	Class I	2.26	1.05	1	2	4
	Class II	2.82	.79	1	3	4
	Class III	3.20	.88	1	3	4
	Class IV	3.20	.79	1	3	4
	Class V	3.25	.87	1	3	4
	Overall (*n*=202)	3.05	.90	1	3	4
Frequency of compromise:	Class I	2.53	1.07	1	3	4
	Class II	2.94	1.22	1	3	5
	Class III	3.06	1.30	1	3	5
	Class IV	3.22	1.27	1	3	5
	Class V	3.37	1.38	1	4	5
	Overall (*n*=185)	3.08	1.27	1	3	5
Formality of communication:	Class I	3.26	.87	1	3	5
	Class II	3.32	1.12	1	4	5
	Class III	2.94	1.12	1	3	5
	Class IV	2.89	1.09	1	3	5
	Class V	2.61	1.15	1	3	5
	Overall (*n*=203)	2.97	1.11	1	3	5

Table C-2: Descriptive statistics for team integration measures

Team Integration Measures		**Descriptive Statistics**				
		Mean	SD	Min.	Median	Max.
Participation in BIM planning:	Class I	.07	.18	.00	.00	.60
	Class II	.11	.24	.00	.00	1.00
	Class III	.24	.35	.00	.00	1.00
	Class IV	.27	.33	.00	.00	1.00
	Class V	.20	.33	.00	.00	1.00
	Overall (*n*=204)	.20	.31	.00	.00	1.00
Number of BIM uses:	Class I	.89	1.05	0	1	4
	Class II	1.38	1.43	0	1	5
	Class III	2.07	1.53	0	2	5
	Class IV	2.05	1.49	0	3	5
	Class V	1.81	1.62	0	2	5
	Overall (*n*=204)	1.78	1.51	0	2	5
Participation in goal setting:	Class I	.37	.12	.20	.40	.60
	Class II	.42	.18	.20	.40	1.00
	Class III	.59	.18	.20	.60	1.00
	Class IV	.58	.17	.20	.60	1.00
	Class V	.54	.23	.20	.60	1.00
	Overall (*n*=195)	.53	.20	.20	.60	1.00
Participation in design charrettes:	Class I	.29	.22	.00	.40	.80
	Class II	.43	.30	.00	.40	1.00
	Class III	.54	.25	.00	.60	1.00
	Class IV	.71	.26	.00	.80	1.00
	Class V	.71	.28	.00	.80	1.00
	Overall (*n*=185)	.57	.30	.00	.60	1.00
Participation in co-location:	Class I	.00	.00	.00	.00	.00
	Class II	.12	.27	.00	.00	1.00
	Class III	.18	.32	.00	.00	1.00
	Class IV	.23	.33	.00	.00	1.00
	Class V	.26	.37	.00	.00	1.00
	Overall (*n*=204)	.18	.32	.00	.00	1.00
Offsite prefabrication:	Class I	2.32	1.11	1	2	5
	Class II	2.37	1.00	1	2	5
	Class III	2.51	1.01	1	2	5
	Class IV	2.62	1.21	1	2	5
	Class V	2.64	1.13	1	3	5
	Overall (*n*=201)	2.52	1.09	1	2	5

