EVALUATION OF
INTEGRATED PROJECT DELIVERY ON
THE PERFORMANCE OF CONSTRUCTION PROJECTS

by

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To my wonderful wife and children. Your devoted love and eternal happiness are truly inspirational. Thank you for your constant support and patience.
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Abstract

The construction industry is fraught with waste and inefficiencies resulting in projects often failing to meet owners’ expectations. Integrated Project Delivery (IPD) is the newest project delivery system and changes the traditional roles and relationships of key project stakeholders. Through increased early collaboration IPD attempts to eliminate waste and deliver the highest value projects to owners. It is seen as a potential solution to many of the challenges impeding successful project performance. However, a transformational change towards IPD has yet to reach a “tipping point” and its use is not prevalent throughout the construction industry. Little research has been done to quantitatively analyze IPD compared to the more commonly used delivery methods. Through substantial collection of quantitative project performance data and univariate statistical analysis, this study fills the gap in research by evaluating the effects of IPD on building construction projects across a wide range of performance metrics from the perspective of general contractors and construction managers. This research demonstrated that IPD/IPD-ish outperformed Non-IPD projects with respect to performance in communication, change management, and business performance areas. Evidence of superior communication performance was found in terms of the number of requests for information (RFIs) per million dollars; change management in terms of change order processing time; and business performance in terms of a project’s impact on company image and the potential for return business. A new term called the Project Quarterback Rating (PQR) that combines key performance metrics was used to quantitatively evaluate overall performance. Statistically significant evidence of overall superior IPD/IPD-ish performance was found compared to Non-IPD projects. This research also evaluated other project attributes and found evidence suggesting that higher overall performance was related to implementation of Lean construction techniques, a more engaged and empowered project leadership team, a higher level of stakeholder involvement throughout a project,
and inclusion of an incentive clause in a construction contract. The results should encourage owners to consider the use of IPD, or the utilization of IPD principles in conjunction with other delivery methods, in future capital facilities endeavors.
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Chapter 1. Introduction

There is significant opportunity to improve project delivery in the construction industry. Frequently projects fail to meet owners’ expectations performing poorly with respect to the most commonly used success measures, cost, schedule, and quality (CURT 2007). Thomsen et al. (2010) reported that 40-50% of construction projects consistently fell behind their original schedule. A root cause of chronic schedule and cost overruns is an inherent lack of cooperation and poor integration between key project stakeholders (CURT 2004). It has been estimated that $200B of the $650B annual expenditure on construction in the U.S. can be attributed to mistakes, inefficiencies, and delays (Economist 2000).

Traditional project delivery systems (PDSs) operate in mutually exclusive silos that inefficiently pass information between stakeholders (AIA 2007a). Approximately $17-36B is lost annually due to communication breakdowns between designers and constructors alone (Forbes and Ahmed 2011). Integrated Project Delivery (IPD) removes the barriers that encumber other PDSs and has been regarded as a viable solution to the construction industry’s productivity challenges (Thomsen et al. 2010). Its foundation of principles are considered advantageous “…to optimize project results, increase value to the owner, reduce waste, and maximize efficiency through all phases of design, fabrication, and construction” (AIA, 2007). However, there is a void of quantitative research that supports the beneficial claims of IPD which provides the opportunities for this research to contribute to the body of knowledge regarding IPD.

1.1 Definition of Terms

Before evaluating the impacts of IPD principles on project performance it is important to establish a common understanding of some key terms as they apply to this research. IPD terminology
is not consistent throughout the construction industry which can potentially be confusing (El Asmar 2012; Cho and Ballard 2011). A more thorough discussion of terminology is presented in Chapter 2 and only the key definitions used in this research are presented in this section. For this research a project delivery system (PDS) is defined as “the system that defines the relationship between different contracting parties and the timing of involvement in that relationship” (Hanna 2010).

The PDSs included in this research were IPD, construction management at risk (CMR), design-build (DB), and design-bid-build (DBB). The most common delivery system is DBB where the owner enters into two separate, sequential contracts with the designer and builder (CMAA 2012). In short, DBB is the least integrated approach where the design is 100% complete and is used to solicit bids from construction contractors. This linear approach virtually eliminates the opportunity to incorporate the builder’s expertise early in the capital facilities process which can result in inefficient designs, increased errors and disputes, higher costs, and longer project durations (Konchar and Sanvido 1998). In CMR, among other roles, a Construction Manager acts as an advisor to the owner throughout the design phase. The CMR is subsequently responsible for meeting the guaranteed maximum price (GMP) at the end of the project. DB is where an owner enters into a single contract with one entity for the design and construction of a project (Halpin 2006). Diagrams of the formal relationships are shown below in Figure 1. Throughout this thesis these three delivery methods will be referred to as “traditional” PDSs.
There are various definitions of IPD used throughout the AEC community which are discussed in greater detail in Chapter 2. For this research IPD (as a project delivery system) is defined as “a method of project delivery distinguished by a contractual arrangement among a minimum of owner, constructor and design professional that aligns business interests of all parties” (AIA and AGC 2011). IPD principles inherent in this definition include the following:

Contractual:

- Key participants bound together as equals
- Shared financial risk and reward based on project outcomes
- Liability waivers between key participants
- Fiscal transparency between key participants
- Early involvement of key participants
- Intensified design
- Jointly developed project target criteria
- Collaborative decision making

Behavioral:
- Mutual respect and trust
- Willingness to collaborate
- Open communication

Figure 2 provides a graphical representation of IPD where the overlapping circles represent contractually required collaboration with shared risk and reward between at least the owner, designer, and builder through a multi-party agreement.

Figure 2: Minimum Formal Relationship in an IPD Project

IPD principles can be applied to a variety of delivery systems (AIA 2007a). CMR and DB projects that do not utilize a multi-party contract but incorporate some of the IPD principles listed above to achieve an “enhanced” level of collaboration are called IPD-ish (NASFA et al. 2010). DBB cannot achieve an integrated approach because of the inability to get all three key stakeholders involved early in the planning or design of a project (AIA 2007b). Therefore, they cannot be considered IPD-ish. For this research, multiple projects were identified by Project Managers (PMs) as being IPD-ish. They incorporated many of the core IPD principles yet lacked a multi-party contract.

As part of this research a comprehensive metric, the Project Quarterback Rating (PQR), was used to evaluate overall performance. As the name implies, the PQR was modeled after the National Football League’s Quarterback Rating that uses key performance metrics to measure and equitably
compare quarterbacks. Similarly, the PQR combines key performance metrics that impact a project’s outcome. A full discussion of PQR is provided in Chapter 5.

One of the other potentially confusing aspects of the IPD discussion within the AEC community is the often interchangeable use of the terms “Integrated Project Delivery”, “Lean construction”, and “Lean Project Delivery System (LPDS™)”. According to the Lean Construction Institute (LCI) website, “Lean construction is a production management-based approach to project delivery” with the objectives to maximize value and minimize waste (LCI 2013a). Lean construction is mutually supportive of a common goal of achieving project success in combination with IPD (NASFA et al. 2010). LPDS™ was coined by LCI and is a lean technique used to maximize collaboration among team members and integrate all phases of a project from development to utilization (LCI 2013b). Some commonly used Lean construction tools were considered as independent variables to evaluate their effects on overall project performance in Chapter 6. A complete glossary of terms is provided in Appendix B.

1.2 Background

1.2.1 Industry Factors

Productivity in the construction industry is still somewhat of a mystery because it has not been fully measured and consistent metrics and benchmarking are not common place (Forbes and Ahmed 2011). What is known is that construction productivity has not kept pace with improvements in other non-farm industries. Despite technological advances, construction productivity actually decreased between 1964 and 1998 by nearly 20% as depicted below in Figure 3 (Teicholz 2001).
Not all of the factors affecting construction productivity can be controlled, such as one-of-a-kind projects or the project environment, but many of the factors can be consciously influenced. Selecting a project delivery system is considered to be one of the most important decisions for an owner to make when embarking upon a capital facilities project (CMAA 2012). Yet often it is overlooked when discussing productivity (Hanna 2010). Cho et al. (2010) suggested the ideal PDS aligns stakeholder interests to maximize value to the client, integrates parties with collaboration in both early and late processes, and implements lean production theory. One of the possible causes of the decline in productivity is increased fragmentation throughout the construction industry (Teicholz 2001). A “project-first” attitude is not required in transactional contracts and mutual trust is a major
concern for stakeholders (Thomsen et al. 2010). This results in each stakeholder padding their estimated costs due to perceived risk and passing the bill to owners.

Mistakes and rework are generally accepted as a routine part of the construction business and result in substantial wasted resources (Forbes and Ahmed 2011). Womack and Jones (2003) define waste as “any human activity which absorbs resources but creates no value.” The negative effects of mistakes and rework are amplified considering the inherently wasteful nature of construction labor itself. Hanna (2010) asserted that labor is the largest cost component of a construction project accounting for 40-60% of total cost and found only 42% of labor to be value added to the project (see Figure 4).

![Figure 4: Value Added Labor in Construction (Hanna 2010)](image)

Poor productivity and waste in the construction industry are very detrimental to the American society. The construction industry is the largest manufacturing industry in the United States (Halpin
According to the Annual Industry Accounts released by the Bureau of Economics, the construction industry accounted for 3.4% of the U.S. Gross Domestic Product (GDP) in 2011 (Kim et al. 2012). This amounted to $512B of the $15,075B GDP in 2011 (US Department of Commerce 2012). In previous years construction costs have made up an even larger percentage of the GDP. From 1964 to 2001 the construction industry accounted for 6-8% of the U.S. GDP (Teicholz 2001). More recently in 2006, construction output was $1,260B (Forbes and Ahmed 2011). By any account construction spending consistently makes up a noticeable portion of the U.S. economy and any opportunities to improve productivity and efficiency could achieve substantial cost savings.

In order for IPD to be fully adopted by the construction industry research needs to be done to provide satisfactory evidence that it will improve profits, save money, and reduce operating costs (Kent and Becerik-Gerber 2010) or provide other tangible benefits that will promote its widespread utilization. The void of IPD research combined with the wide-spread interest of IPD provides an ideal opportunity to make significant contributions to the body of knowledge within the AEC community with respect to IPD.

1.3 Motivation to Conduct Research

The literature review, discussed in Chapter 2, confirmed there is an extremely limited amount of quantitative evidence on the effects of IPD on project performance. Excluding previous research from the University of Wisconsin-Madison that has yet to be published, the literature is completely void of research on the effects of IPD in terms of labor productivity, lost time incidents, construction costs, and contractor profits (Ilozor and Kelly 2012).

This research was part of a continuous effort at the University of Wisconsin-Madison and attempts to help fill the void of quantitative IPD research in literature by evaluating the performance
of IPD and IPD-ish projects from a unique dataset collected from 2012 to 2013. Specifically, the objectives of this research were to:

1) Compare performance of integrated projects (IPD/IPD-ish) to non-integrated projects (Non-IPD) across a wide range of individual metrics from eight performance areas as listed in Table 1;

Table 1: Individual Performance Metrics by Performance Area

<table>
<thead>
<tr>
<th>Performance Area</th>
<th>Performance Metric</th>
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<tr>
<td>Cost</td>
<td>Construction Cost Growth</td>
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<td></td>
<td>Construction Unit Cost</td>
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<tr>
<td>Quality</td>
<td>Overall Systems Quality</td>
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<td></td>
<td>Number of Punchlist Items per Million Dollars</td>
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<td></td>
<td>Percent Cost of Punchlist Items</td>
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<td>Number of Deficiencies per Million Dollars</td>
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<td>Percent Cost of Warranty Items</td>
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<td></td>
<td>Percent Cost of Latent Defects</td>
</tr>
<tr>
<td>Safety</td>
<td>Lost Time Incidents Rate</td>
</tr>
<tr>
<td></td>
<td>OSHA Recordable Incidents Rate</td>
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<tr>
<td>Schedule</td>
<td>Construction Speed</td>
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<tr>
<td></td>
<td>Project Delivery Speed</td>
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<tr>
<td></td>
<td>Construction Schedule Growth</td>
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<td></td>
<td>Construction Schedule Intensity</td>
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<tr>
<td>Labor</td>
<td>Schedule Compression Techniques</td>
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<tr>
<td></td>
<td>Percent Plans Complete (PPC) Trend</td>
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<tr>
<td>Business</td>
<td>Overhead and Profit</td>
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<td></td>
<td>Company Image / Return Business Potential</td>
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<tr>
<td>Change Management</td>
<td>Total Changes</td>
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<td></td>
<td>Change Order Processing Time</td>
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<tr>
<td>Communication</td>
<td>Number of Requests for Information (RFIs) per Million Dollars</td>
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<td>RFI Response Time</td>
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<td>Rework</td>
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<td>Number of Resubmittals per Million Dollars</td>
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2) Enhance the PQR model by including additional key metrics that contribute to overall performance;
3) Evaluate the overall performance of IPD/IPD-ish compared to Non-IPD projects in terms of the PQR;

4) Evaluate the effects of other key project attributes identified in literature as being influential on project performance in terms of PQR.

1.4 Research Methodology

A two phase approach was taken to conduct the research as shown in Figure 5. Phase I consisted of a literature review and data collection. Phase II consisted of univariate data analysis of individual performance metrics, analysis of a comprehensive performance metric, and analysis of other attributes potentially affecting performance.

![Figure 5: Methodology](image)

1.4.1 Literature Review

Generally speaking a literature review is used to provide relevant background of a particular topic through analysis of other similar research and case studies in order to provide a nexus between
the current research objectives and the larger body of knowledge that already exists (Creswell 2003). Specifically, for this research, the literature review focused on accomplishing three main objectives:

1) Gain an understanding of the AEC community’s definitions and current knowledge of IPD,

2) Identify previous IPD research and their findings,

3) Identify performance metrics used in previous PDS research to establish a basis for this analysis.

By accomplishing these goals this research will better fill the gaps in the existing IPD body of knowledge. Also, the terminology and metrics used in this research will be anchored to existing IPD literature and PDS research. The complete literature review is provided in Chapter 2.

1.4.2 Project Delivery System Data Collection Tool

A comprehensive data collection tool was developed at the University of Wisconsin-Madison and was used for this research. It is provided in Appendix C. As part of its development, the data collection tool underwent scrupulous expert reviews, was used in a pilot experiment, and was created with the support of the nationally renowned UW-Madison Survey Center. It was designed to collect quantitative and qualitative data to evaluate project performance across a wide range of key performance metrics (El Asmar and Hanna 2012). In total, the data collection tool was able to collect data on approximately 250 key independent, dependent, and control variables. The data collection tool consisted of five main sections described below in Table 2.
Table 2: Data Collection Tool Sections

<table>
<thead>
<tr>
<th>Section I</th>
<th>Project Characteristics and Contract</th>
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<tr>
<td>Section II</td>
<td>Project Performance</td>
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<td>Section III</td>
<td>Project Systems – Complexity and Quality Factors</td>
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<td>Section IV</td>
<td>Project Team and Collaboration</td>
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<tr>
<td>Section V</td>
<td>Contractor Background and Success Measures</td>
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In many cases, raw responses required conversion (i.e. qualitative ratings were converted to numerical values) prior to analysis. Also, some of the individual responses were combined to create a more insightful metric (i.e. “overall systems quality” consisted of twelve individual responses from the survey). The details of how the data were organized and evaluated in the analysis are provided throughout Chapters 3, 4, 5, and 6.

1.4.3 Data Collection

Contact via email and/or phone calls was attempted to 70 industry professionals representing 42 different construction companies. Positive exchanges, those communications where a response was received by the researcher, were made with 42 professionals from 31 companies. In total, twelve construction companies provided data on at least one project resulting in a company response rate of 28.6%. This was within the range of response rates found in other PDS studies which varied from 5.1% (Konchar and Sanvido 1998) to 65% (Songer and Molenaar 1997).

Ideally, random project sampling would have been used to ensure a true representative sample was studied; however, due to the limited data available for IPD/IPD-ish projects, purposive sampling was necessary. Companies with IPD experience were identified from case studies and other
literature as well as from professional references. For this research, company leadership was targeted including Project Managers (PMs), Senior PMs, Project Executives, Directors of Marketing, Directors of Business Development, Vice Presidents, and Owners. Because of the span of influence of many of the individuals contacted it was not feasible to determine an exact individual contact rate. Often times the direct point of contact delegated out the task of completing the surveys to PM’s within their area of influence and numerous surveys were received from PMs not originally contacted directly by the researcher.