Table C-3: Descriptive statistics for cost and schedule metrics

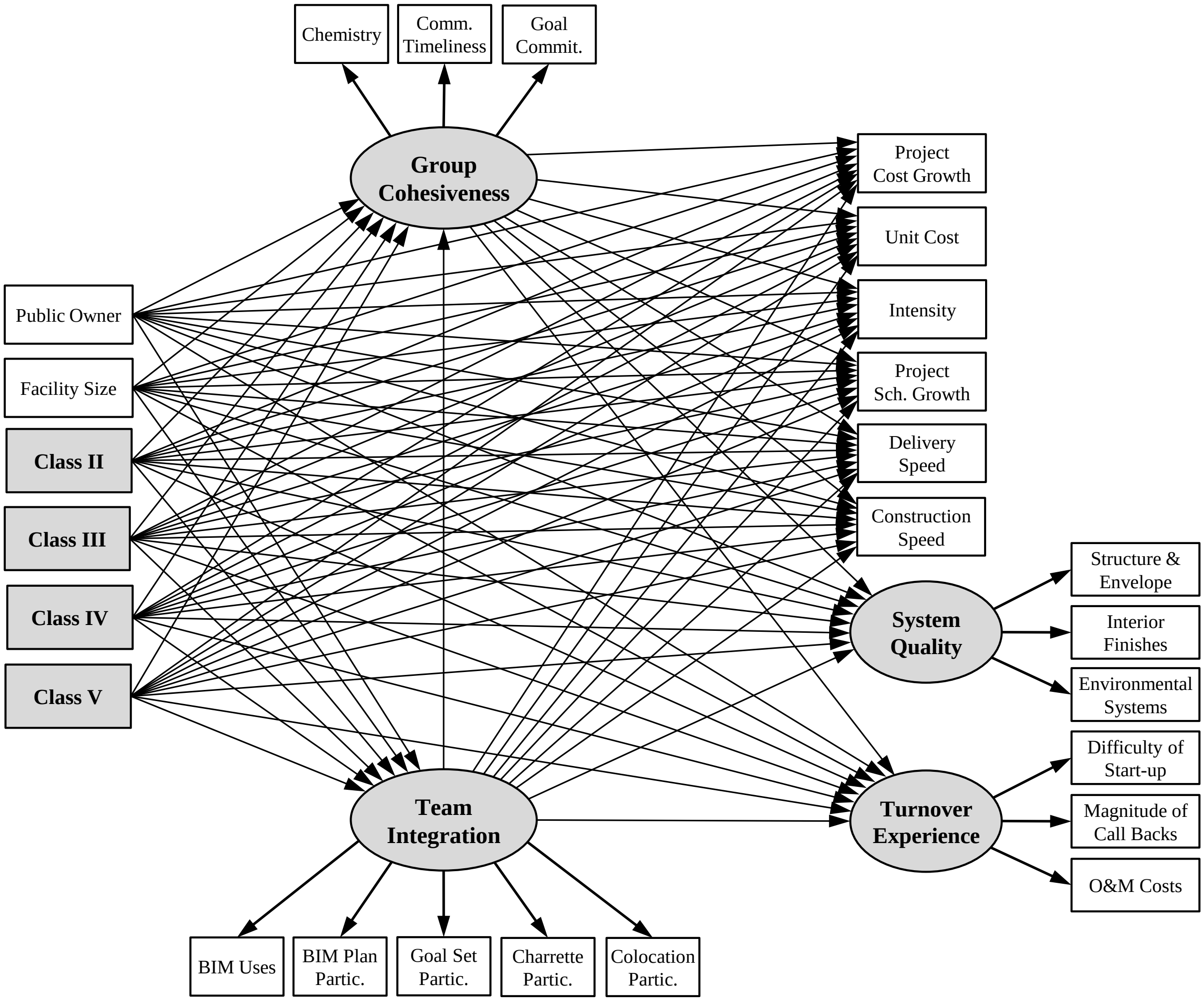
Performance Metrics		**Descriptive Statistics**				
		Mean	SD	Min.	Median	Max.
Cost growth (%):	Class I	5.34	6.72	-3.59	4.35	22.00
	Class II	2.43	7.90	-16.67	1.44	28.24
	Class III	3.19	8.07	-8.20	.50	33.33
	Class IV	5.14	7.68	-8.35	3.10	26.77
	Class V	1.81	5.75	-10.18	.41	16.62
	Overall (*n*=195)	3.57	7.51	-16.67	1.52	33.33
Unit cost ($/ft^2):	Class I	488	322	207	381	1,360
	Class II	480	286	94	440	1,209
	Class III	415	217	71	400	927
	Class IV	390	210	53	344	942
	Class V	380	235	97	288	893
	Overall (*n*=197)	422	245	53	380	1360
Intensity ($/ft^2/Month):	Class I	11.3	8.5	5.0	9.0	39.0
	Class II	12.5	8.8	3.0	10.0	38.0
	Class III	11.7	6.9	2.0	11.0	39.0
	Class IV	17.4	9.7	3.0	16.5	43.0
	Class V	15.9	8.9	4.0	14.5	42.0
	Overall (*n*=197)	14.1	8.9	2.0	12.0	43.0
Schedule growth (%):	Class I	4.56	8.40	-9.12	1.67	24.31
	Class II	3.77	12.64	-20.16	.00	36.87
	Class III	5.80	16.88	-9.59	.03	86.45
	Class IV	2.10	11.96	-37.48	.00	45.05
	Class V	2.19	18.41	-24.23	.00	74.11
	Overall (*N*=204)	3.64	14.49	-37.48	.00	86.45
Delivery speed (ft^2/Month):	Class I	2,849	3,315	140	1,502	11,408
	Class II	3,285	3,154	347	2,368	14,218
	Class III	7,009	7,022	172	4,307	32,487
	Class IV	7,277	7,433	410	4,634	41,763
	Class V	6,474	5,536	482	4,662	27,101
	Overall (*N*=204)	5,889	6,249	140	3,674	41,763
Construction speed (ft^2/Month):	Class I	5,389	4,844	225	3,893	18,254
	Class II	5,897	4,675	585	4,222	21,128
	Class III	11,306	10,265	611	7,198	47,645
	Class IV	10,141	9,488	669	6,895	50,919
	Class V	9,155	7,648	974	6,493	32,907
	Overall (*n*=197)	9,021	8,544	225	6,079	50,919