Data collection was accomplished over an approximately five month period between September 2012 and January 2013. The survey was sent as a fillable PDF to encourage maximum participation, and ensure consistently formatted responses. Approximately 30% of the surveys were completed through person-to-person or phone interviews while the others were completed autonomously by respondents. Completed surveys were reviewed for completeness and follow-on communications via phone or email were used to clarify ambiguities and gather missing data when possible. Not all of the surveys were completed in their entirety for various reasons including a lack of available data and reluctance to provide sensitive data. In a few rare cases, missing information was available from other industry publications (i.e. construction cost or project size) and was used in conjunction with the survey responses to develop the most accurate and complete data possible. Two partially completed surveys were excluded from the dataset and not considered in the analysis because they were missing a substantial amount of key data, including cost and schedule information. Repeated attempts to receive a response from those PMs proved unsuccessful.

1.4.4 Analysis of Data

The survey data consisted of independent, dependent, and control variables. The independent and control variables are the explanatory variables. The dependent variables are the response
variables. The dependent variables of interest were the 24 individual metrics listed in Table 1 as well as the PQR. A detailed explanation and derivation of the PQR is provided in Chapter 5. The primary independent variables for this research were IPD and IPD-ish (IPD/IPD-ish) projects compared to Non-IPD projects. For each dependent variable the null hypothesis was that the two groups (IPD/IPD-ish and Non-IPD) were the same while the alternative two-sided hypothesis was that there was a difference between the groups. For example, the null hypothesis for construction unit cost was: 

*There is no difference in construction unit cost between IPD/IPD-ish and Non-IPD projects.*

The alternative hypothesis for construction unit cost was: *

*There is a difference in construction unit cost between IPD/IPD-ish and Non-IPD projects.*

Each hypothesis was formally tested using two-tailed t-tests or Mann-Whitney-Wilcoxon (MWW) tests, depending on whether the data were normally distributed. The t-test is more powerful when data are normally distributed and the MWW test is more powerful when data are not normally distributed (Devore 2004). Levene’s test was used to compare the variability between the two groups. A statistically significant difference in performance was determined at a 95% confidence level (p-value of 0.05). This significance threshold is typical in other construction PDS studies (Konchar and Sanvido 1998; Rosner et al. 2009). The details of the analysis for each of the 24 metrics are discussed further in Chapter 4.

Other independent variables were analyzed with respect to overall performance including Building Information Modeling (BIM), Lean construction techniques, use of incentives, key stakeholder involvement, the role of the project leadership team, and past team experience. Regression analysis and formal hypothesis tests were used to evaluate the impacts of each of these project attributes on overall performance. The details of these analyses are provided in Chapter 6.

Control variables are project attributes that may influence project outcomes yet cannot be influenced by the project team including: project size, project type, site access, type of owner, and
complexity. Analysis of the key control variables was performed to account for their potential impacts. The effects of control variables on overall project performance were evaluated in Chapter 6. A more detailed discussion of all three types of variables applicable to this research is provided in Chapter 3.

### 1.5 Research Contributions

This research contributes to the AEC and construction engineering and management academic communities by:

1. Offering owners a demonstration of IPD/IPD-ish project performance across a wide range of metrics including an overall performance metric for their consideration when selecting a project delivery system for future capital facilities projects;
2. Increasing the AEC community’s understanding of the effects of IPD principles in an attempt to eliminate some of the barriers impeding IPD implementation;
3. Identifying other key project attributes that affect project performance.

### 1.6 Organization of Thesis

Up to this point, the opportunity to improve project delivery in the construction industry, the motivation to conduct this research, and the methodology used to accomplish the research objectives has been provided. The following chapter consists of a literature review that identifies gaps in existing IPD research, defines IPD and IPD-related terms, and identifies performance metrics used in previous PDS research. Chapter 3 organizes the variables used in this research into the three operating environments of a PDS and describes the metrics that were analyzed as part of this research. Chapter 3 also provides key summary statistics of the dataset in order for the reader to have a clear understanding of the characteristics of the sample data analyzed in this research. Chapter 4 contains
the statistical analysis of each of the 24 individual performance metrics. Chapter 5 describes the
development of the PQR and the statistical analysis of IPD/IPD-ish versus Non-IPD projects for
overall project performance. Chapter 6 includes analysis of other key project attributes on overall
project performance through regressions analysis and hypothesis testing. Chapter 7 is comprised of a
final summary of the findings and a conclusion of the research including, barriers affecting IPD
implementation, applicability to public owners, and the research limitations and opportunities for
future research.
2.1  *Project Delivery in the Construction Industry*

Numerous definitions of a project delivery system can be found throughout literature. Halpin (2006) asserts a PDS is,

“the organization or the development of the framework relating the organizations required to complete or deliver a project and the establishment of the formal (i.e. contractual) and the informal relationships between these organizations.” (Halpin 2006)

In 2004, the Association of General Contractors defined a PDS as “the comprehensive process of assigning the contractual responsibilities for designing and constructing a project” (Cho et al. 2010). Further, Cho et al. (2010) highlighted six other PDS definitions used throughout the construction industry and nearly all of them included the relational aspects, both formal and informal, of the contracting parties as well as the timing of the establishment of those relationships. Hanna’s (2010) definition of a PDS, “the system that defines the relationship between different contracting parties and the timing of involvement in that relationship,” is adopted for this research. It captures the two key elements inherent in most of the other PDS definitions.

According to Thomsen et al. (2010) all PDSs operate in three domains consisting of: commercial terms, the operating system, and project organization. This model was challenged slightly by El Asmar (2012) where he asserted that the three domains are better represented by the “3 T’s” which include “tone” (social), “terms” (economic), and “tools” (physical). El Asmar’s model was adopted by this research and the performance metrics, organized within each domain, are discussed in greater detail in Chapter 3. Regardless of the PDS selected by an owner, all three
operating domains must be in alignment in order to maximize performance in construction (Thomsen et al. 2010).

The “terms” of project delivery are described by the contract. A contract is established when there is “an agreement between two or more parties to do something for a consideration…” (Halpin 2006). It is the legal framework upon which the project and all of its components are built upon with the primary function of assigning risk (Mullens 2012). The most common traditional construction contracts are Fixed Price Lump Sum, Guaranteed Maximum Price (GMP), Cost Plus Fee, and Fixed Unit Prices (Forbes and Ahmed 2011). Project risk can be assumed more predominantly by the owner or contractor depending on the type of contract used (see Figure 6). Inappropriately shifting risk can be financially detrimental to owners and is most prevalent when a contractor is not in a position to negotiate or influence the contents of a contract (CII 2006).

A commonality for each of the traditional PDSs (DBB, CMR, and DB) is that their terms are based upon transactional contracts. These contracts are more successfully used in the exchange of goods and services. They do little to promote cooperation and innovation among project stakeholders because they reward or penalize individual performance even at the detriment of others within a project team (Forbes and Ahmed 2011). Matthews and Howell (2005) asserted that traditional contracting negatively affects overall project performance in four primary areas:

![Risk Scale for Transactional Construction Contracts](https://example.com/risk_scale.png)
1) Throughout the design process ideas are not shared freely between trade specialists as each subcontractor fights to secure their place on the construction team.

2) The structure of having individual and meticulously detailed subcontracts with each trade prevents cross-trade cooperation.

3) Full coordination is not possible because there are no formal mutual expectations.

4) Beneath the outward posturing of teamwork is a basic premise of individual survival because of the contractual structure.

As the construction industry pursued implementation of Lean practices in the “tools” domain and optimization of the “tone” of a project, it became apparent that traditional contracting methods was inhibitive (Forbes and Ahmed 2011).

Due to the high degree of uncertainty and variability in the building process, relational contracts are considered advantageous over transactional contracts because they require cooperation, collaboration, and dependency between the primary stakeholders (Forbes and Ahmed 2011; NASFA et al. 2010). Relational contracts foster teamwork among the core group of stakeholders and put project goals ahead of individual outcomes by rewarding or penalizing the group as a whole rather than individually. The multi-party contract is a relational contract that attempts to eliminate the challenges and potential friction points inherent in transactional contracts (NASFA et al. 2010). Multi-party contracting had not been realized in construction until 2004 when the Integrated Form of Agreement (IFOA) was developed (Forbes and Ahmed 2011), making it a rather new phenomenon still operating in uncharted territory. With the development of the multi-party agreement the IPD project delivery system became possible.
2.1.1 Integrated Project Delivery and Lean Construction

Integrated Project Delivery is the most recent arrow added to an owner’s quiver of PDSs from which to choose when embarking upon a capital facilities project. IPD has been regarded as a viable solution to the industry’s low production and inefficiencies that are still prevalent today (Thomsen et al. 2010). It is purported to be beneficial to the primary triad (owner, designer, and builder) in a construction project and it delivers lower cost projects with less changes on tighter schedules than traditional PDSs (AIA 2007a).

One of the most significant difference between IPD and traditional PDSs, besides the multi-party contract, is the “forward shift of work volume to earlier stages of design” in conjunction with the early involvement of key stakeholders (Ilozor and Kelly 2012). Furthermore, there are notable differences between IPD and traditional PDSs as shown in Figure 7 below. Within each element listed IPD promotes collaboration, earlier involvement of stakeholders, and an environment of higher trust and transparency.
Still, there is not a universally accepted definition of IPD within the construction industry (El Asmar 2012; Cho and Ballard 2011; Kent and Becerik-Gerber 2010). Previously, AIA defined IPD as;

“a project delivery approach that integrates people, systems, business structures and practices into a process that collaboratively harnesses the talents and insights of all participants to reduce waste and optimize efficiency through all phases of design, fabrication, and construction (AIA 2007b)”.

IPD is also succinctly defined as a “delivery system distinguished by a multiparty agreement and the very early involvement of the key participants” (El Asmar and Hanna 2012). Similarly, NASFA et al. (2010) identified IPD projects as having owners sign a
multi-party contract with the designer, contractor, and potentially other key team members (i.e. subcontractors) as part of “a collaborative process and a relational contract.”

The Lean Construction Institute (2013)’s definition of IPD is:

“a delivery system that seeks to align interests, objectives, and practices, by reconceiving the Organization, Operating System, and Commercial Terms governing the project. The primary Team Members would include the Architect, key technical consultants as well as a general contractor and key specialty contractors. It creates an organization able to apply the principles and practices of the Lean Project Delivery System.”

One of the essential elements of IPD projects is the early involvement of key stakeholders in order to promote establishment of a Lean enterprise where overall project interests transcends the self-interests of individual companies and the team eliminates waste, collectively (Womack and Jones 2003). IPD and Lean construction are mutually supportive to reaching a common goal for the owner (NASFA et al. 2010). Often times the terms Lean Project Delivery and IPD are used interchangeably within industry (NASFA et al. 2010). However, Lean is an overarching business philosophy rooted in the principles of the Toyota Production System. Lean construction is defined by CII as “the continuous process of eliminating waste, meeting or exceeding all customer requirements, focusing on the entire value stream, and pursuing perfection in the execution of a constructed project” (Forbes and Ahmed 2011). IPD establishes an environment where Lean Project Delivery practices can be optimally applied (Matthews and Howell 2005).
2.1.2 IPD as a Philosophy

Compounding potential confusion within the construction industry regarding the definition of IPD is the fact that integrated principles can, and often times are, utilized in conjunction with traditional PDSs, obscuring “pure” IPD as a project delivery method. At this point it is important to distinguish between IPD as a philosophy and IPD as a delivery method. Not all owners have the desire, or the capability (i.e. public), of entering into a multi-party contract yet feel IPD principles are beneficial to project success. The National Association of State Facilities Administrators (NASFA); Construction Owners Association of America (COAA); APPA: The Association of Higher Education Facilities Officers; the Associated General Contractors (AGC); and AIA collaborated to produce an IPD guide for owners that identifies three levels of collaboration in project delivery (NASFA et al. 2010). The degrees of collaboration can be summarized as:

- Level 1: Collaboration is not a requirement.
- Level 2: Some collaboration is contractually required.
- Level 3: Full collaboration is contractually required via a multi-party contract.

Accordingly, “pure” IPD, including a multi-party contract, resides in level 3. The utilization of IPD principles in conjunction with other PDSs are grouped in levels 1 and 2 depending upon the degree to which they are applied (NASFA et al. 2010). DB and CMR projects demonstrating “enhanced” degrees of collaboration are referred to as “IPD-ish” as illustrated in Figure 8.
An example of an “IPD-ish” project, based upon the preceding definitions, is the Orlando Utilities Commission, North Chiller Plant project constructed in 2003. LCI credits the project as having been one of the first to use the IPD process in construction (Forbes and Ahmed 2011). The contractor entered into a traditional DB contract with the owner and an IPD team was contractually formed by the construction business partners. Not having a multi-party contract with the owner, the project is not considered IPD based on this research’s definition. Still, the project implemented an enhanced level of collaboration and implementation of many of the principles of IPD.

Realizing the rarity of “pure” IPD projects, the American Institute of Architects (AIA) considered a project to be IPD if it incorporated certain IPD “markers” for their case studies in 2012. A multi-party contract was not necessary to be considered IPD. In fact, three of the twelve projects in their case studies did not have a multi-party contract.

Interestingly, on numerous occasions while interacting with industry professionals for this research, the inconsistent use of the term IPD became very apparent. Some construction professionals asserted a project was accomplished using IPD, however, no multi-party contract had
been established. In other cases, owners indicated they wanted to implement IPD but were adamant against entering into a multi-party contract.

2.2 **IPD Research**

An abundance of analytical research has been conducted to analyze the performance of traditional project delivery systems at great length. To varying degrees, much of the existing PDS research has found that the more collaborative delivery systems outperformed the less collaborative PDSs (Konchar and Sanvido 1998; Kulkarni et al. 2012; Pocock et al. 1996; Rosner et al. 2009; Songer and Molenaar 1997; Thomas et al. 2002). The results of these studies suggest that the more collaborative IPD may outperform the other PDSs; however, very little research has been accomplished to validate that suggestion.

2.2.1 **IPD Case Studies**

There are far more case studies proclaiming the benefits of IPD than there are actual comparative analyses demonstrating evidence of superior performance. In nearly all of the published IPD case studies the projects were finished on time, under budget, and with a project team having positive relations (Franz and Leicht 2012).

The AIA and University of Minnesota performed 12 project case studies in 2012 as listed in Table 3. Nearly every project achieved substantial successes because of the flexible and collaborative team approach and early involvement of stakeholders inherent in IPD. In some cases, just meeting the schedule and budget were tremendous successes because of the unforeseen conditions, owner-driven changes, and extreme adverse conditions that were overcome during project execution. Even if a cost savings was not recognized, the value delivered to the owner was usually significantly higher
because of creative problem solving, team decision making, and a project-first attitude among the key project team members.

Table 3: AIA and University of Minnesota Case Studies (2012)

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<tr>
<td>1</td>
<td>Cathedral Hill Hospital</td>
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<tr>
<td>2</td>
<td>MERCY Master Plan Remodel</td>
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<tr>
<td>3</td>
<td>Lawrence &amp; Schiller Remodel</td>
</tr>
<tr>
<td>4</td>
<td>SpawGlass Austin Regional Office</td>
</tr>
<tr>
<td>5</td>
<td>Edith Green Wendell Wyatt Federal Office Building Modernization</td>
</tr>
<tr>
<td>6</td>
<td>Autodesk Inc.</td>
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<tr>
<td>7</td>
<td>Sutter Health Fairfield Medical Office Building</td>
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<td>8</td>
<td>Cardinal Glennon Children’s Hospital Expansion</td>
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<tr>
<td>9</td>
<td>St. Clare Health Center</td>
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<tr>
<td>10</td>
<td>Encircle Health Ambulatory Care Center</td>
</tr>
<tr>
<td>11</td>
<td>Walter Cronkite School of Journalism</td>
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<tr>
<td>12</td>
<td>UCSF Mission Bay Medical Center</td>
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</tbody>
</table>

Within the larger AIA case study, members from five of the IPD project teams were surveyed and indicated:

1) A multi-party agreement with shared risk and reward, fiscal transparency, and liability waivers positively affected trust and respect among the project team;

2) Lean construction positively affected information sharing with team members, sharing ideas and opinions, and project efficiency;

3) Colocation was perceived to have no effect on the ability to openly and effectively communicate. However, it was found to positively affect efficiency and communication with team members from other contracting parties;

4) The use of team builder facilitators was mixed with respect to its effects on communication;

5) To varying degrees all parties believed that collaborative project delivery had a positive effect.
The following paragraphs highlight some of the key successes of each of the twelve projects included in the AIA and University of Minnesota (2012) IPD case studies as well as other case studies available in the literature.

The Cathedral Hill Hospital project experienced a significant delay prior to construction as a result of external factors and IPD allowed the project team the flexibility to adjust productivity without incurring increased cost. Also, the owner was able to achieve substantial financial benefits during the design, estimated to be 400% return on invest beyond typical design, by having stakeholders involved early and an overall project oriented focus through Target Value Design.

The MERCY Master Plan Remodel case study benefited from IPD with superior cost and schedule control on a very complex and challenging project with frequently occurring unforeseen conditions. This case study is a premier example of how IPD benefits may not be realized in decreased cost or schedule, but in the prevention of increases in each, and improved control and predictability. The project used the Last Planner System (LPS) and achieved an 80% reliability of commitments. According to the owner’s IPD consultant, research showed that traditional PDSs more frequently have 50% reliability. Trade contractors remarked that their ability to talk directly with the designers was empowering and led to problem solving prior to construction in the field.

The Lawrence & Schiller remodel project was expected to save 10% of total cost using IPD compared to a DB approach. The savings were largely attributable to early involvement of key team members. During early site visits subcontractors identified potential issues and gained an early and clear understanding of the owner’s goals. They were able to offer suggestions into systems and solutions saving both construction time and cost.

The General Services Administration (GSA) needed an alternative approach to meet a significantly reduced schedule for the Edith Green Wendell Wyatt Federal Building Modernization project and looked to IPD as the solution. The project met the decreased timeline and reduced the
GMP from $145M to $125M. The CM absorbed $1.2M due to unforeseen conditions and other latent defects without increasing the cost to the owner. They were able to do this through improved collaboration with the architect during the design, value engineering, and effective management of the buy-out process. Another key success was the ability to exceed the owner’s goals by $11M for using small disadvantaged, women-owned, HUBZone, veteran, and service-disable veteran owned businesses. GSA viewed the project as a test case in an effort to shift to IPD as their sole delivery method in their northwest region. One of the reported advantages of IPD over DB in this project was that the owner received separate input from the designer and constructor and was in a better position to make decisions. The high performing team positively affected timely decision making and problem resolution, achieved energy goals, and increased innovation.

Autodesk utilized IPD to construct their regional office in Massachusetts and realized many benefits. One of the main benefits was completion of the entire capital facility process in 8.5 months; a schedule none of the other delivery systems would have been able to meet. The collaborative team environment afforded them the flexibility to efficiently respond to numerous owner-driven scope changes. Throughout the project, collaboration promoted informed decision making. The overall project value was maximized because key stakeholders were willing to move funds between individual line items in keeping project success as the top priority.

In 2005, Sutter Health pioneered the use of IPD as a delivery system with a multi-party contract for their Fairfield Medical Office Building. The $19.4M, medical office project engaged LCI and their attorney, Mr. Will Lichtig, to draft the first tri-party agreement used in the construction industry. Overall, Sutter was very satisfied with the project. It was completed $135K below budget even after $835K of value-added, owner-initiated scope was included. The team felt the increased upfront effort made IPD better suited for large, complex projects rather than small, simple projects. According to subcontractors on the project the rewards for upfront efforts were quickly realized with
virtually no rework. Effective use of BIM identified over 400 clashes of various systems during design, minimizing cost and schedule impacts as a result of field changes. The layout was accomplished in 2-3 days instead of 2-3 weeks, and the architect’s time was reduced because less detailing was needed. The integrated team established trust and respect which made each member more efficient and gave them a sense of professional satisfaction throughout the project.

The $45.5M Cardinal Glennon Children’s Hospital project in St. Louis, Missouri was not originally an IPD project. After the project’s owner attended an LCI workshop it was determined that IPD better suited the project than traditional delivery which had more lengthy schedules and could not provide the desired flexibility. Even though the project budget and schedule had been established prior to using IPD, the PDS was changed because of the owner’s experiences with risk being shifted at the detriment of the project. Through open communication and teamwork, creative solutions to construction issues were identified in a timely manner and the project was completed six weeks ahead of schedule.

Following the successful implementation of IPD on the Cardinal Glennon Children’s Hospital Expansion, the same project team of owner, architect, and contractor used IPD for the $157M St. Clare Health Center in Fenton, Missouri. For this project, the owner did not hold the team to a GMP, but rather compensated them on a cost-plus basis so that there would be a complete change in behavior towards IPD for the overall good of the project. Typical of IPD the architect experienced a dramatic forward shift of effort from construction administration to schematic design. The result was less “busy work” reviewing RFIs, submittals, and substitutions later in the project and more time on-site. The project successfully utilized the “Big Room” concept, resulting in fewer RFIs and less field coordination issues. Even while construction was ongoing, the owner made a significant change to the layout of the patient rooms and the project team was able to make necessary adjustments without
major cost or schedule impacts. A similar situation in the fragmented traditional delivery approach would not have been able to adapt as quickly without major cost impacts.

The Encircle Health Ambulatory Care Center was constructed in 2006 in Appleton, Wisconsin using a tri-party IPD contract. Additionally, four key subcontractors, mechanical, electrical, plumbing/fire protection, and exterior glazing, signed joining agreements binding them to the financial incentives of the multi-party contract. The project was completed on schedule overcoming extreme winter weather conditions. By involving trades into the early phases of the project, the design was efficiently completed with virtually no duplication of effort. The project team had experience working together and they felt that contributed to the success of the project. Architects, fabricators, and subcontractors worked collaboratively to eliminate redundancy of efforts in drawing details and shop drawings. The overall project cost was met and the value was maximized throughout the project. Because there was complete fiscal transparency, the project team was able to make decisions more effectively and move costs between line items. Efficiencies were realized by removing equipment costs from individual contractors and sharing them across the team (i.e. material handling equipment and clean-up costs). The contractor’s PM indicated the project went more smoothly than any with which he had been involved during his 23 year career. The project-first mentality flattened the traditional hierarchy in project delivery enabling creative decision-making which benefited the project.

The Walter Cronkite School of Journalism in Phoenix, Arizona was completed in 2008 as part of Arizona State University’s downtown campus. The project began with immense schedule and cost constraints; therefore, a typical DB method was determined to be unable to meet the stringent requirements. However, city regulations required a two-way contract between the owner and design-builder, so a multi-party contract could not be utilized. So, the project was awarded as a DB project, and the team agreed to implement IPD principles (i.e. it was IPD-ish) where key stakeholders were
brought on board early. Effective application of IPD principles, even though not contractually required, was seen as the only way to meet the high expectations with respect to quality and technical complexity while simultaneously minimizing risk. The other less transparent and less collaborative delivery methods were deemed inadequate to meet all the project challenges. At project commencement, the original program was not attainable with the specified budget and it was anticipated that a portion of the facility would be left unfinished. At project completion, the entire program was constructed because of savings and efficiencies realized during construction and buyout.

In January 2007, University of California San Francisco (UCSF) commenced design and construction of a $1.5B, three building hospital complex using multiple traditional delivery contracts with IPD characteristics. The project was not completed at the time of the case study but the owner was very satisfied to date with the value being achieved and predictability of cost. One of the main benefits of implementing IPD characteristics, specifically transparency and creation of a high performance team, was reduced risk compared to traditional delivery methods according to the project director. The project team identified a high degree of owner involvement as an important benefit of IPD that is not common in other delivery methods. One year after the design was awarded the construction contractor was hired. Even though it was delayed, the involvement of the construction team in the design phase allowed for improved productivity and efficiency in construction. For example, the design details were so well coordinated that welding of structural steel could be performed in a controlled shop environment instead of on-site. IPD behavioral principles were applied outside of contractual commitments and co-location was credited as the biggest factor impacting team relationships.

Matthews and Howell’s (2005) research included the study of the performance of an integrated team of contractors and an architect on four successful projects, including the Orlando Utilities Commission North Plant. The project was awarded as a DB project, but the contractor
formed an integrated team with key stakeholders binding them all together equally. The $5.4M project was constructed in less than three months and achieved a 10% cost savings below the GMP of $6M. The project incorporated many innovative design features and prefabrication of multiple systems, including the installation of utilities, pipe hangars, and structural steel, which could not have been achieved without IPD. The most appropriate team member performed work in the best interest of the overall project. For example, the general contractor over excavated the building site by 30 inches to accommodate below grade installation of utilities which saved substantial time, rework, and cost for the project. Also, pipe hangars were welded onto structural steel before arriving on site improving quality and efficiency.

At the 2006 AIA Integrated Practice Conference, Australia’s use of project alliances was presented (Khemlani 2006). Project alliance is one of the newest alternative delivery systems used in Australia and is quite similar to IPD in that the project team, including owner, designer, constructor, and subcontractors, enter into a multi-party contract, or alliance. Project alliance includes virtually every contractual and behavioral IPD principle. The delivery approach was used on 30-40 large (over $55M) and complex projects in the past few years with impressive results. Most of the projects were completed under budget and months early. Designers also reported higher profits and very positive experiences.

A case study on the $320M Sutter Medical Center Castro Valley project suggested IPD was the best approach to successfully execute the project because of its accelerated schedule and aggressive cost target (Khemlani 2009). The schedule was 30% tighter than a conventional project and traditional delivery could not fulfill the expectations. Ten stakeholders entered into a multi-party contract and 25 additional firms were on the expanded project team. The project team utilized BIM extensively resulting in numerous benefits including more accurate quantity take-offs, eliminating
redundancies, and improving communication. A remarkable achievement on the project was a high quality structural steel design accomplished in eight months rather than the expected 15 months. Overall, a higher quality design was accomplished faster and at no cost increase because of collaboration and an integrated approach.

A summary of case studies and the suggested benefits of IPD are provided in Table 4.

Table 4: IPD Case Studies

<table>
<thead>
<tr>
<th>Mathews</th>
<th>Year</th>
<th>Project(s)</th>
<th>PDS</th>
<th>Cost/Value</th>
<th>Schedule</th>
<th>Quality</th>
<th>Efficiency</th>
<th>Changes</th>
<th>Innovation</th>
<th>Risk</th>
<th>Others</th>
</tr>
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<tbody>
<tr>
<td></td>
<td>2005</td>
<td>Orlando Utilities Commission North Plant</td>
<td>DB</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
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</tbody>
</table>

| Khemlani | 2006 | Approximately 30-40 Projects in Australia | PA  | *          | *        | *       | *          |         |            |      |        |
| AIA & U of MN | 2009 | Sutter Medical Center Castro Valley | IPD | *          | *        | *       | *          | *       | *          |      |        |
|           | 2012 | Cathedral Hill Hospital | IPD | *          | *        | *       | *          | *       | *          |      |        |
| Khemlani  | 2009 | MERCY Master Plan Remodel | IPD | *          | *        | *       | *          | *       | *          |      |        |
|           | 2012 | Lawrence & Schiller Remodel | IPD | *          | *        | *       | *          | *       | *          |      |        |
|           | 2012 | SpawGlass Austin Regional Office Modernization | CM  | *          | *        | *       | *          | *       | *          |      |        |
|           | 2012 | E.G.W.W. Fed. Office Building Modernization | CM  | *          | *        | *       | *          | *       | *          |      |        |
|           | 2012 | Autodesk Inc. | IPD | *          | *        | *       | *          | *       | *          |      |        |
|           | 2012 | Sutter Health Fairfield Medical Office Building | IPD | *          | *        | *       | *          | *       | *          |      |        |
|           | 2012 | Cardinal Glennon Children's Hospital Expansion | IPD | *          | *        | *       | *          | *       | *          |      |        |
|           | 2012 | St. Clare Health Center | IPD | *          | *        | *       | *          | *       | *          |      |        |
|           | 2012 | Encircle Health Ambulatory Care Center | IPD | *          | *        | *       | *          | *       | *          |      |        |
|           | 2012 | Walter Cronkite School of Journalism | DB  | *          | *        | *       | *          | *       | *          |      |        |
|           | 2012 | UCSF Mission Bay Medical Center | DBB | *          | *        | *       | *          | *       | *          |      |        |

| Franz & Leicht | 2012 | PSU Dormitory Renovations | DB  | In Progress |        |         |            |         |            |      |        |
|                | 2012 | PSU Recreational Facilities | CMR | In Progress |        |         |            |         |            |      |        |
|                | 2012 | PSU Research Facility | CMA | In Progress |        |         |            |         |            |      |        |

* In Progress
2.2.2 IPD Performance Studies

Recognizing the lack of research that existed on the use of IPD in the construction industry, Kent and Becerik-Gerber (2010) launched a study to investigate the current status of IPD adoption and the industry’s knowledge and experience with IPD. Of the 415 survey participants, IPD was reported to reduce change orders and achieve cost savings by 70.3% of respondents, have shorter schedules by 69.4% of respondents, have fewer requests for information (RFIs) (58.6%), have less construction administration (36%), and have fewer injuries (21.6%). Improved quality, less friction, and more enjoyable projects were also reported. Their research, although very intriguing and important, only gathered qualitative responses regarding individuals’ beliefs and thoughts about IPD. It was not aimed at comparing specific performance measures between projects in order to draw conclusions based on quantitative analysis.

The first published quantitative analysis comparing IPD performance with other project delivery systems was done by Cho and Ballard (2011). Their hypothesis, that a project using IPD performs different than projects using other delivery methods, “failed to be supported definitively.” However, their investigation was limited to evaluating two performance metrics: cost reduction and time reduction. In their study the dependent variable, measure of project performance, was the sum of cost reduction ratio and duration reduction ratio. The independent binary variable they used was whether a project used IPD or some other PDS. Their research did not consider other metrics such as quality, communication, safety, business, or change management.

Through extensive univariate and multivariate statistical analyses El Asmar and Hanna (2012) provided the first-ever quantitative and statistically validated evidence that IPD projects out-perform Non-IPD projects. Thirty-one individual performance metrics were evaluated resulting in evidence of superior IPD performance in 14 metrics at a 0.05 significance threshold. The individual
metrics with evidence of superior IPD performance are summarized below in Table 5. The metrics spanned six performance areas including quality, communications, change management, business, recycling, and schedule. The p-values of each of the hypothesis tests are listed in the right-hand column of the table.

<table>
<thead>
<tr>
<th>Performance Metric</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Change Order Processing Time</td>
<td>0.000</td>
</tr>
<tr>
<td>2 Deficiency Issues</td>
<td>0.001</td>
</tr>
<tr>
<td>3 Request For Information (RFI)</td>
<td>0.001</td>
</tr>
<tr>
<td>4 Punchlist Cost</td>
<td>0.003</td>
</tr>
<tr>
<td>5 Punchlist Items</td>
<td>0.014</td>
</tr>
<tr>
<td>6 Resubmittals</td>
<td>0.018</td>
</tr>
<tr>
<td>7 Tons of Waste</td>
<td>0.022</td>
</tr>
<tr>
<td>8 Overhead &amp; Profit</td>
<td>0.024</td>
</tr>
<tr>
<td>9 RFI Processing Time</td>
<td>0.025</td>
</tr>
<tr>
<td>10 Systems Quality</td>
<td>0.032</td>
</tr>
<tr>
<td>11 Design Changes</td>
<td>0.032</td>
</tr>
<tr>
<td>12 Warranty Costs</td>
<td>0.040</td>
</tr>
<tr>
<td>13 Delivery Speed</td>
<td>0.046</td>
</tr>
<tr>
<td>14 Regulatory Changes</td>
<td>0.050</td>
</tr>
</tbody>
</table>

Further, El Asmar developed a comprehensive performance metric, the Project Quarterback Rating (PQR), which combined key success measures, as identified in literature and by industry professionals who provided data for the research, into a single overall rating. A comparison of the PQR scores for IPD, IPD-ish, and Non-IPD projects for El Asmar’s data are summarized by the boxplots below in Figure 9. Because the PQR score is standardized on a standard normal distribution, projects with average performance would have a PQR score of zero and each number on the y-axis represents one standard deviation above or below the average. El Asmar (2012) found that Non-IPD projects had a mean PQR score of -0.31 while the mean PQR score for IPD projects was 0.54. For
the first time, statistically significant evidence (p-value of 0.015) demonstrated IPD projects outperform Non-IPD projects from a comprehensive performance standpoint.