Table C-4: Descriptive statistics for quality measures

Quality Ratings		**Descriptive Statistics**				
		Mean	SD	Min.	Median	Max.
Difficulty of start-up:[1]	Class I	3.50	1.29	2	3	6
	Class II	4.44	1.55	1	5	6
	Class III	4.19	1.54	1	5	6
	Class IV	4.13	1.54	1	4	6
	Class V	4.42	1.47	1	5	6
	Overall (*n*=144)	4.19	1.51	1	5	6
Magnitude of call backs:[1]	Class I	3.62	1.71	1	4	6
	Class II	4.93	1.21	1	5	6
	Class III	4.43	1.66	1	5	6
	Class IV	4.63	1.23	1	5	6
	Class V	4.50	1.56	1	5	6
	Overall (*n*=143)	4.52	1.47	1	5	6
Operation and maintenance costs:[1]	Class I	3.67	1.87	1	4	6
	Class II	4.67	1.27	1	5	6
	Class III	4.11	1.33	1	4	6
	Class IV	4.39	1.35	1	5	6
	Class V	4.71	1.46	1	5	6
	Overall (*n*=135)	4.36	1.42	1	5	6
Satisfaction with structure and envelope:	Class I	2.57	1.09	1	3	4
	Class II	3.25	0.70	1	3	4
	Class III	3.42	0.83	1	4	4
	Class IV	3.00	0.89	1	3	4
	Class V	3.15	0.92	1	3	4
	Overall (*n*=145)	3.14	0.89	1	3	4
Satisfaction with interior finishes:	Class I	2.43	1.02	1	3	4
	Class II	2.89	0.79	1	3	4
	Class III	3.26	0.86	1	3	4
	Class IV	2.69	1.03	1	3	4
	Class V	2.77	0.99	1	3	4
	Overall (*n*=145)	2.87	0.96	1	3	4
Satisfaction with environmental systems:	Class I	2.64	0.63	2	3	4
	Class II	3.10	0.86	1	3	4
	Class III	2.97	0.91	1	3	4
	Class IV	2.67	1.06	1	3	4
	Class V	2.85	1.08	1	3	4
	Overall (*n*=146)	2.86	0.96	1	3	4

[1] Rating scales were reversed from raw data for consistency. Higher numbers correspond to easier start-up, fewer call backs and lower O&M costs

Appendix D: EXPANDED STRUCTURAL MODEL



Appendix E: WHITE PAPER

Owner's Guide to Maximizing Success in Integrated Projects

A Summary of Study Performance Metrics

White Paper for Industry Advisory Panel Use Only

November 2012

A white paper for the Charles Pankow Foundation
and the Construction Industry Institute

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INTRODUCTION

Successful project completion is an owner's primary goal. Key owner project delivery decisions involve the selection of an organizational structure, team selection, and contract payment definition. These decisions have been shown to affect the performance and overall success of a project. There is interest among owners to understand the relationships among these decisions and typical definitions of project success such as cost, time, and quality outcomes. However, there is little data available to support these complex decisions. Therefore, creating an empirical database to compare the performance of various project delivery decisions is promising. This type of quantitative evidence will improve the impact and reliability of key projects decisions. One of the main studies that addressed this owners' need was conducted by the Construction Industry Institute (CII)[1].

In 1998, CII and Penn State University completed a research study titled "Project delivery systems: CM at risk, design-build, design-bid-build." The goal of the study was to improve delivery method selection by providing practical guidelines though empirical evidence. To fulfill this objective, key performance metrics (cost, schedule, and quality) of projects under the three most common project delivery systems in the US were compared for 351 building projects. Multivariate linear regression models were developed to predict average project performance using near 100 explanatory and interacting variables. It was concluded that the DBB projects had higher unit cost, and slower construction and delivery speed (Table 1). The DB projects also had the lowest schedule and cost growth. While the unit cost, construction and delivery speed had higher level of certainty, cost and schedule growth explained a significantly lesser degree of variation. The most prominent contribution of the study was to provide guidance for owners on how to organize a successful project. The results were widely disseminated through the construction industry and highly recognized by both academia and practitioners. The salient findings of this study are summarized in Table 1.

***Study Benefit*:**

Creating an empirical database to compare the performance of various project delivery decisions, will yield a suite of guides to help owners successfully finish capital design and construction projects.

Table 1. Summary of principal metrics studied by CII (1998)

Performance metrics	DB vs. DBB	CM@R vs. DBB	DB vs. CM@R	Level Of Certainty
Unit Cost	6.1% lower	1.6% lower	4.5% lower	99%
Construction Speed	12% faster	5.8% faster	7% faster	89%
Delivery Speed	33.5% faster	13.3% faster	23.5% faster	88%
Cost Growth	5.2% less	7.8% more	12.6% less	24%
Schedule Growth	11.4% less	9.2% less	2.2% less	24%

MOTIVATION FOR CONDUCTING A NEW STUDY

While the contribution of the CII study was outstanding, there are several limitations in applying its findings to the contemporary projects:

- The data is 15 years old and the landscape of the construction industry has changed significantly. For example, new developments in project integration and team behavior have surfaced and may affect project performance. These factors were not considered in past studies.
- The performance criteria used in the study were limited to cost, schedule, and quality. However, new performance criteria have been tested over the past 15 years such as absence of legal claims, safety, and owners' satisfaction[2,3,4]. Including these performance criteria can provide a better assessment of project success.
- Finally, the focus of CII was mainly on delivery methods while recent studies have shown that team selection and contract methods can also considerably affect the project performance[5].