![Figure 9: PQR Performance Results (El Asmar 2012)](image)

Other quantitative analyses of IPD that have yet to be published have been performed by Iwanski and Boodai at the University of Wisconsin-Madison. Each researcher evaluated IPD from the perspective of different stakeholders (i.e. mechanical, electrical, and plumbing (MEP) subcontractors and owners). The first analysis of IPD from a subcontractor’s perspective compared 32 projects and found evidence of superior performance in four metrics related to schedule, communication, quality, and change management (Iwanski and Hanna 2013). Another ongoing study to evaluate IPD performance from an owner’s perspective is being done by Boodai at the University of Wisconsin-Madison. The results of that study are yet to be determined.
2.3 **Performance Metrics**

Throughout the multitude of publications and research regarding project delivery in the construction industry it is clear that there is no single, or agreed upon, set of performance metrics or criteria that are used to measure project performance. The most common performance indicators have been schedule, cost, and quality which are considered to be the “iron triangle” of metrics (Chan et al. 2002; Suk et al. 2012). Repeatedly these indicators are used in research; however, even within these three general areas, the details of how each are measured varies between studies.

Pocock et al. (1996) measured project performance in their research using cost growth, schedule growth, and number of modifications. They also considered other metrics; however, they were found to be inconclusive for measuring performance. Those other metrics included claims, savings due to value engineering, and safety. Songer and Molenaar (1997) utilized schedule, cost, and quality as well as an owner satisfaction performance metric in their research. For cost performance they measured if a project was completed at or below the planned budget and, similarly for schedule performance, they measured whether a project was completed on time or early. They defined quality in terms of meeting specifications, conformance with owners’ expectations, and workmanship exceeding acceptable standards. They also considered the aggravation of the construction to the owner.

In 1998 Konchar and Sanvido compared DB, CMR, and DBB using various cost, schedule, and quality metrics. Specifically they used unit cost, cost and schedule growth, construction and delivery speed, intensity, turnover quality, system quality, and equipment quality. Of the various performance metrics analyzed by Chan et al. (2002) it was concluded that objective measures including cost, time and quality and subjective measures including satisfaction were the most significant. Time measures included the amount of overrun as the percent change from the estimated
duration, the overall construction time, and the construction speed in terms of square feet and construction duration. The cost measures included cost overrun and unit construction cost in terms of cost per square foot of constructed area. Data for each of these objective measures is relatively straightforward; however, they may not represent actual performance. For example, schedules and costs can change due to variations in a project’s program based on owner’s changed requirements or other external factors that do not necessarily reflect performance. Even more difficult is assessing subjective performance measures. The two most significant subjective measures were determined to be quality and satisfaction. Quality was measured using a Likert scale which is common when trying to measure subjective data for conformity with owner’s expectations, the administrative burden for the client, and overall owner satisfaction. Satisfaction was measured throughout the project in the pre-construction, construction, and post-construction phases.

For their research comparing DB and DBB projects Thomas et al. (2002) used cost, schedule, safety, changes, and rework as their performance metrics. Ibbs et al. (2003) also relied upon cost and schedule, as well as productivity, in their research to study the performance of DB and DBB project performance. In 2008 Rojas and Kell compared the performance of CMR and DBB in public school construction projects using overall project cost growth, change order growth, and GMP performance.

In their research of success measures in the construction industry Chan and Chan (2004) offered a “consolidated framework” to measure overall project success consisting of performance with respect to cost, time, safety, satisfaction, user expectation/satisfaction, environmental, commercial, and quality. They referred to these critical project indicators as KPI (key performance indicator) and used them to assess overall performance of three large healthcare projects.

In their research of U.S. Air Force construction projects, Rosner et al. (2009) utilized six dependent variables to measure project performance. Specifically, they used cost and schedule
growth, change in the current working estimate to programmed amount, unit cost, modifications per million dollars, and total project time. Cho et al. (2010) established the “Commonly Acknowledged Performance (CAP)” measures as cost, schedule, safety, defects, and satisfaction. As mentioned previously Cho and Ballard (2011) used two metrics, cost and schedule change, in their research to determine if IPD outperformed non-IPD projects.

Kulkarni et al. (2012) studied 30 CMR and Competitive Sealed Proposal (CSP) projects to determine if the more integrated approach achieved better cost performance and decreased the cost of reducible change orders. These change orders were categorized as errors, omissions, and design modifications. Their research provided evidence of superior performance in both metrics of the more integrated CMR approach (Kulkarni et al. 2012). Suk et al. (2012) suggested using cost, schedule, dimension, and quality as metrics to contribute towards benchmarking of pharmaceutical projects.

The most comprehensive IPD research to date was accomplished by El Asmar and Hanna (2012) where 31 metrics from nine different performance areas were evaluated as dependent variables. The performance areas analyzed were cost, quality, schedule, safety, changes, communication, labor, recycling, and business performance.

In an ongoing case study of four projects at Penn State University Franz and Leicht (2012) will attempt to measure the effects of applying IPD principles to traditional contracts via a collaboration addendum. The performance metrics they will use go beyond the basic cost, quality, and schedule metrics and also include safety and team metrics. For one of the projects the performance metrics include OSHA LTC rate, percentage of RFIs returned within three days, percentage of submittals returned as approved (or approved as noted) within two weeks, percentage of milestone dates achieved, percentage of change order responses within 30 days, percentage difference of buyout and pre-bid estimate, percentage difference of actual and target project costs, number of
field installation conflicts, percentage of quality control log items resolved within 30 days, and other team metrics.

A summary of the performance metrics used in previous PDS research is provided below in Table 6. The research analyzing IPD projects are highlighted in yellow. It is apparent that most PDS research looked at a narrow range of performance metrics to measure performance of project delivery systems. The metrics most commonly utilized included cost, schedule, and changes. This is not especially surprising since cost and schedule are generally considered two of the three “iron triangle” metrics and quantitative information for them is usually available and attainable. Collecting data on many of the other metrics can be very difficult and often times there are no quantitative data available to assess performance. An example of this is quality where there is no single tangible metric that can be used to compare performance between multiple projects.

Table 6: Summary of Performance Metrics Used in PDS Research.

<table>
<thead>
<tr>
<th>Performance Metric</th>
<th>Pocock</th>
<th>Songer</th>
<th>Konchar</th>
<th>Chan</th>
<th>Thomas</th>
<th>Ibis</th>
<th>Chan</th>
<th>Rojas</th>
<th>Rosner</th>
<th>Cho</th>
<th>Kulkarni</th>
<th>Suk</th>
<th>El Asmar</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cost</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
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</tr>
<tr>
<td>Schedule</td>
<td>*</td>
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<tr>
<td>Safety</td>
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<tr>
<td>Productivity</td>
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<tr>
<td>Business</td>
<td>*</td>
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<tr>
<td>Quality</td>
<td>*</td>
<td>*</td>
<td>*</td>
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<td>*</td>
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<tr>
<td>Occupants</td>
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<td></td>
</tr>
<tr>
<td>Use-ability / Value</td>
<td>*</td>
<td></td>
<td></td>
<td></td>
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<td></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Operations &amp; Maintenance</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
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<td>*</td>
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<td>*</td>
<td>*</td>
<td>*</td>
</tr>
<tr>
<td>Other</td>
<td></td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
</tr>
</tbody>
</table>

Parts of this table are adapted from El Asmar (2012). Only the name of the first author is included in the table. Full citations are included in Appendix A.
2.4 **Scope of Research**

For this research the project data was provided by Project Managers (PMs) of building construction projects located throughout the United States. Only projects completed within the last five years were considered in order to minimize differences between integrated and non-integrated projects due to technological advancements and modern construction techniques. Because IPD is typically used on large and complex projects, an approximately $1M threshold was established. The far majority (91%) of the projects were commercial or institutional type projects. A more detailed and thorough description of the dataset is provided in Chapter 3.

Chapter 2 provided the literature review that established the foundation and background for this research and presented the opportunities to contribute to the AEC community’s body of knowledge on IPD. Next, Chapter 3 will define the variables used in this research and provide the general characteristics of the dataset.
Chapter 3. Data Organization and Performance Metrics

This chapter accomplishes two primary objectives:

1) Define the independent, dependent, and control variables used in this research;
2) Provide general statistical characteristics of the dataset analyzed in this research

3.1 Independent, Dependent, and Control Variables

3.1.1 Independent Variables

The independent variables used in this research are premised upon the overarching question this research attempted to answer which is whether integrated projects outperform non-integrated projects. For the majority of this research the two independent variables were integrated (IPD/IPD-ish) and non-integrated (Non-IPD) projects. The availability of project data collected shaped the organization of the independent variables. A decision was made to combine the IPD and IPD-ish projects into a single group because they are similar in utilizing many of the principles inherent in IPD. IPD-ish projects were classified as such based upon the PM indicating the project was IPD-ish.

The preceding independent variables were used in the analysis of the individual performance metrics and the PQR. Other key project attributes were identified as independent variables to analyze their effects on overall project performance. Those attributes are listed in Table 7 as the “Intermediate Level” factors. They were evaluated in this research because previous research suggested that they affected performance. The right-hand column, “Survey Level Data”, identifies the survey data that constitutes each of the intermediate level characteristics. The left-hand column identifies which of the three project domains the project characteristic belongs.
Table 7: Project Characteristics Used as Independent Variables to Analyze PQR

<table>
<thead>
<tr>
<th>PDS Domain</th>
<th>Intermediate Level</th>
<th>Survey Level Data</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>TERMS</strong></td>
<td>Incentives</td>
<td>Did the Contact Include Incentives?</td>
</tr>
<tr>
<td><strong>TOE</strong></td>
<td>Project Leadership Team</td>
<td>Number of stakeholders involved</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Authority to manage/lead project</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Jointly develop project criteria/goals</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Collaborative decision making</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Periodic project reviews</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Frequency of meeting-planning</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Frequency of meeting-construction</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Frequency of meeting-commissioning</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Lessons learned</td>
</tr>
<tr>
<td><strong>TONE</strong></td>
<td>Past Team Experience (CM/GC, A/E, Subs, Owner)</td>
<td>Experience with the type of construction</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Experience with the size of construction</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Experience with the PDS</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Experience as a project team</td>
</tr>
<tr>
<td></td>
<td>Unconventional Stakeholders Involvement</td>
<td>Subs involved in Risk Review Process</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Contractor Familiarity with Owner’s Goals</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Owner Participation in construction</td>
</tr>
<tr>
<td></td>
<td></td>
<td>A/E Support in construction</td>
</tr>
<tr>
<td></td>
<td></td>
<td>CM/GC involvement in Design/Planning</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Subs involved in Design</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Risk Review Process prior to construction</td>
</tr>
<tr>
<td><strong>TOOLS</strong></td>
<td>Lean Construction Tools</td>
<td>Pull Planning</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Last Planner System (LPS)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Set Based Design (SBD)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Point Cloud Technology</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Value Stream Mapping (VSM)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>5S</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Just-In-Time (JIT)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Target Value Design (TVD)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Visual Management</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Daily Huddles</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Mockups</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Constructability Reviews</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Co-location</td>
</tr>
</tbody>
</table>
The methodology used to combine the survey data to create each of the independent variables listed in Table 7 is provided in Chapter 6 in conjunction with the statistical analysis for each of the respective variables. Now we will turn our attention to the dependent variables.

### 3.1.2 Dependent Variables

Along with PQR, the 24 project performance metrics identified in Table 1 constitute the dependent variables for this research. As previously stated, each of the metrics belongs to one of eight project performance areas. The survey included questions to capture data for one additional

<table>
<thead>
<tr>
<th>Use of BIM</th>
<th>Was BIM used Yes/No?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Used for Visualization</td>
<td></td>
</tr>
<tr>
<td>Space Validation</td>
<td></td>
</tr>
<tr>
<td>Site Logistics</td>
<td></td>
</tr>
<tr>
<td>Environmental Analysis</td>
<td></td>
</tr>
<tr>
<td>Early Design Coordination</td>
<td></td>
</tr>
<tr>
<td>MEP Coordination</td>
<td></td>
</tr>
<tr>
<td>Design Collaboration</td>
<td></td>
</tr>
<tr>
<td>Clash Detection</td>
<td></td>
</tr>
<tr>
<td>Submittals</td>
<td></td>
</tr>
<tr>
<td>Estimating</td>
<td></td>
</tr>
<tr>
<td>4D Scheduling</td>
<td></td>
</tr>
<tr>
<td>Prefabrication</td>
<td></td>
</tr>
<tr>
<td>Virtual Mock-ups</td>
<td></td>
</tr>
<tr>
<td>Project Turnover</td>
<td></td>
</tr>
<tr>
<td>Facilities Management</td>
<td></td>
</tr>
<tr>
<td>Code Checking</td>
<td></td>
</tr>
<tr>
<td>Foundation</td>
<td></td>
</tr>
<tr>
<td>Structure</td>
<td></td>
</tr>
<tr>
<td>Interior Finishes</td>
<td></td>
</tr>
<tr>
<td>Exterior Enclosure</td>
<td></td>
</tr>
<tr>
<td>Roofing</td>
<td></td>
</tr>
<tr>
<td>Mech. Syst.</td>
<td></td>
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<tr>
<td>Elec. Syst.</td>
<td></td>
</tr>
<tr>
<td>Site</td>
<td></td>
</tr>
<tr>
<td>Process Equipment</td>
<td></td>
</tr>
<tr>
<td>Conveying Syst. and Specialties</td>
<td></td>
</tr>
</tbody>
</table>

*Portions of this table were adopted from El Asmar (2012).*
performance area, material waste, except an insufficient number of responses was collected to perform a meaningful analysis. The eight performance areas included in this research were:

1. Cost
2. Quality
3. Safety
4. Schedule
5. Labor
6. Business
7. Change
8. Communication

_Converting Data for Statistical Analysis_

The dependent variables consisted of both quantitative and qualitative data in many different forms including; continuous (cost data), binary (yes or no for the use of BIM), discrete (number of lost time incidents), interval (OH&P from 0-5%, 6-10%, etc.), and ordinal data (rating of co-location from Exceptional to None). The count data (i.e. number of punchlist items, deficiencies, OSHA recordable incidents, lost time incidents, requests for information (RFIs), and resubmittals) was normalized based on final construction cost in order to legitimately compare projects of various sizes. Qualitative data, often times provided on Likert scales, and interval data, were converted to numerical values as shown in Table 8. Only the dependent variables that required conversion are listed in the table. The details of how each variable was converted are provided throughout Chapter 4 in conjunction with the analysis of each metric.
Table 8: Summary of Converted Dependent Variables

<table>
<thead>
<tr>
<th>Performance Area</th>
<th>Metric</th>
<th>Intermediate Level</th>
<th>Survey Data</th>
<th>Converted Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quality</td>
<td>Overall Systems Quality</td>
<td>Quality of 11 Major Building Systems</td>
<td>Economy, Standard, High, Premium, High Efficiency Premium</td>
<td>1 to 5</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Overall As-Built Quality</td>
<td>Economy, Standard, High, Premium, High Efficiency Premium</td>
<td>1 to 5</td>
</tr>
<tr>
<td></td>
<td>Cost of Punchlist Items</td>
<td>N/A</td>
<td>zero-0.25%; 0.25-0.5%; 0.5-1.0%; 1-2%; &gt;2%</td>
<td>1 to 5</td>
</tr>
<tr>
<td></td>
<td>Cost of Warranty Items</td>
<td>N/A</td>
<td>zero; 0-0.5%; 0.6-1%; 1-2%; 2-3%; &gt;3%</td>
<td>0 to 5</td>
</tr>
<tr>
<td></td>
<td>Cost of Latent Defects</td>
<td>N/A</td>
<td>zero; 0-0.5%; 0.6-1%; 1-2%; 2-3%; &gt;3%</td>
<td>0 to 5</td>
</tr>
<tr>
<td>Labor</td>
<td>Schedule Compression Techniques</td>
<td>Overtime</td>
<td>none; 0-5%; 6-10%; 11-15%; &gt;15%</td>
<td>0 to 4</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Shift work</td>
<td>none; 0-5%; 6-10%; 11-15%; &gt;15%</td>
<td>0 to 4</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Congestion</td>
<td>more crowded than average; about average; less crowded than average</td>
<td>-1 to 1</td>
</tr>
<tr>
<td></td>
<td>PPC Trend</td>
<td>N/A</td>
<td>decreased; stable; increased</td>
<td>-1 to 1</td>
</tr>
<tr>
<td>Business</td>
<td>OH&amp;P</td>
<td>N/A</td>
<td>negative; &lt;5%; 5-10%; 11-15%; &gt;15%</td>
<td>0 to 4</td>
</tr>
<tr>
<td></td>
<td>Company Image / Return Business</td>
<td>N/A</td>
<td>very negative; negative; neutral; positive; very positive</td>
<td>-2 to 2</td>
</tr>
<tr>
<td>Change Management</td>
<td>CO Processing Time</td>
<td>N/A</td>
<td>1-7 days; 8-14 days; 15-21 day; 22-28 days; 29-35 days; 36-42 days; &gt;42 days</td>
<td>1 to 7</td>
</tr>
<tr>
<td>Communication</td>
<td>RFI Response Time</td>
<td>N/A</td>
<td>1-7 days; 8-14 days; 15-21 day; 22-28 days; 29-35 days; &gt;35 days</td>
<td>1 to 6</td>
</tr>
<tr>
<td></td>
<td>Rework</td>
<td>N/A</td>
<td>zero; 0-1%; 1-2%; 2-3%; 3-4%; &gt;4%</td>
<td>0 to 5</td>
</tr>
</tbody>
</table>
Survey respondents provided actual dates for the project milestones including design start
date, design completion, construction start date, substantial completion date, end of commissioning,
and the date of occupancy. This input was used to determine project durations. Similarly,
respondents provided the total initial project cost or target value, the final contract value including
changes, and the final actual costs which were used to calculate cost metrics.