Therefore, conducting a new study to address these limitations has a great practical contribution to aid owners to overcome challenges in selecting suitable project delivery system. In the following sections of the paper, the point of departure, survey instrument development, dependent variables, and independent variables will be discussed.

Why is there a need for new study?

- ✓ *The original CII project data is 15 years old;*
- ✓ *New concepts are being introduced and tested in industry, such as project integration and team behavior;*
- ✓ *The performance outcomes collected in the CII study was limited to cost, schedule, and quality;*

POINT OF DEPARTURE

This study departs from the current body of knowledge by collecting quantitative data on emerging issues and practices such as project integration, team selection, and team behavior as potential indicators of project success. The result will be developing a large, comprehensive, and reliable project delivery performance database to study relationships among project delivery decisions, team factors and project outcomes.

DEVELOPING SURVEY INSTRUMENT

To develop a "project delivery performance database", a survey questionnaire must be developed to capture relevant historical information from industry. This questionnaire will be based on an in-depth literature review of studies related to project performance metrics and critical success factors. Two types of variables were identified from literature: dependent and independent. The dependent variables are project outcomes that reflect the measured performance or success of the project. The independent variables are those factors, including project delivery decisions, which can impact performance outcomes. The relationship between independent and dependent variables is depicted in Figure 1. As it is shown, independent variables (e.g. delivery methods) will be used to predict the amount of changes in dependent variables (e.g. cost, time, quality, etc). The notable results of the literature review and discussion of dependent and independent variables are provided in the following sections.

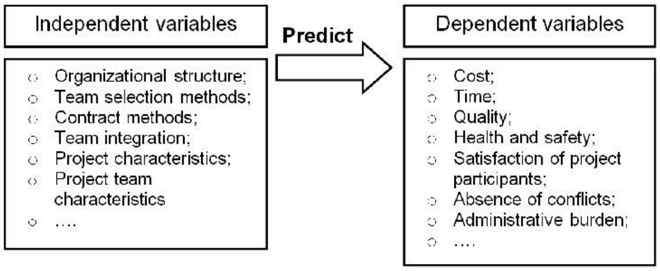

Figure 1. The relationship between independent and dependent variables

DEPENDENT VARIABLES

Project outcomes and defining success

Quantifying project success is challenging because the definition of success varies by stakeholder. For example, contractors may consider profitability on a project as the most important measure of success, while the owner may place more emphasize on completing the project on time or to a certain level of quality. In literature and practice, the outcomes most frequently used to define project success are cost, time, and quality (also known as the iron triangle[2]). Other researchers have suggested more subjective outcomes such as participant satisfaction[3], the absence of legal claims[4], safety records[6], aesthetics[7], flexibility to users[8], friendliness of environment[9], and meeting specifications[10] as additional indicators of project success. Recently, in addition to these success criteria, the "level of achievement in sustainable high-performance standards" is also considered important to measure outcomes of green and sustainable building projects[11].

By reviewing large number of studies, the research team found the following success criteria to be the most cited categories

(Figure 2): cost; time quality; health and safety; satisfaction of project participants; absence of conflicts and administrative burden.

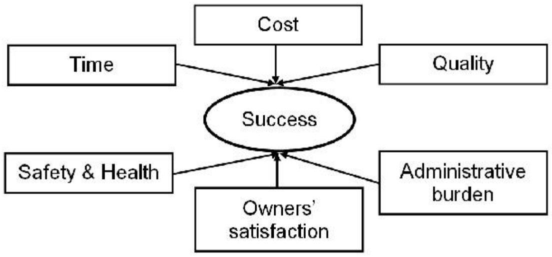

Figure 2. Common categories of performance criteria

Performance metrics

Performance of construction projects should be measured both in-progress and at completion to inform decisions and enable continuous improvement processes. Performance metrics usually measure change from the original contract's time and cost. Different metrics identified in previous literature are summarized below:

- *Cost*: unit cost (design, construction , and DB); cost growth; award growth; intensity; average cost per change order; average percent increase per change order; and average liquidated damages as percent of total cost.
- *Time*: construction speed; delivery speed; schedule growth (design/construction); and average percentage of additional days granted.
- *Quality*: turn over (start up, call backs, submittal review, operation and maintenance costs); system (envelope, roof, structure, foundations, interior space and layout, environmental system), process equipment, and layout.
- *Design and/or Construction Intensity*: a measure of cost per unit of time ($/month or $/SF or time/SF).
- *Owners' satisfaction*: Likert scale.
- *Safety and health*: recordable injury rate (RIR), days away, restriction, and transfers (DART); experience modification rate (EMR); lost time case rate; lost work day rate.
- *Administrative burden*: Likert scale.

These performance metrics can be grouped into three main categories[11]:

- *Relative*: these measures are independent from the size of a project and are expressed as a percentage such as cost, time, and award growth.
- *Static*: these measures are discrete numerical measures that do not change with time, such as design and construction unit cost.
- *Dynamic*: dynamic measures vary with time and are project size dependent such as intensity and design/construction placement.

There are some limitations regarding common performance measures[12]. First, these measures do not indicate the reason for change or assign responsibility for change. For example, cost growth can occur due to poor or incomplete design documents, costly unforeseen site conditions or mismanagement by the general or specialty contractor. In these examples, fault for the increase in project cost varies by cause. Second, careful attention should be paid to interpret performance measures. For instance, negative metrics for cost and schedule growth are typically considered as an indicator of successful project; however, these values can occur due to scope reductions by owner, rather than superior management by the project team. The third issue that should be considered in applying project performance metrics is the type of construction or contractual basis of construction projects. For example, vertically oriented projects tend to have fixed price contracts, such as lump sum, while horizontally oriented projects are typically reimbursed by GMP or cost plus a fee. Cost plus contracts are based on actual quantities and work-in-place, so cost growth is not a strong indicator of success. As a result, it is more difficult to measure performance metrics on horizontal projects.

INDEPENDENT VARIABLES

Six independent variables identified from the literature: (1) organizational structure; (2) team selection methods; (3) contract methods; (4) team integration; (5) project characteristics; and (6) project team characteristics. These variables are explained in more details in the following sections.

Organizational structure

The orginazational structure used on construction projects has been found to influence project outcomes. It is therefore important to determine the most suitable structure during the development phase of a project. Several studies were conducted to compare performance of construction projects under different organizational structures (i.e., DBB, DB, and

CM at risk)[4,13,14,15]. These studies were aimed at informing owners making project delivery decisions according to their objectives and level of risk aversion. For example, Ibbs et al. (2003)[16] analyzed the characteristics of 67 global projects and found that the performance of DB projects is not superior to DBB method in all criteria. The study indicated that the project management expertise and experience of the contactor may have a greater impact on project performance outcomes than just project delivery strategy. In another study, the performance of 39 DBB projects and 38 DB projects was compared empirically and found that DB projects takes less time to complete and have less time and cost growth. The strength of their study was that they compared similar military buildings of the same typology which could result in a more meaningful comparison[17]. In summary, it can be concluded that owners selecting a DB method can expect less cost and schedule growth in comparison to other organizational structures. However, no study could conclude a significant relationship between specific delivery method and better quality performance.

Most of the previous studies compared project performance of DB and DBB organizational structures for building projects (vertical construction) and industrial projects, with limited studies comparing the performance on highway projects (horizontal construction). To address this gap in the knowledge, the relationship between project performance outcomes (i.e., cost, schedule, and change orders) and project characteristics of 130 large highway projects (>$50 million) in Texas was evaluated[18]. The researchers concluded that the construction speed and project delivery speed per lane mile of DB projects were significantly faster than of DBB projects.

As new methods and practices have been introduced into the industry, researchers have studied additional methods of project performance. Korkmaz et al. (2010)[11] examined more than 100 variables in green project delivery to identify important metrics those lead to project success. The results indicated that the following performance metrics were more likely to be affected by project delivery processes: intensity, construction speed, unit cost, energy rate, and green rate. In a similar study, the extent of influence of different project delivery attributes on project outcomes of 12 sustainable, high-performance office buildings was studied[19] and found that strong owner commitment towards sustainability, the integration in the delivery process by an early involvement of the constructor, and the early inclusion of green strategies (contractual relationship) were crucial attributes to delivery process.

Recently, new delivery concepts are being introduced and tested in the construction industry, such as the multi-party contracts used in Integrated Project Delivery (IPD). Owners who utilize IPD aim to enhance project outcomes thorough increasing collaboration among different party members[20]. The main principals of IPD can be summarized as multiparty agreement, early involvement of all parties, and shared risk and rewards[21]. While several studies demonstrated IPD's superior performance to traditional delivery methods, the adoption of IPD in US is still very low.

Team selection methods

Several studies evaluated the impact of team selection methods on project performance outcomes. For example, the performance of public DB projects was compared under three different team selection methods used by public owners[14]: the one-step; two-step; and qualifications based. It was found that the two-step method had the least cost (3% over) and schedule growth (2% behind). The one-step projects were second, which delivered on average 4% over budget and 3.5% behind the schedule. The qualifications based procurement method had the worst measured cost (5.6% over) and schedule (3.5% behind) performance.

In another study, the data from 76 DB projects was collected to develop a series of guidelines to help owners in selecting the design-build team aligned with their project goals[5]. The performance metrics were based on the traditional outcomes of time, cost, and quality and the team selection methods were sole source, qualification-based, best value, and low bid selection. While the findings of the study illustrated that there were no specific team selection methods that outperform all others across every performance metric, the qualification-based selection method showed the lowest cost growth.