Cost Adjustments

All raw project cost data was normalized to Chicago, Illinois prices as of January 2013 using
the Engineering News Record (ENR) Construction Cost Index (CCI) History table (ENR 2013) and
RS Means City Cost Index. The ENR CCI was used to normalize for time, whereas the RS Means
City Cost Index was used to adjust for location. The CCI is based upon steel, concrete, and lumber
material prices as well as common labor rates (Grogan 2009a). CCI was used instead of the Building
Cost Index (BCI), another of ENR’s non-residential construction cost indexes, because it is less
influenced by changes in material prices (Grogan 2009a) which have been dramatic due to the
economic recession and depressed housing markets throughout the U.S. in recent years.

The national, 20-city average, CCI was used to account for the time period of construction
because it provided a complete and up-to-date index based on the 20-city national averages for
common labor and material. Consistent with other CII Benchmarking literature, the time adjustment
for project costs was based on the approximate halfway point of the construction period (Lilly and
Hill 2009) measured from the actual notice to proceed to actual substantial completion dates. The
time adjustments were applied to the location adjusted prices according to the following equation:

\[
\frac{CCI \text{ in January 2013}}{CCI \text{ at midpoint of Construction Period}} \times Location \text{ Adjusted Cost} = Normalized \text{ Project Cost}
\]
The project costs were adjusted for location using the RS Means City Cost Index. This index was used in lieu of the ENR city indexes because of the much larger selection of cities in the RS Means index. In the event the exact city where a project was constructed was not included then the nearest city was used to account for cost variations due to location. Also, the ENR cost index by cities is more likely to misrepresent accurate figures because price data is collected from point sources and may not be consistent between cities (Grogan 2009b). The equation used in making the location adjustments is:

\[
\frac{\text{Chicago City Cost Index}}{\text{City Cost Index at, or nearest, the Project}} \times \text{Actual Project Cost} = \text{Location Adjusted Cost}
\]

Throughout this dissertation when any project cost data, or metrics based upon cost are presented, the values have been adjusted as previously described.

### 3.1.3 Control Variables

The third type of variable applicable to this research is the control variables. For the most part, these variables cannot be affected by the project team even though they may potentially affect project performance. Previous research has identified some control variables that can impact project performance including size, complexity, facility type, and type of owner to name a few (Andersen et al. 2012; El Asmar 2012; Konchar and Sanvido 1998). This research accounted for various control variables as much as possible by minimizing their effect, i.e. normalizing the number of RFIs and punchlist items based on project cost. The effects of control variables on overall project performance are evaluated in Chapter 6.
3.2 General Dataset Characteristics

Prior to performing statistical analyses it is important to understand the characteristics of the sample data. The importance of this is amplified because the dataset is very small compared to the larger population of vertical construction projects in the U.S. therefore drawing conclusions about the population is difficult.

Of the 32 total projects, each of the four primary project delivery methods are represented. The dataset consisted of 19% DBB, 31% DB, 41% CMR, and 9% pure IPD projects as shown in Figure 10.

It is not surprising that there are relatively few IPD projects because of the small number of IPD projects that have been completed to date. Additionally, companies who are utilizing IPD may be hesitant to divulge information on project performance because of concerns with losing a competitive edge over their peers or limitations in releasing proprietary information. None of the
projects utilized in previous University of Wisconsin-Madison PDS research were included in this research.

The composition of the dataset does not exactly match the PDS composition of the non-residential industry as a whole as reported by the Design Build Institute of America. In 2010, the market shares for Design-Bid-Build, Design-Build, and Construction Manager at Risk were approximately 51%, 40%, and 9%, respectively (Design Build Institute of America 2013). There are a much higher percentage of projects using CMR and a markedly lower percentage of projects using DBB represented in this dataset compared to the industry as a whole.

The analysis was not performed considering IPD as a delivery method but rather grouped IPD and IPD-ish projects together and compared them to Non-IPD projects. The IPD and IPD-ish projects accounted for 28% of the total projects while the Non-IPD projects made up the remaining 72%. The ratio of projects with the Non-IPD projects separated by PDS is shown in Figure 11.

Figure 11: Dataset Composition of IPD/IPD-ish and Non-IPD projects (separated by PDS)
Both public and private owners were represented in the dataset nearly evenly with approximately 41% of the projects coming from public owners and 59% from private owners as shown in Figure 12. It is not altogether surprising that public owners have a significantly higher use of DB considering its recent popularity represented by the fact that 80% of military construction (MILCON) projects between 2005 and 2010 used Design-Build (Design Build Institute of America 2013). Although public projects are usually unable to implement IPD in its purest form, they are able to implement IPD-ish projects by incorporating IPD principles.

![Figure 12: PDS Breakdown by Owner](image)

The majority of projects are institutional with some commercial and even less residential and industrial type projects as depicted below in Figure 13. The residential projects are large multi-story, multi-family dwellings.
All projects were completed between 2008 and 2013 with the majority of projects having been completed within the last two years. The distribution of projects based upon their actual substantial completion dates is provided below in Figure 14.
The dataset consisted of large projects ranging from just over one million dollars to over $700M. The highest proportion of Non-IPD projects were between $10M and $50M while the IPD/IPD-ish projects were mostly $1-$5M (see Figure 15). In total, the dataset represented more than $1.5B with IPD/IPD-ish accounting for approximately $297M and non-IPD accounting for roughly $1.2B.

Figure 15: Project Distribution Based Upon Project Cost

A majority of the projects had less than 50,000 square feet with the largest project having over one million square feet. The dataset distribution based on gross project size is shown below in Figure 16.
The project distribution based upon the number of floors for each project is provided below in Figure 17. The majority of projects had one to three floors.
The majority of projects were new construction with more than 50% of the projects being completely or mostly new work (see Figure 18). The remainder of the projects consisted of additions or renovations.

![Figure 18: Dataset Composition Based on Construction Type](image)

Project data was solicited throughout the U.S. without any preference to a particular location. The dataset includes projects from 15 states and represents a wide variety of locations as depicted in Figure 19.
Chapter 3, identified the independent, dependent, and control variables used in this research and provided the general characteristics of the dataset. The next chapter provides the analysis of each individual metric.
Chapter 4. Individual Performance Metrics Analysis

Chapter 3 introduced the dataset and made general comments describing the important characteristics and distribution of the data. This chapter provides the results of the univariate analysis of each of the 24 performance metrics analyzed in this research. The specific question of interest for each performance metric was: Do IPD and IPD-ish projects outperform Non-IPD projects? Each performance metric was analyzed in a similar fashion using descriptive statistics (i.e. boxplots) and formal hypothesis tests using the statistical computing software program R (R Development Core Team 2011).

4.1 Statistical Methodology

First, comparative boxplots were created to provide a good visual summary of key information for each group including the minimum and maximum observations, interquartile range (IQR), median, range, extent of departure from symmetry, and identification of outliers (Devore 2004). The “box” portion of the boxplot contains 50% of the observations therefore the top and the bottom lines of the box represent the third and first quartiles, respectively. The solid, horizontal line within the “box” identifies the median value of the group.

Next, each hypothesis was formally tested using two-tailed t-tests and Mann-Whitney-Wilcoxon (MWW) tests. For each performance metric the null hypothesis was that the groups were the same while the alternative hypothesis was that there was a difference between the groups. The hypothesis tests represented mathematically are as follows:

\[ H_0: \mu_{IPD/IPD-ish} = \mu_{Non-IPD} \]
\[ H_A: \mu_{IPD/IPD-ish} \neq \mu_{Non-IPD} \]
Also, formal testing for a difference in variances was performed using Levene’s test.

Represented mathematically the hypothesis tests are:

\[ H_0: \sigma^2_{\text{IPD/IPD-ish}} = \sigma^2_{\text{Non-IPD}} \]

\[ H_A: \sigma^2_{\text{IPD/IPD-ish}} \neq \sigma^2_{\text{Non-IPD}} \]

The outcomes of the formal hypothesis tests were p-values which were compared against a significance threshold 0.05. This significance threshold was established because it is typical in other PDS studies (Konchar and Sanvido 1998; Rosner et al. 2009). The more conservative two-tailed tests were used instead of one-tailed tests to increase the certainty of any statistically significant findings.

The hypothesis tests require certain assumptions to be satisfied. Both the t-test and MWW test require the data to be independent (Clayton and Zhu 2012). This assumption was satisfied because each project had its own unique location, conditions, scope, and overall set of circumstances. The independent t-test also requires equal variances between the groups. This assumption was tested using Levene’s test which resulted in a p-value that was compared to a threshold of 0.20. If Levene’s test resulted in a p-value less than 0.20, the variances were considered unequal and Welch’s t-test was used in lieu of the independent sample t-test. Dr. Murray Clayton, as part of the Statistical Methods 571 course at the University of Wisconsin-Madison, Fall 2012, commented that a threshold of 0.20 is generally acceptable for this application of Levene’s test.

The third assumption for the t-test requires the data in each group to be normally distributed. Normality was evaluated using a normal scores plot (a.k.a. quantile comparison plot or quantile-quantile (Q-Q) plot). This method is advantageous over other descriptive statistics such as histograms or stem and leaf plots (Clayton and Zhu 2012). In a Q-Q plot the sample quantiles are plotted on the \( y \)-axis and the theoretical quantiles are plotted on the \( x \)-axis. If the data are normally distributed then the plot results in a straight line. The t-test is more powerful when data are normally distributed and
the MWW test is more powerful when data are not normally distributed (Devore 2004). The MWW test is a nonparametric test that can be conservative because the actual values of the data are replaced by their ranks and therefore the magnitude of the observations does not affect the hypothesis test. Since the median of the ranked values is used in the MWW test it is also robust against outliers (Clayton and Zhu 2012); whereas the t-test is based upon the sample mean and can be significantly affected by extreme observations (Devore 2004). Levene’s test is robust against non-normality (Clayton and Zhu 2012). The Q-Q plots for performance metrics resulting in significant findings are provided in Appendix D for reference.

4.2 Individual Performance Metric Univariate Analysis

The following eight sections provide the detailed results and interpretations of the statistical analyses for each performance metric and are organized by the eight performance areas, communication, change management, business, cost, quality, safety, schedule, and labor as shown in Table 9.

<table>
<thead>
<tr>
<th>Performance Area</th>
<th>Performance Metric</th>
<th>Units</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Communication</td>
<td>RFI No. / $M</td>
<td>0.8</td>
<td>36.8</td>
</tr>
<tr>
<td></td>
<td>RFI Processing Time</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>Rework</td>
<td>Scale (0 to 5)</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Resubmittals</td>
<td>No. / $M</td>
<td>0</td>
</tr>
<tr>
<td>Change Management</td>
<td>Absolute Total Changes</td>
<td>% of Total Cost</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>Change Order Processing Time</td>
<td>Weeks</td>
<td>1</td>
</tr>
<tr>
<td>Business</td>
<td>Overhead and Profit</td>
<td>Scale (0 to 4)</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Company Image/Return Business</td>
<td>Scale (-2 to 2)</td>
<td>-1</td>
</tr>
<tr>
<td>Cost</td>
<td>Construction Cost Growth</td>
<td>% of Total Cost</td>
<td>-20.2</td>
</tr>
<tr>
<td></td>
<td>Construction Unit Cost</td>
<td>$ / SF</td>
<td>47.9</td>
</tr>
<tr>
<td>Quality</td>
<td>Overall Systems Quality</td>
<td>Scale (1 to 5)</td>
<td>1.5</td>
</tr>
<tr>
<td></td>
<td>Punchlist Items</td>
<td>No. / $M</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>Cost of Punchlist Items</td>
<td>Scale (1 to 5)</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Deficiencies</td>
<td>No. / $M</td>
<td>0</td>
</tr>
</tbody>
</table>
4.2.1 Performance Area Analysis: Communication

Effective communication among stakeholders throughout the construction process is integral to successfully completing a project. There are many failure points for communication that can lead to costly overruns and delayed completion of a project. This research looked at key performance metrics indicative of communication between the main stakeholders in a construction project. Specifically, four performance metrics were analyzed: 1) Number of requests for information (RFIs) per million dollars, 2) RFI response time, 3) Rework, and 4) Number of resubmittals per million dollars.

Survey respondents provided the number of RFIs for their respective project which was standardized on total project cost in order to accurately compare between projects of various sizes. The resulting metric was the number of RFIs per million dollars. The comparative boxplots show that IPD/IPD-ish projects had fewer RFIs per million dollars with medians of 4.06 and 4.61, respectively and less variability than Non-IPD projects (see Figure 20). The average number of RFIs per million dollars for IPD/IPD-ish was 3.9 compared to Non-IPD with an average of 8.0. This difference was statistically significant based on a t-test resulting in a p-value of 0.035. Therefore, evidence of superior IPD performance was demonstrated. The boxplots also suggest there is less variability/spread with IPD/IPD-ish than Non-IPD projects but Levene’s test did not indicate a
statistically significant difference with a p-value of 0.14. The 95% confidence interval for the difference in RFIs per million dollars between IPD/IPD-ish and Non-IPD projects is 0.32 to 7.90. Through personal communications with a construction company’s Vice President, it was estimated that the administrative processing cost of an RFI is approximately $2,500. Multiplying the administration cost of each RFI by the upper limit of the 95% confidence interval equates to $19,750. This value represents the savings per million dollars (roughly 2%) for IPD/IPD-ish projects as a result of having fewer RFIs.

Looking at the boxplots it is apparent that there is an extreme Non-IPD observation. A second t-test was performed after eliminating the observation to re-evaluate the two groups. Evaluation of the reduced dataset still yielded significant results with a p-value of 0.047.

RFI processing time was measured in weeks and is the duration from when a contractor submits an RFI until a response is received. A t-test resulted in no evidence of a difference between the two groups with a p-value of 0.83. The IPD/IPD-ish and Non-IPD groups averaged 1.4 and 1.5 weeks, respectively. There was no evidence of a difference in variances between the groups. The
comparative boxplots in Figure 21 show equal medians of 1.0 for RFI response times for IPD/IPD-ish and Non-IPD projects.