Contract methods

In one of the recent studies, Bogus et al. (2010)[21] compared the performance of public water and waste water projects procured under cost-plus fee with a guaranteed maximum price (GMP) contracts with traditional lump sum contracts. The data was collected from 9 projects and the results showed that the mean cost growth of projects procured under cost-plus fee with GMP contract was significantly less than that of projects procured under lump sum contracts.

Team integration

Project performance cannot be improved without effective team working and several studies stated that "relational integration" is a prerequisite for successful teamwork[23]. One of the prominent examples of relational contracts in the U.S. is Integrated Project Delivery (IPD) method. While IPD is a new project delivery method, its main objective is to increase the likelihood of success by promoting trust, cooperation, and teamwork and reducing waste, inefficiency, and adversarial relationship. Several IPD principals identified from the previous literature: multi-party contract; shared risk and rewards; liability waivers; early involvement of key participants; collaborative decision making and control; and jointly developed goals[24,25,26]. To provide standardize contractual documents for multi-party contracting, American Institute of Architect (AIA)[20] and Associated general Contractors (AGC)[27] initiated development of their own type of multi-party contract documents.

Project characteristics

Project characteristics identified from the literature are: ownership of building, gross floor area of the project, type of building, level of design/construction complexity, percent of repetitive elements, level of technologically advancement, and level of specialization required of contractors.

Project team characteristics

Team characteristics usually reference the following factors for the owners, designers, and contractors: experience with similar projects (i.e. size, type, etc); level of sophistication; communication among project team members; track record for successful completion of project; staffing level; adequacy of plant and equipment; key personnel's management ability; ability in financial management; quality control and management capacity; health and safety management capability; and magnitude of change orders, claims, and disputes in contractor's past projects. Some studies assessed the relative importance of these characteristics. For example, Ling (2004)[28] collected data from 42 public and private projects to identify key factors that affect performance of DB projects. He found that the contractor's characteristics are key determinants that impact many of the typical performance metrics. Other studies also found that project nature, the effective project management action, adoption of innovative management approaches, project team commitment, contractor's and client's competencies are success factors for projects[29,30].

CONCLUSIONS

This study aims to develop a project performance database and investigate the role of project delivery decisions (organizational structure, contract type, team selection) and team integration in project success. An in-depth literature review was conducted to identify the critical variables that should be captured in the database. Questions to populate a survey instrument were collected for the factors presented. The questions will be reviewed at an upcoming workshop to develop a comprehensive survey that will be used to gather the required information. The final results of the study will empower owners to make informed decision regarding the selection of factors to drive successful levels of integration on their projects.

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Appendix F: OWNER'S GUIDE

In an effort to develop an Owner's Guide to Integrated Projects, the process developed in the following pages was based upon the results of an empirical study of more than 200 completed projects. Using a variety of statistical methods to gain a full understanding of the projects, and relationships contained therein, the main finding of the research was that delivery decisions, (e.g. organizational structure, procurement processes, and contractual terms) could not be made independent from one another but need to be designed in concert, as a strategy. In particular, the strategies which aligned the project team, through both *integrated processes* and development of a *cohesive group*, were the only means for achieving measures of project success – cost, quality, and schedule performance.

While the development of the team is likely not a surprising insight for many who have experience within the construction industry, the challenge of designing team performance into the delivery process for a project may seem more like random chance than thoughtful strategy. Three critical elements emerged from the empirical research which serves as the themes for enabling the more effective development of a cohesive and integrated team through delivery strategy. Developing a team able to deliver the desired project results was best enabled through: early involvement of the core team, qualification based selection of team members, and transparency in cost accounting. Early involvement, not only of the builder but of critical design-build or design-assist specialty contractors as participants in the design process, is an essential element to delivery of integrated project requirements. Engagement in the process was critical before the development of the schematic design of the project to garner full value from this approach. Early involvement is necessary to enable their participation in key collaborative processes, such as the development of project goals, participation in design charrettes, and the development of a BIM Execution plan. The value of participation is not only at the front end of the process, but continued interaction through construction using strategies, such as colocation and increased sharing of model information through the lifecycle of the project, indicate the need to maintain this collaboration beyond the early design process.

To enable the early and high quality interactions to take place amongst project team members, the means of assembling the team by engaging the builder and specialty trades for the project is essential. Projects with the most cohesive teams relied primarily on qualifications submissions and interview processes to assess the quality of the team members. The shift away from selection based on the cost of the construction scope, toward the qualifications and team chemistry of potential collaborators, is an essential first step to breaking down the barriers to developing an effective team. Incorporating new team members process needs to be considered beyond the selection of firms, and used in the on-boarding every new team member as the project continues.

Finally, the contractual terminology used by the project team needs to reinforce the approach and strategy in aligning the interests of the team. Contracts which bring the team together with shared risk and reward were most common in the delivery of successful projects. In addition, the use of open book accounting processes during the design proved critical in the development of trust amongst the project team. While most common in the builder's contract, the projects in the most effective class often extended this transparency to the core team of specialty trades.