Data for rework was provided based on the percentage of total project cost and was converted to numerical values according to the following scale: $0\% = 0$, $0-1\% = 1$, $1-2\% = 2$, $2-3\% = 3$, $3-4\% = 4$, $>4\% = 5$. The comparative boxplots show that all projects had more than 0% and less than 2% rework (see Figure 22). No projects reported 0% rework which is not surprising considering at least a very small amount of rework is likely even with the best efforts to minimize it. There was no evidence of a difference in averages between the groups. Both groups averaged 1.3 and a t-test yielded a p-value of 0.75. Levene’s test confirmed there was no evidence of a difference in variances.
Survey respondents provided the number of resubmittals that occurred throughout a project. Resubmittals included any project requirements such as samples, shop drawings, product data, etc. that were submitted by the contractor for approval of the owner or A/E. The survey input was normalized based on total construction cost resulting in the number of resubmittals per million dollars. The comparative boxplots in Figure 23 show similar medians between IPD/IPD-ish and Non-IPD projects. The IPD/IPD-ish projects had a smaller range. IPD/IPD-ish projects averaged 1.8 resubmittals per million dollars while Non-IPD projects averaged 2.1 per million. Formal analysis with a t-test did not find any evidence of a difference between the two groups with a p-value of 0.79. There was no evidence of a difference in variances between the two groups.
A summary of the communication performance metrics is provided below in Table 10. The results of the t-test and MWW test are both provided; however, the test that was not relied upon is greyed out. If Welch’s t-test was used in lieu of an independent t-test, then the t-test statistic value was italicized. IPD/IPD-ish projects had statistically significant fewer RFIs per million dollars possibly due to the early involvement of key stakeholders during planning and design. The early collaboration of the entire team reduces the communication gaps between stakeholders that are commonplace in traditional project delivery. El Asmar and Hanna (2012) found a similar result that IPD projects had fewer RFIs than Non-IPD projects.

Table 10: Summary of Communication Performance Univariate Analysis

<table>
<thead>
<tr>
<th>Performance Metric</th>
<th>T-Test</th>
<th>MWW Test</th>
<th>Levene's Test</th>
<th>95% Confidence Interval of the difference in means</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>df</td>
<td>p-value</td>
<td>p-value</td>
<td>p-value</td>
</tr>
<tr>
<td>RFIs per $M</td>
<td>27.5</td>
<td>0.035</td>
<td>0.26</td>
<td>0.14</td>
</tr>
<tr>
<td>RFI Processing Time</td>
<td>29</td>
<td>0.83</td>
<td>0.69</td>
<td>0.83</td>
</tr>
<tr>
<td>Rework</td>
<td>29</td>
<td>0.75</td>
<td>0.76</td>
<td>0.75</td>
</tr>
<tr>
<td>Resubmittals per $M</td>
<td>28</td>
<td>0.79</td>
<td>0.62</td>
<td>0.44</td>
</tr>
</tbody>
</table>
4.2.2 Performance Area Analysis: Change Management

Changes during construction, at the very least, consume time and effort. If not addressed in a timely manner, outstanding changes can have subsidiary consequences that may negatively affect project outcomes. Two performance metrics were used to assess change management including the absolute amount of change on a project and the change order processing time. Survey respondents provided input on the percent of changes in terms of total project cost. The absolute value of the percentage of changes was analyzed because changes that reduce project costs can be just as disruptive as changes that increase the project cost. The percentage change data for four projects was eliminated because, for each case, the owner direct purchased the material and subsequently reduced the contract amount. The change did not reflect a change in project value. The comparative boxplots in Figure 24 show that Non-IPD projects had a slightly lower median percentage of total changes and a smaller range than IPD/IPD-ish projects. The average total change on IPD/IPD-ish and Non-IPD projects was 10.0% and 8.1%, respectively. There was no evidence of a difference between the two groups based on a t-test with a p-value of 0.61. There was no evidence of a difference in variances between the groups.

Figure 24: Total Changes Boxplots
Data for change order processing time was provided in terms of number of weeks. The comparative boxplots in Figure 25 show that IPD/IPD-ish projects had a lower median change order processing time than Non-IPD projects by three weeks. The average processing time for IPD/IPD-ish projects was 1.9 weeks compared to Non-IPD projects with an average of 4.8 weeks. A two-sided t-test resulted in a p-value of $9.5 \times 10^{-6}$ and consequently provided evidence of superior IPD/IPD-ish performance. Although there appears to be a difference in variance between the two groups based on the boxplots, the evidence is not statistically significant based on Levene’s test with a p-value of 0.15.

![Figure 25: Change Order Processing Time Boxplots](image)

Change performance area metrics are summarized below in Table 11. This research found evidence at a 0.05 significance threshold of superior IPD/IPD-ish performance for change order processing time over non-IPD projects. The finding for change order processing time was consistent with El Asmar and Hanna (2012).
4.2.3 Performance Area Analysis: Business

Two business performance metrics were analyzed: 1) Overhead and profit (OH&P) and 2) the effects of a project on company image and potential for return business. Profit data was not requested directly due to the confidentiality of the information. Instead, the data collection tool asked for a range of OH&P. The responses were converted to numerical values as follows: Negative=0, 0-5%=1, 5-10%=2, 11-15%=3, and >15%=4. The comparative boxplots in Figure 26 show a median of 5-10% OH&P for both IPD/IPD-ish and Non-IPD projects. The Non-IPD projects had a smaller range than the IPD/IPD-ish projects. The IPD/IPD-ish projects were the only ones to see OH&P greater than 15%. The IPD/IPD-ish projects averaged 2.4 while the Non-IPD projects averaged 1.9. No evidence of a difference between the groups was found based on a t-test with a p-value of 0.11. There was no evidence of a difference in variances between the two groups based on Levene’s test with a p-value of 0.54.
The second business metric evaluated was the effect of a project on a company’s image and potential for return business from the owner. The PM provided data on a five-point scale with very negative = -2, negative = -1, neutral = 0, positive = 1, and very positive = 2. The median scores for IPD/IPD-ish and Non-IPD projects were 2.0 and 1.5, respectively. The comparative boxplots (see Figure 27) show that IPD/IPD-ish had a higher median and more consistently achieved positive company image and return business than Non-IPD projects. It was determined that the data were not normally distributed so a MWW test was used to perform a hypothesis test. The MWW test did not provide evidence of a difference in medians with a p-value of 0.14. Evidence of a difference in variances was confirmed using Levene’s test which resulted in a p-value of 0.044. Therefore, statistically significant evidence of less variability for the IPD/IPD-ish projects was demonstrated. The IPD/IPD-ish projects consistently reported very positive effects on company image while the Non-IPD projects reported a wide range of effects including negative.
A summary of the business performance area metrics is provided below in Table 12. This section analyzed two important business metrics and found no statistically significant differences between the averages of IPD/IPD-ish projects and Non-IPD projects. However, statistically significant evidence of less variance of a project’s ability to very positively affect a company’s image was found for IPD/IPD-ish.

Table 12: Summary of Business Performance Univariate Analysis

<table>
<thead>
<tr>
<th>Performance Metric</th>
<th>T-Test</th>
<th>MWW Test</th>
<th>Levene’s Test</th>
<th>95% Confidence Interval of the difference in means</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>df</td>
<td>p-value</td>
<td>p-value</td>
<td>p-value</td>
</tr>
<tr>
<td>OH&amp;P</td>
<td>29</td>
<td>0.11</td>
<td>0.17</td>
<td>0.54</td>
</tr>
<tr>
<td>Company Image / Return Business</td>
<td>25.4</td>
<td>0.073</td>
<td>0.14</td>
<td>0.04</td>
</tr>
</tbody>
</table>

4.2.4 Performance Area: Cost

The cost performance area is comprised of two performance metrics: construction cost growth and construction unit cost. Construction cost growth is the percentage difference between the
final construction cost and the awarded construction amount and can be either positive or negative depending on if the project increased or decreased in cost throughout the duration of the project.

Comparative boxplots do not suggest a difference in performance between the IPD/IPD-ish and Non-IPD groups for construction cost growth (see Figure 28). The two groups have similar medians and large variability. The means for IPD/IPD-ish and Non-IPD projects were 0.2% and 4.1%, respectively. No statistically significant difference was found based on a t-test with a p-value of 0.31. Both groups had large standard deviations (10.9% for IPD/IPD-ish and 9.1% for Non-IPD) which precluded any significant findings. There was no difference in variance between the groups based on Levene’s test resulting in a p-value of 0.46.

![Construction Cost Growth Boxplots](image)

Construction unit cost is the final construction cost divided by the square footage of the facility and subsequently has units of dollars per square foot. The comparative boxplots show a smaller range of data for the IPD/IPD-ish group and two extreme observations for the Non-IPD group (see Figure 29). The median unit cost for IPD/IPD-ish ($290) was very similar to the median for Non-IPD projects ($308). Median values better represented the data because of the effects of extreme
observations on the mean. Levene’s test resulted in a p-value of 0.197 and there was no statistically significant evidence of a difference in variances between IPD/IPD-ish and Non-IPD. The formal hypothesis test did not result in any evidence against the null hypothesis with a p-value of 0.30. There was no evidence of a significant difference in construction unit cost between IPD/IPD-ish and Non-IPD projects.

Figure 29: Construction Unit Cost Boxplots

A summary of results from the cost performance area is provided below in Table 13. The analysis of cost performance metrics resulted in findings of no significant differences in construction unit cost or construction cost growth between IPD/IPD-ish and Non-IPD projects. These results are consistent with findings from previous IPD research which found no significant difference between IPD and Non-IPD projects (El Asmar and Hanna 2012; Cho and Ballard 2011).

Table 13: Summary of Cost Performance Univariate Analysis

<table>
<thead>
<tr>
<th>Performance Metric</th>
<th>T-Test</th>
<th>MWW Test</th>
<th>Levene’s Test</th>
<th>95% Confidence Interval of the difference in means</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>df</td>
<td>p-value</td>
<td>p-value</td>
<td>p-value</td>
</tr>
<tr>
<td>Cost Growth</td>
<td>30</td>
<td>0.31</td>
<td>0.25</td>
<td>0.46</td>
</tr>
<tr>
<td>Unit Cost</td>
<td>24.1</td>
<td>0.30</td>
<td>0.61</td>
<td>0.20</td>
</tr>
</tbody>
</table>
4.2.5 Performance Area Analysis: Quality

The quality performance area consisted of six individual performance metrics that offered a thorough assessment of project quality. The performance metrics analyzed were: 1) Overall systems quality, 2) Number of punchlist items per million dollars, 3) Cost of punchlist Items, 4) Number of deficiencies, 5) Latent defects costs, and 6) Warranty costs.

The eleven primary building systems (see Table 14) were qualitatively assessed by survey respondents on a Likert scale of; economy, standard, high, premium, and high efficiency premium.

Table 14: Eleven Primary Building Systems Included in the Survey

<table>
<thead>
<tr>
<th>Primary Building Systems</th>
</tr>
</thead>
<tbody>
<tr>
<td>Foundation</td>
</tr>
<tr>
<td>Exterior Enclosure</td>
</tr>
<tr>
<td>Electrical Systems</td>
</tr>
<tr>
<td>Conveying Systems</td>
</tr>
<tr>
<td>Structure</td>
</tr>
<tr>
<td>Roofing</td>
</tr>
<tr>
<td>Site</td>
</tr>
<tr>
<td>Specialties</td>
</tr>
<tr>
<td>Interior Finishes</td>
</tr>
<tr>
<td>Mechanical Systems</td>
</tr>
<tr>
<td>Process Equipment</td>
</tr>
</tbody>
</table>

The respondents also provided an overall as-built quality rating for the project on the same scale from economy to high efficiency premium. The qualitative ratings were converted to numerical values from one through five with economy corresponding to (1) and high efficiency premium corresponding to (5). The average score for the eleven primary systems quality was combined with the overall as-built quality score to generate a single overall systems quality score. An equation describing the overall systems quality score is provided below:

\[
\text{Overall Systems Quality} = (0.5 \times \text{Avg of Primary Systems}) + (0.5 \times \text{Overall AsBuilt Quality})
\]

From the boxplots it was evident that IPD/IPD-ish had a similar median overall systems quality than Non-IPD projects (see Figure 30). The median values for IPD/IPD-ish and Non-IPD of
2.88 and 2.95, respectively, related to qualitative rankings of nearly high. The average IPD/IPD-ish score was 3.29 while the Non-IPD average was 3.00. Based on formal hypothesis testing, there was no evidence of a difference in performance based on a t-test resulting in a p-value of 0.45. The difference in variances between the IPD/IPD-ish and Non-IPD groups was not significant with Levene’s test resulting in a p-value of 0.70.

Punchlist items are the unsatisfactory items that require correction after substantial completion of a project. Respondents provided the number of punchlist items, and their input was normalized on final construction cost. The comparative boxplots show similar medians between the two groups (16.9 for IPD/IPD-ish and 17.4 for Non-IPD) (see Figure 31). IPD/IPD-ish projects had an average of 19.8 punchlist items per million dollars compared to 35.9 for Non-IPD projects. The difference was not statistically significant with the t-test resulting in a p-value of 0.35. Levene’s test confirmed there was no statistically significant difference in variances with a p-value of 0.27.
Not only is the number of punchlist items reflective of a contractor’s quality control (QC) program, the costs associated with the punchlist items may also provide insight into a project’s QC. A high cost associated with correcting punchlist items, even if they were not numerous, may imply serious QC shortcomings. Data for the cost of punchlist items was collected in pre-established bins and converted to a numerical scale with $0-0.25\% = 1$, $0.25-0.5\% = 2$, $0.5-1\% = 3$, $1-2\% = 4$, and $>2\% = 5$. The comparative boxplots for IPD/IPD-ish and Non-IPD projects show equal medians of 1 for each group (see Figure 32). However, the boxplots suggest IPD/IPD-ish projects more consistently resulted in a lower percent cost of punchlist items. The majority of projects in both groups had 0-0.25% cost of punchlist items. Further analysis of IPD/IPD-ish compared to Non-IPD resulted in no evidence that the groups had different means based on a t-test with a p-value of 0.21. There was no statistically significant evidence of a difference in variances based on Levene’s test with a p-value of 0.21.
Deficiency issues are defined as items that require correction during construction as a result of field inspections by an A/E or inspector, or a result of non-compliance with code, for example. In order to accurately compare between projects, the number of deficiencies was normalized on final construction cost. The comparative boxplots show similar medians for IPD/IPD-ish and Non-IPD (see Figure 33). The median for IPD/IPD-ish was 0.90 deficiencies per million dollars and the median for Non-IPD projects was 0.75 deficiencies per million dollars. The boxplots suggest a smaller range for the Non-IPD projects because of an extreme IPD/IPD-ish observation. For that project, the PM remarked specifically that an overly zealous inspector was very aggressive in identifying deficiencies throughout the project. Formal analysis resulted in no significant evidence of differences between IPD/IPD-ish and Non-IPD projects based on a MWW test with a p-value of 0.98. Levene’s test confirmed there was no statistically significant difference in variances with a p-value of 0.11.
Figure 33: Deficiencies per Million Dollars Boxplots

Warranty costs are those costs associated with correcting defects measured up to one year after substantial completion. Data was provided based on percentages of total cost and converted to numerical values according to the following scale: 0%=0, 0-0.5%=1, 0.6-1%=2, 1-2%=3, 2-3%=4, >3%=5. The comparative boxplots for IPD/IPD-ish and Non-IPD show very similar results for each group with the exception that Non-IPD project(s) had a score of two (see Figure 34). No statistically significant differences were found between IPD/IPD-ish and Non-IPD based on the t-test with a p-value of 0.80. The averages for each group were very similar at 0.63 and 0.69 for IPD/IPD-ish and Non-IPD, respectively. Those averages equate to the percent cost of warranty items being less than 0.5% of total project cost, and, therefore, there is no discernible difference between the groups.
Latent defect costs are costs associated with correcting defects that were identified after the first year following occupation of the facility. Identical to the percent cost of warranty items, the survey data from respondents was converted to numerical values as follows: $0\% = 0$, $0.5\% - 1\% = 1$, $1\% - 2\% = 2$, $2\% - 3\% = 3$, $3\% - 4\% = 4$, $>4\% = 5$. The comparative boxplots show very similar results for each group with no latent defect costs for nearly all the projects (see Figure 35). The IPD/IPD-ish and Non-IPD projects averaged 0.14 and 0.27, respectively, for latent defect costs. The latent defect data was considered to be not normally distributed so the MWW test was used to perform a hypothesis test. No evidence of a difference between the groups was found based on a MWW test with a p-value of 0.75. There was no evidence of a difference in variances between the groups based on Levene’s test resulting in a p-value of 0.62.
A summary of the quality performance area metrics is provided below in Table 15. This researcher found it surprising that there was no evidence demonstrating superior IPD/IPD-ish performance in terms of quality. Previous research (El Asmar and Hanna 2012), and nearly all of the published case studies, suggest IPD projects deliver more value through higher quality with no cost premiums. The lack of evidence supporting such claims in this research may be a result of the dataset containing a high proportion of DB and CMR projects and few IPD projects. Even though not identified by the PM as IPD-ish, many of the DB and CMR projects incorporated IPD principles to some extent which possibly minimized any differences in performance between the two groups.

Table 15: Summary of Quality Performance Univariate Analysis

<table>
<thead>
<tr>
<th>Performance Metric</th>
<th>T-Test df</th>
<th>p-value</th>
<th>MWW Test df</th>
<th>p-value</th>
<th>Levene’s Test df</th>
<th>p-value</th>
<th>95% Confidence Interval of the difference in means</th>
</tr>
</thead>
<tbody>
<tr>
<td>Overall Systems Quality</td>
<td>30</td>
<td>0.45</td>
<td>0.53</td>
<td>0.70</td>
<td>-0.47</td>
<td>1.04</td>
<td></td>
</tr>
<tr>
<td>Punchlist Items per $M</td>
<td>27</td>
<td>0.35</td>
<td>0.76</td>
<td>0.27</td>
<td>-51.13</td>
<td>18.91</td>
<td></td>
</tr>
<tr>
<td>Cost of Punchlist Items</td>
<td>28</td>
<td>0.21</td>
<td>0.26</td>
<td>0.21</td>
<td>-1.33</td>
<td>0.30</td>
<td></td>
</tr>
<tr>
<td>Deficiencies per $M</td>
<td>7.4</td>
<td>0.35</td>
<td>0.98</td>
<td>0.11</td>
<td>-7.14</td>
<td>17.76</td>
<td></td>
</tr>
<tr>
<td>Warranty Costs</td>
<td>22</td>
<td>0.80</td>
<td>0.89</td>
<td>0.78</td>
<td>-0.58</td>
<td>0.46</td>
<td></td>
</tr>
<tr>
<td>Latent Defect Costs</td>
<td>20</td>
<td>0.62</td>
<td>0.75</td>
<td>0.62</td>
<td>-0.64</td>
<td>0.39</td>
<td></td>
</tr>
</tbody>
</table>
4.2.6 Performance Area Analysis: Safety

The safety performance metrics analyzed included the number of lost time incidents (LTIs) and the number of OSHA recordable incidents (RIs) on a project. Since not all of the respondents provided the number of man-hours for a project, the incident rates were calculated based on total project cost (in terms of $100 million). A factor of one hundred million dollars was used because of the low number of incidents reported for any of the projects.

The comparative boxplots for LTI rates did not show any significant differences between the medians for IPD/IPD-ish and Non-IPD (see Figure 36). Both groups consistently had zero lost time incidents with a small number of projects experiencing a low number of LTIs. Formal analysis of IPD/IPD-ish compared to Non-IPD resulted in no evidence of statistically significant differences for LTIs per hundred million dollars. The MWW test resulted in a p-value of 0.57. There was no evidence of a difference in variances between the groups with Levene’s test resulting in a p-value of 0.75.

![Lost Time Incidents Boxplots](image-url)
Comparative boxplots for the OSHA RIs per hundred million dollars are provided below in Figure 37 and show equal medians of zero for the two groups. With the exception of one observation, the IPD/IPD-ish projects appear to have less variability than the Non-IPD projects. No statistically significant evidence of a difference between IPD/IPD-ish and Non-IPD projects was found. The average number of RIs per hundred million dollars for IPD/IPD-ish and Non-IPD projects was 9.51 and 2.27, respectively. The means were affected by a few projects and the median number of RIs for each group was zero. The data were determined to be not normally distributed so the MWW test was used to compare medians which resulted in a p-value of 0.31.

![Figure 37: OSHA Recordable Incidents Boxplots](image)

A summary of the safety performance area metrics is provided below in Table 16. These results are not completely surprising considering the dedicated focus on safety that is prevalent throughout the construction industry regardless of the delivery method. This research did not find any statistically significant evidence of differences between IPD/IPD-ish and Non-IPD. These findings are consistent with El Asmar’s (2012) conclusions for the same safety metrics. The only significant result El Asmar found was the number of LTI’s per million dollars with a p-value of
0.083; however, it is not clear whether this was a one-tailed or two-tailed hypothesis test. Either way, the metric was not significant at 0.05, the threshold used for this research.

Table 16: Summary of Safety Performance Univariate Analysis

<table>
<thead>
<tr>
<th>Performance Metric</th>
<th>T-Test</th>
<th>MWW Test</th>
<th>Levene’s Test</th>
<th>95% Confidence Interval of the difference in means</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>df</td>
<td>p-value</td>
<td>p-value</td>
<td>p-value</td>
</tr>
<tr>
<td>LTI per $100M</td>
<td>25</td>
<td>0.75</td>
<td>0.57</td>
<td>0.75</td>
</tr>
<tr>
<td>OSHA Recordables per $100M</td>
<td>4.2</td>
<td>0.46</td>
<td>0.31</td>
<td>0.14</td>
</tr>
</tbody>
</table>

4.2.7 Performance Area Analysis: Schedule

The schedule performance area consisted of four metrics: 1) Construction speed, 2) Delivery speed, 3) Schedule growth, and 4) Schedule intensity. Construction speed was measured in square feet per day and was defined as:

\[
\text{Construction Speed} \left( \frac{sq. ft}{day} \right) = \frac{\text{Gross Square Feet}}{\text{Construction Duration}}
\]

Where: Construction Duration is measured from the Notice to Proceed (NTP) date to Substantial Completion date.

The comparative boxplots show a larger interquartile range (IQR) and a slightly higher median for IPD/IPD-ish than Non-IPD projects (see Figure 38). However, the Non-IPD projects had a larger overall range with some very large extreme values. There was considerable variability in the Non-IPD group causing the mean and median to be substantially different. The mean construction speed for IPD/IPD-ish and Non-IPD projects was 188.6 SF/day and 307.8 SF/day while the medians were 145.1 SF/day and 81.0 SF/day, respectively. Formal hypothesis testing using the MWW test resulted in no evidence of a difference between the groups based on a p-value of 0.95. There was no
evidence of a difference in variances between IPD/IPD-ish and Non-IPD projects based on Levene’s test with a p-value of 0.47.

![Figure 38: Construction Speed Boxplots](image)

Delivery speed is slightly different than construction speed because it measures the output per day from the design start date until the substantial completion date of a project.

\[
\text{Delivery Speed} \left( \frac{\text{sq. ft}}{\text{day}} \right) = \frac{\text{Gross Square Feet}}{\text{Project Duration}}
\]

Where: Project duration is measured from the Design Start date to Substantial Completion date.

The comparative boxplots suggest very similar results to the above analysis of construction speed which is not surprising (see Figure 39). Similar to construction speed, the large variability in the Non-IPD group caused the mean and median to differ considerably. The mean delivery speed for IPD/IPD-ish and Non-IPD projects was 125.4 SF/day and 282.0 SF/day while the medians were 100.6 SF/day and 49.3 SF/day, respectively. Formal hypothesis testing using the MWW test resulted in no evidence of a difference between the groups based on a p-value of 0.66.
Schedule growth is an important metric for owners who rely on timely completion of a project to begin occupying a building and, in many cases, begin generating revenue. Construction schedule growth is the percent change between the actual duration and target duration of construction as represented by the following equation:

\[
\text{Schedule Growth (\%)} = \frac{\text{Substantial Comp. (Actual)} - NTP (Actual)}{\text{Substantial Comp. (Target)} - NTP (Target)} - 1
\]

Schedule growth can be either positive or negative depending on whether the project duration was extended or compressed compared to the target dates. The comparative boxplots show that most often projects do not experience large amounts of schedule growth (see Figure 40). However, infrequently there are occurrences of extreme schedule growth on a project. The median schedule growth for each group was zero percent. The medians better represented the sample average due to a few extreme observations in each group which affected the means. No differences were found between IPD/IPD-ish and Non-IPD based on a MWW test with a p-value of 0.14. This result is
consistent with Cho and Ballard (2011). There was no evidence of a difference in variances between IPD/IPD-ish and Non-IPD projects.

The final schedule performance metric analyzed was schedule intensity which is a measure of the value of work put in place over the duration of a project (El Asmar 2012). The schedule intensity metric identifies the pace that a project is constructed. The length of time to complete a project alone may not be indicative of performance because some projects estimate, and strive for, a more aggressive schedule than others. This metric is calculated by the following equation:

\[
\text{Schedule Intensity} \left( \frac{\text{\$}}{\text{day}} \right) = \frac{\text{Final Construction Cost}}{\text{Construction Duration}}
\]

Where: Construction duration is measured from the Notice to Proceed (NTP) date to Substantial Completion date.

The comparative boxplots show higher median schedule intensity for IPD/IPD-ish ($36.8K/day) than Non-IPD ($32.6/day) (see Figure 41). An extreme Non-IPD observation resulted from the largest project included in the dataset which had a significantly higher number of laborers on average than any other project. The averages for IPD/IPD-ish and Non-IPD were $61,268 per day
and $61,683 per day, respectively. No evidence of a difference in schedule intensity was found between the groups based on a t-test with a p-value of 0.99. There was no evidence of a difference in variances between the two groups.

![Construction Schedule Intensity Boxplots](image)

**Figure 41: Construction Schedule Intensity Boxplots**

A summary of the schedule performance area hypothesis tests is provided below in Table 17. This research did not find any statistically significant differences in schedule performance between IPD/IPD-ish and non-IPD projects. Schedule performance area metrics, construction speed, delivery speed, and schedule intensity, can be highly influenced by many factors including project complexity, type of project, program, and labor intensity, to name a few. The results of the schedule performance analysis are consistent with the findings of Cho and Ballard (2011) who found no differences in schedule growth between IPD and non-IPD projects.
4.2.8 Performance Area Analysis: Labor

Labor is an important aspect of all construction projects because it accounts for a high percentage of a project’s cost. Two labor performance metrics, including the use of schedule compression techniques and the percent plan complete (PPC) trend, were analyzed in this research. The schedule compression technique score was the summation of overtime, shift work, and jobsite congestion. Overtime and shift work were measured on a five-point scale according to the following: none=0, 0-5%=1, 5-10%=2, 11-15%=3, >15%=4. Congestion was measured by the work space for each worker on a jobsite and reported as more crowded than average (1), about average (0), or less crowded than average (-1). The comparative boxplots in Figure 42 show similar medians for the two groups and less variability for the IPD/IPD-ish projects. The average scores for schedule compression techniques for IPD/IPD-ish and Non-IPD projects were 2.0 and 2.4, respectively. No evidence of a difference between the groups was found based on Welch’s t-test with a p-value of 0.37. The difference in variance between IPD/IPD-ish and Non-IPD projects was not statistically significant based on Levene’s test with a p-value of 0.07. During data collection some industry members commented that often times schedule compression techniques, whether it was overtime or shift work, were used to minimize disturbances to clients and allow them to maintain important operations throughout the construction phase.

<table>
<thead>
<tr>
<th>Performance Metric</th>
<th>T-Test df</th>
<th>T-Test p-value</th>
<th>MWW Test p-value</th>
<th>Levene’s Test p-value</th>
<th>95% Confidence Interval of the difference in means</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constr. Speed</td>
<td>28</td>
<td>0.51</td>
<td>0.95</td>
<td>0.47</td>
<td>-486.0, 247.6</td>
</tr>
<tr>
<td>Delivery Speed</td>
<td>20</td>
<td>0.39</td>
<td>0.66</td>
<td>0.32</td>
<td>-526.8, 213.6</td>
</tr>
<tr>
<td>Schedule Growth</td>
<td>24</td>
<td>0.76</td>
<td>0.14</td>
<td>0.79</td>
<td>-16.9%, 22.9%</td>
</tr>
<tr>
<td>Schedule Intensity</td>
<td>29</td>
<td>0.99</td>
<td>0.72</td>
<td>0.91</td>
<td>-$79.0K, $78.2K</td>
</tr>
</tbody>
</table>
PPC is a workflow reliability measurement (Forbes and Ahmed 2011). Approximately 58% of the respondents indicated that PPC was tracked during construction. Respondents indicated whether the PPC trend was stable (0), increased (1), or decreased (-1) throughout the duration of a project. The comparative boxplots indicated all but a few projects maintained a stable PPC trend (see Figure 43). The average PPC trend for IPD/IPD-ish and Non-IPD projects was 0.3 and -0.1, respectively. There was no evidence of a difference in PPC trend between the two groups based on a MWW test with a p-value of 0.17. There was no evidence of a difference in variances between the two groups.
A summary of the labor performance metrics is provided below in Table 18.

Table 18: Summary of Labor Performance Univariate Analysis

<table>
<thead>
<tr>
<th>Performance Metric</th>
<th>T-Test</th>
<th>MWW Test</th>
<th>Levene’s Test</th>
<th>95% Confidence Interval of the difference in means</th>
</tr>
</thead>
<tbody>
<tr>
<td>Schedule Compression Techs.</td>
<td>29.9</td>
<td>0.37</td>
<td>1.0</td>
<td>0.07</td>
</tr>
<tr>
<td>PPC Trend</td>
<td>9</td>
<td>0.14</td>
<td>0.17</td>
<td>0.48</td>
</tr>
</tbody>
</table>

### 4.3 Conclusions

A summary of the 24 metrics tested in Chapter 4 is provided below in Table 19. The metrics are ordered from lowest to highest p-values. This study demonstrated statistically significant evidence of superior IPD/IPD-ish performance at a 95% confidence level in the communication, change management, and business performance areas. IPD/IPD-ish had fewer RFIs per million dollars and a shorter change order processing time than Non-IPD projects. IPD/IPD-ish projects also had a smaller variance with respect to a project’s effects on a company’s image and potential for return business. The IPD/IPD-ish projects more consistently had very positive effects on a company’s
image. None of the metrics demonstrated statistically significant evidence of inferior IPD/IPD-ish performance.

There are less significant results in this research than El Asmar and Hanna (2013) as shown in Table 20. A possible reason for this is because El Asmar had a larger sample of pure IPD projects and only compared pure IPD projects to Non-IPD projects. The IPD-ish projects were not included in

<table>
<thead>
<tr>
<th>Performance Metric</th>
<th>T-Test p-value</th>
<th>MWW p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO Processing Time</td>
<td>9.5e-6</td>
<td>8.1e-3</td>
</tr>
<tr>
<td>RFI s</td>
<td>0.03456</td>
<td>0.2631</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Averages</td>
<td>Mean</td>
<td>Median</td>
</tr>
<tr>
<td></td>
<td>IPD/IPD-ish</td>
<td>Non-IPD</td>
</tr>
<tr>
<td></td>
<td>IPD/IPD-ish</td>
<td>Non-IPD</td>
</tr>
<tr>
<td>CO Processing Time</td>
<td>1.9</td>
<td>4.8</td>
</tr>
<tr>
<td></td>
<td>1.0</td>
<td>5.0</td>
</tr>
<tr>
<td>RFI s</td>
<td>3.9</td>
<td>8.0</td>
</tr>
<tr>
<td></td>
<td>4.1</td>
<td>4.6</td>
</tr>
</tbody>
</table>

Results above were Statistically Significant at 0.05

*There is evidence of less variability for IPD/IPD-ish projects with a p-value of 0.044 from Levene’s test.
his comparison. This may have resulted in a more definitive difference in performance between the pure IPD and Non-IPD groups. Not all of the metrics analyzed by El Asmar were included as part of this study and are depicted as NA in the below table. The two statistically significant differences in means found in this study are listed in red text.