These themes―early involvement, qualification driven selection, and cost transparency―may be incorporated into a variety of delivery strategies. The key to the process lies in designing a strategy that enables the team processes best suited to your project needs. The pages that follow will help you in defining your project needs and constraints, and offer paths to improving the team capabilities through the design of a delivery strategy; extending beyond the methods, procurement, and contract to outlining an approach to the integrated process and team development needs for your project.

The Owner's Guide can be accessed at: http://bim.psu.edu/delivery

Appendix G: DISSEMINATION PLAN

Introduction

The research team benefited from strong industry collaboration on this project. Mr. Greg Gidez, Corporate Director for Preconstruction and Design Management Services for Hensel Phelps Construction Co., and Dr. Mark Konchar, Vice President Business Acquisition for Balfour Beatty Construction served as the industry champions for the project and as co-chairs for the industry panel. Mr. Gidez is a licensed architect and is active in the leadership of the Charles Pankow Foundation (CPF) and the Design-Build Institute of America (DBIA). Dr. Konchar, along with Dr. Sanvido who served on the advisory panel, were principal investigators on the 1997 project delivery study for the Construction Industry Institute (CII), “Project delivery systems: CM at Risk, Design-Build, Design-Bid-Build,” which has proven to be the seminal empirical study on project delivery methods for the building design and construction industry. The co-chairs proved to be invaluable in assisting the research team with scoping, data collection and review of the final project results.

The research team and the co-chairs formed an industry advisory panel with leaders from the design and construction industry. The following members actively participated in the project:

- Mr. Greg Gidez, Hensel Phelps Construction Co.
- Dr. Mark Konchar, Balfour Beatty Construction
- Mr. Howard W. Ashcraft, Esq., Hanson Bridgett LLP
- Dr. Russell Manning, Department of Defense
- Mr. Spencer Brott, Trammell Crow Real Estate Services, Inc.
- Dr. John Miller, Barchan Foundation, Inc.
- Mr. Bill Dean, M.C. Dean, Inc.
- Mr. Brendan Robinson, U.S. Architect of the Capitol

- Mr. Tom Dyze, Walbridge
- Dr. Victor Sanvido, Southland Industries
- Mr. Matthew Ellis, US Army Corps of Engineers
- Mr. Ronald Smith, Kaiser Permanente
- Ms. Diana Hoag, Xcelsi Group, LLC
- Mr. David P. Thorman, FAIA, Former California State Architect
- Mr. Mike Kenig, Holder Construction

The industry panel assisted the team with the development of the final data collection questionnaire, helped with testing, contributed project data to the study and reviewed the final results. They also helped the team to develop products that are ready for immediate implementation. The research team is indebted to them for their assistance and thankful for all of their advice.

Dissemination Accomplishments to Date

While the data collection portion of this study took longer than planned due to the detailed nature of the data collection requirements, the research team has met all of its dissemination goals to date. The following are papers, proceedings and presentations that have been completed to date.

Reports

Esmaeili, B., Franz, B., Messner, J. Leicht, R. M. and Molenaar, K.R. (2012) "Owner's Guide to Maximizing Success in Integrated Projects: A Summary of Study Performance Metrics," *White Paper for the Charles Pankow Foundation and the Construction Industry Institute*, November 2012.

Conference Presentation with Paper

Esmaeili, B., Pellicer, E., and Molenaar, K.R. (2014). "Critical Success Factors for Construction Projects," *18th International Congress on Project Management and Engineering*, Alcañiz, Spain, July 2014. (Note: this paper won the *Jaume Blasco*

Award for Innovation, the second place paper award in project management track of the conference.)

Pellicer, E., Sanz, A., Esmaeili, B. and Molenaar, K. (2014). "Collaborative Behavior in the Spanish Building Industry: A Preliminary Analysis," *18th International Congress on Project Management and Engineering,* Alcañiz, Spain, July 2014.

Franz, B., Esmaeili, B., Leicht, R.M., Molenaar, K.R., Messner, J. (2014). "Exploring the Role of the Team Environment in Building Project Performance," *2014 ASCE Construction Research Congress,* Atlanta, GA, March 2014.

Esmaeili, B., Franz, B., Molenaar, K.R., Leicht, R.M., Messner, J., (2013). "Construction Projects' Performance Metrics and Critical Success Factors." *CSCE Annual Conference (CSCE 2013)*, Montreal, Canada, May.

Conference Presentations

"Measuring Project Delivery Performance," *Pankow Foundation Board of Directors Meeting*, Denver, CO, June 2012.

"Project Delivery Selection," *Design-Build Institute of America Rocky Mountain Region Annual Conference,* Denver, CO, May, 2013.

"Project Delivery Performance: Lessons Learned from Vertical Construction", 2014 Transportation Research Board (TRB) and National Institute of Building Sciences (NIBS), AFH30: Digital Project Delivery, Washington DC, January 2014.

"Project Delivery Performance: Lessons Learned from Vertical Construction", *Project Management Institute (PMI) Mid-Nebraska Chapter*, Lincoln, NE, May 2014.

"Impacts of Project Delivery Methods on Project Outcomes" Construction Management Association of America, Capital Projects Symposium, Baltimore, Maryland, May 2014.

"Project Delivery Research," as part of the *Research Trends* Panel, The Design Build Association of America, Annual Conference, Dallas, TX, November 2014.

" Driving Innovation Through Facilitated Collaboration," Construction Owners Association of America, Annual Conference, November 20, 2014.

Project Website

Project Data Collection Website: https://cpf.colorado.edu

The project data collection website was developed with the intent of providing basic project information and disseminating the project data collection survey. Additionally, the website was used to disseminate the project team's white paper titled "Owner's Guide to Maximizing Success in Integrated Projects: A Summary of Study Performance Metrics." The website proved useful for general communications during the project.

Project Dissemination Website: http://bim.psu.edu/delivery

The project dissemination website will aid in publishing the completed project information and the on-going owner guidance. The site design is being modeled from the successful BIM Planning Website (http://bim.psu.edu/) that contains the BIM Project Execution Guide, which is a similar product from a CPF/CII/Penn State research collaboration. The website will be used to disseminate the project's research report, owner's guide, project data for future researcher's use and on-going research relating to this study.

Continuing Dissemination Plan

While the project is complete, the project team remains committed to disseminating the research through conference presentations, peer-reviewed journal publications and dissemination of the owner's guides through the project dissemination website.

Dissemination Focus

The focus of the project team's continuing efforts is to facilitate owner decision making in relation to the project delivery process. The owner group includes the facility managers, operators and end users. Owner representatives, or agency firms, will also receive benefit from the resources. More broadly, this research will be helpful to all members of the construction industry. It helps to determine the various stakeholders' responsibilities, requirements and deliverables. By utilizing the research products, the various project team members will be better able to meet the needs of the facility owner and end users. Furthermore, many of the industry professional organizations have interests in the research products and will provide opportunities for dissemination at their conferences and meetings.

Conference Presentations

The research team and members of the advisory panel are committed to "getting the word out" through meeting and conference presentations. This has been demonstrated by the presentations of in-progress work that has already been made. The team will now more aggressively seek opportunities for dissemination in the coming year. The following are conferences at which the research team is committed to present its findings pending final acceptance of our presentation proposals.

- Associated General Contractors of America Public/Private Industry Advisory Council's On-Line Meeting Forum, Feb 2, 2015

- “Project Delivery Performance: The Impact of Team Selection Process”, 2015 Nebraska Architectural Engineering Conference (NAEC) - AEI/ASHRAE Expo, Omaha, NE, March 2015
- Architectural Engineering Institute – Annual Conference – Milwaukee, March 27 2015
- PACE Research Seminar 2014, April, University Park, PA.
- Construction Owner’s Association of America, Spring Owners Leadership Conference, May 13-15, 2015, Baltimore, MD
- Canadian Society for Civil Engineering Construction Specialty Conference, Jun 8-10, 2015, Vancouver, British Columbia
- CII Annual Conference, Aug 3-5, 2015, Boston, MA
- DBIA/Society of Military Engineers (SAME) Federal Project Delivery Symposium, Aug 18-20, Washington, DC
- DBIA Annual Conference and Expo, Nov 2-4, 2015, Denver, CO
- Construction Management Association of America (CMAA), National Conference & Trade Show, October 11-13, 2015, Orlando, FL

Typical Media Release(s)

Upon review of the research products by CPF and CII, the team will use media releases to various venues to announce the research project’s purpose, results, outcomes, and products. The releases will include the reason for the release, the projects website, as well as a thank you to the project sponsors including the Charles Pankow Foundation and CII. The following is an example of a typical media release:

> The University of Colorado and Pennsylvania State University are pleased to announce the release of the Owner’s Guide to Maximizing Success in Integrated Projects. The Guide provides a practical manual to assist owners when organizing and executing projects with integrated teams. The Guide is available for download on the project’s website (www.xxx). The research team would like to thank the Charles Pankow Foundation and the Construction Industry Institute

for their generous support of this project. We would also like to thank the more than 200 individuals who provided empirical data for this study.

Paper in Process

The team is currently working on manuscripts for multiple peer-reviewed journals. The goal of these publications is to share the details of the research methods, data analysis and results with other researchers. By adding to the body of research knowledge in the area of project delivery methods and integration, the research team hopes to spur continued study that builds upon the findings of this research. The peer-reviewed journals include, but are not limited to:

- Journal of Management in Engineering (paper and electronic)
- Journal of Construction Engineering and Management (paper and electronic)
- Engineering, Construction and Architectural Management (paper and electronic)

Conclusions

The research team is aware of CPF's and CII's strong commitment to putting their research results into practice. The completed and future actions described in this dissemination plan provide evidence of the research team's commitments to these same goals. Although the funding for this project has been expended, the research team is dedicated to the topic and looks forward to disseminating the findings in 2015 and beyond. The results are expected to have a lasting impact on the industry. The results are also expected to spur future research initiatives through a discussion of the results and the questions that remain.