Table 20: A Comparison of El Asmar (2012)'s IPD vs. the Results of this Research

<table>
<thead>
<tr>
<th>Performance Metric</th>
<th>P-Value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>El Asmar</td>
</tr>
<tr>
<td>Change Order Processing Time</td>
<td>0.000</td>
</tr>
<tr>
<td>Deficiency Issues per $M</td>
<td>0.001</td>
</tr>
<tr>
<td>RFIs per $M</td>
<td>0.001</td>
</tr>
<tr>
<td>Punchlist Cost</td>
<td>0.003</td>
</tr>
<tr>
<td>Punchlist Items per $M</td>
<td>0.014</td>
</tr>
<tr>
<td>Resubmittals per $M</td>
<td>0.018</td>
</tr>
<tr>
<td>OH&amp;P</td>
<td>0.024</td>
</tr>
<tr>
<td>RFI Processing Time</td>
<td>0.025</td>
</tr>
<tr>
<td>Overall Systems Quality</td>
<td>0.032</td>
</tr>
<tr>
<td>Design Changes</td>
<td>0.032</td>
</tr>
<tr>
<td>Warranty Costs</td>
<td>0.040</td>
</tr>
<tr>
<td>Delivery Speed</td>
<td>0.046</td>
</tr>
<tr>
<td>Regulatory Changes</td>
<td>0.050</td>
</tr>
</tbody>
</table>

The results of this research alone provide conclusive evidence of superior IPD/IPD-ish performance in three of the eight performance areas analyzed including change management, communication, and business. It is possible that more pure IPD projects may have increased the relative differences between IPD/IPD-ish and Non-IPD projects. Looking at the performance of individual metrics is enlightening; however, an analysis of overall project performance is even more pertinent when comparing multiple projects. Owners are certainly less interested in maximizing any given performance metric and more concerned with overall project performance. The next chapter will analyze overall project performance in order to test the claim of superior IPD/IPD-ish performance.
Chapter 5. Project Quarterback Rating

5.1 PQR Background

In the previous chapter performance metrics were analyzed independently to evaluate the effects of integrated delivery on key project metrics. This approach is enlightening, except, project success cannot be based upon a single factor (Tatum 2012). A comprehensive metric is necessary to evaluate overall performance. There is not a widely accepted comprehensive measure of project performance in the construction industry. Owners’ goals are unique to each project making comparisons between various projects challenging. Each owner’s unique objectives and priorities determine the influence of each success measure. It would be nearly impossible to develop a widely accepted model that includes every factor affecting performance. Still, a cumulative method of evaluating project performance is desirable and the Project Quarterback Rating (PQR) is an approach to accurately measure overall project performance based on the most important factors affecting success.

The PQR quantitatively assesses cumulative project performance of PDSs by combining the key variables that affect project performance (El Asmar 2012). As the name implies, the PQR was modeled after the National Football League’s Quarterback Rating that uses key performance metrics to measure and equitably compare quarterbacks. Similarly, the PQR combines key performance metrics that impact a project’s outcome.

5.2 The PQR Formula

The PQR is a three-tiered model that linearly combines 25 key metrics into a single score in an effort to quantitatively assess overall performance from the contractor’s perspective. The metrics
are consolidated into performance areas that are subsequently combined into a single overall performance score, see Figure 44.

Tier I is the PQR score. Tier II includes seven performance areas: owner satisfaction, schedule, profit, safety, budget, quality, and change management. These performance areas reflect the most important success measures cited by the PMs who provided data for this research and are shown in Figure 45.

Each of the seven performance areas consist of various metrics as shown in Figure 46. As part of this research, two additional metrics were added to the original model developed at the University of Wisconsin-Madison so that it better reflects overall performance. The first metric added was a project team satisfaction score under the owner satisfaction performance area. This metric assesses the degree of satisfaction of the PM with the owner and architect after project
completion. It is representative of the relationship between the constructor and owner throughout a project. The second metric added was the number of fatalities under the safety performance area. This metric is vital to accurately gauging safety performance in the tragic event of a fatality on a construction project.

Figure 46: PQR Components

In general, the PQR score is derived according to the below equation where each performance area score is weighted and summed together.
\[ PQR_j = \sum_{i=1}^{I} w_i z_{ij} \]

Where: 

- \( PQR_j \) = Project Quarterback Rating for project \( j \) \( 1 \leq j \leq J, J=32 \)
- \( w_i \) = weighted value of performance area \( i \) \( 1 \leq i \leq I, I=7 \)
- \( z_{ij} \) = the standardized score of project \( j \) for performance area \( i \)

The PQR model assumes that each of the performance areas is independent and not influenced by changes in other areas. Also, the model is assumed to be linear at each tier. This simplifies the model and makes it possible to combine multiple variables in a straightforward manner. It also makes it useful for others to customize the model as they see fit based upon their unique success criteria.

The various metrics within each performance area cannot be combined directly because they contain different units of measure and, in many cases, are based upon different scales. For example, the quality performance area includes five metrics: systems quality (measured on a scale from one through five), punchlist items per million dollars, deficiencies per million dollars, and warranty and latent defect cost data (measured on values from zero to five). If the metrics were combined directly they would have unequal influence on the quality performance area because of the inconsistent scales and differing magnitudes of each metric. Standardization eliminates this disparity and equalizes the influence of each metric so they can be combined.

Each metric, \( X_{ijk} \), was standardized on a standard normal distribution resulting in a unit-less value. The average of each standardized metric was centered on zero with a standard deviation of one. The term \( X_{ijk} \) denotes the score for each performance metric with \( 1 \leq k \leq K \), where \( K \) is the
number of metrics in each performance area. To accomplish this standardization the mean was subtracted from, \( X_{ijk} \), and then divided by the standard deviation of the performance metrics for all the projects. The mean of each performance metric, \( \mu_{ik} \), is calculated by summing \( X_{ijk} \) for all the projects and dividing by \( J \) given by the equation: 

\[
\mu_{ik} = \frac{\sum_{j=1}^{J} X_{ijk}}{J}.
\]

The standard deviation of each performance metric is given by the equation:

\[
\sigma_{ik} = \frac{1}{J} \sum_{j=1}^{J} \left( X_{ijk} - \frac{1}{J} \sum_{j=1}^{J} X_{ijk} \right)^2.
\]

Through standardization the original metrics, \( X_{ijk} \), are converted to z-scores according to:

\[
z_{ijk} = \frac{X_{ijk} - \mu_{ik}}{\sigma_{ik}}.
\]

With each performance metric standardized they can be combined to calculate the performance area scores, \( s_{ij} \), according to the following equation:

\[
s_{ij} = \sum_{k=1}^{K} w_{ik} z_{ijk}
\]

Where: \( w_{ik} \) = weighted value of each performance metric in a given performance area, \( i \).

\( z_{ijk} \) = the standardized score for each performance metric

After each performance area score, \( s_{ij} \), was calculated it was subsequently standardized in the same fashion by subtracting the mean score of the performance area and dividing by the standard deviation of all \( s_{ij} \) according to: 

\[
z_{ij} = \frac{s_{ij} - \mu_{ij}}{\sigma_{ij}}.
\]

The resulting standardized value, \( z_{ij} \), is one of the two factors in the PQR equation. Each \( s_{ij} \) was standardized to facilitate comparing project performance in each of the seven areas and make the results of the analysis more readily interpretable. A project with a positive performance area score indicates above average performance in that particular area; while a negative performance area score indicates below average performance in that particular area. The standard deviation of each performance area is one therefore the performance area score represents a commonly understood measure of variance from the average.
After the performance area scores are combined, a third standardization was performed on the PQR value itself by dividing by the standard deviation of all $PQR_j$. There was no need to subtract the average of the PQR scores in this standardization because the average PQR of all the projects was zero. Again, this standardization was done to standardize the PQR scores on a standard normal distribution so that each project’s score reflected the number of standard deviations that project was from the average. For example, a project with a score of 1.0 is exactly one standard deviation above the average.

5.3 $PQR$ Performance Area Factors

The Tier II performance areas were based upon the measures of success identified by the survey respondents. The fifth section of the data collection tool asked the respondents to identify the specific success measures for their project in order of importance. The data collection tool included space for them to identify the five most important measures. Twenty-nine of the 32 respondents provided responses for this section of the survey. The overall importance of the success measures was calculated based upon the frequency and the priority ranking of the respondents’ input. Because the survey question was in an open-ended format, there were some variations in responses and some of the responses were bundled when appropriate. Most notably, responses of “return business”, “improved/continued relations”, and “recommendations” were considered to reflect owner satisfaction and included in that performance area. The change management performance area included responses of “communication”, “owner’s satisfaction with the design”, and “collaboration”. The profit performance area included “fee” and budget included “cost” responses. The weighted value of each success measure was calculated by multiplying by a factor from five to one depending on the rank of the success measure from most important to the fifth most important, respectively. The overall importance of each measure was calculated by adding up the weighted scores for each success
measure. To explain this more clearly the “owner satisfaction” performance area score is described in the following paragraph.

Twelve respondents identified owner satisfaction as the most important success measure $(12 \times 5 = 60)$; nine PMs identified it as the second most important success measure $(9 \times 4 = 36)$; three PMs identified it as the third most important measure $(3 \times 3 = 9)$, three PMs identified it as the fourth most important measure $(3 \times 2 = 6)$, and three PMs identified it as the fifth most important metric $(3 \times 1 = 3)$. The total overall importance for “owner satisfaction” was 114 $(60+36+9+6+3)$. This was repeated for each success measure listed by respondents and seven predominant success measures were identified as shown in Figure 47. The other success measures listed included ethics/integrity (score of 11), innovation (score of 6), marketability (score of 3), and experience (score of 3).

![Figure 47: Overall Importance Scores of Success Measures](image-url)
The coefficients, \( w_i \), in the PQR equation were derived based upon the ratio of the total overall importance scores for each of the seven success measures. Summing the overall importance scores for the top seven success measures gives a total of 406. Looking at owner satisfaction with a score of 114, it represents 28% of the total scores of the seven success measures (i.e. 114/406). The value 28% became the coefficient, \( w_i \), for owner satisfaction in the PQR equation (shown as 0.28 in the equation). The percentage of overall importance scores for each of the seven performance areas is shown in Figure 48.

![Figure 48: Percentage of Overall Importance Score of the Seven Performance Areas](image)

Although the same seven performance areas were identified by El Asmar (2012) the relative importance of each measure was slightly different. One possible reason for the differences is that this research weighted the responses based upon ranks whereas El Asmar summed the success measures solely based upon frequency. A comparison of the coefficients used in each of the studies is provided.
below in Table 21. Note that El Asmar used *communication/collaboration* instead of *change management*, but the terms are equivalent as used in this capacity.

<table>
<thead>
<tr>
<th>Success Measure</th>
<th>Percentage of responses (El Asmar 2012)</th>
<th>Percentage of importance (current study)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Owner Satisfaction</td>
<td>23%</td>
<td>28%</td>
</tr>
<tr>
<td>Safety</td>
<td>17%</td>
<td>15%</td>
</tr>
<tr>
<td>Schedule Compliance</td>
<td>16%</td>
<td>18%</td>
</tr>
<tr>
<td>Budget Compliance (Cost)</td>
<td>13%</td>
<td>10%</td>
</tr>
<tr>
<td>Quality</td>
<td>12%</td>
<td>8%</td>
</tr>
<tr>
<td>Profit</td>
<td>11%</td>
<td>17%</td>
</tr>
<tr>
<td>Change Management</td>
<td>9%</td>
<td>4%</td>
</tr>
</tbody>
</table>

Using the data collected from the surveys to calculate each $w_i$, the project quarterback rating can be represented by the following equation:

$$PQR = \frac{(0.28 \times Owner\ Sat) + (0.15 \times Schedule) + (0.17 \times Profit) + (0.15 \times Safety) + (0.10 \times Budget) + (0.08 \times Quality) + (0.04 \times Change\ Mgmt)}{0.44}$$

The above equation uses plain language to represent the PQR equation. A more concise equation identifies the performance area scores as standardized values as shown below:

$$PQR = \frac{(0.28 \times Z_O) + (0.15 \times Z_{Sw}) + (0.17 \times Z_P) + (0.15 \times Z_{Sa}) + (0.10 \times Z_B) + (0.08 \times Z_Q) + (0.04 \times Z_C)}{0.44}$$

For the remainder of this chapter the latter version of the equation is used to reinforce the idea that the performance areas were standardized before they were included in the PQR equation.

### 5.4 Calculation of PQR Performance Areas

This section provides the details of how the various performance metrics were combined within each of the seven performance areas, as shown in Figure 46. Except for the owner satisfaction
101

and safety performance areas, the calculations for each of the performance areas were consistent with El Asmar (2012). In that research, thorough collaboration with industry participants identified the metrics that best represented each performance area as well as the relative importance of each metric.

5.4.1 PQR Performance Area I: Owner Satisfaction

The most important success measure identified by survey respondents was owner satisfaction. This research collected both qualitative and quantitative data to measure owner satisfaction. The performance metrics included: 1) Return business/company image, 2) Claims, and 3) Project team satisfaction with the owner/architect. Recall, return business was rated on a scale of negative two to two, which corresponded to very negative to very positive, respectively. The average return business score was 1.48 and the standard deviation was 0.71. The highest score reported was two and the lowest was negative one.

Claims were measured on a binary scale. A zero indicated there was at least one claim on a project; whereas a value of one was assigned to projects that had no claims. A majority of the projects did not report any claims resulting in an average of 0.88 and a standard deviation of 0.34. The counterintuitive coding was done because having no claims indicates positive performance and will increase the owner satisfaction score when added to the equation. The third metric, project team satisfaction with the owner/architect, was rated as: poor = 1, fair = 2, good = 3, very good = 4, Excellent = 5. The average project team satisfaction score was 4.1 with a standard deviation of 1.1. The highest score was a five and the lowest was a one.

It is obvious the scales of each variable are different, therefore standardization was necessary. The average and standard deviation for each variable were used to independently standardize the variables which generated individual z-scores. The z-scores were combined based on the relative contribution each factor was perceived to have on measuring the level of satisfaction of an owner.
The potential for return business and effect on company image was determined the most indicative of an owner’s satisfaction with a project and was weighted highest at 50%. The remaining factors, claims and project team satisfaction with the owner/architect, were considered equally influential and given coefficients of 25% each. The relative importance of return business and claims established by El Asmar (2012) was maintained in this research even though the weights were changed because a third metric was included in this research. The standard deviation for the overall owner satisfaction score, $s$, was 0.72 and was included as the denominator in the equation in order to calculate a standardized score. The standardized score is used directly in the final PQR equation and represented by:

$$Z_o = \frac{0.50 \times \frac{X_1 - 1.48}{0.71} + 0.25 \times \left(\frac{X_2 - 0.88}{0.34} + \frac{X_3 - 4.1}{1.1}\right)}{0.72}$$

Where: $Z_o = \text{Standardized owner satisfaction performance area score}$

$X_1 = \text{Return business}$  \hspace{1cm} $X_2 = \text{Claims}$

$X_3 = \text{Project team satisfaction with owner/architect}$

An analysis of the owner satisfaction performance area resulted in statistically significant evidence of a difference in performance based on Welch’s t-test with a p-value of 0.045. The average owner satisfaction scores for IPD/IPD-ish and Non-IPD projects were 0.44 and -0.17, respectively. Levene’s test did not suggest a difference in variance between the two groups with a p-value of 0.10. A 95% confidence interval for the differences in averages between IPD/IPD-ish and Non-IPD projects is 0.014 to 1.23. Comparative boxplots are provided in Figure 49.
5.4.2 PQR Performance Area II: Schedule

After owner satisfaction, schedule was the next most important success measure. Four performance metrics were consolidated to generate a single schedule performance area score. The four variables were: 1) Construction speed, 2) Delivery speed, 3) Construction schedule intensity, and 4) Schedule growth. These metrics were defined as part of the analysis in Section 4.2.7. The average construction speed for the projects was 276 ft$^2$/day and the standard deviation was found to be 429.6 ft$^2$/day. There was a wide range of data from 23.36 ft$^2$/day to 1,785.71 ft$^2$/day. The average delivery speed was 225.1 ft$^2$/day with a standard deviation of 398 ft$^2$/day. The range of input was 4.68 ft$^2$/day to 1,493 ft$^2$/day. The average construction schedule intensity for the projects was $61,562$/day with a standard deviation of $95,504$/day. The range of schedule intensity was $7,429$/day to $504,795$/day. The average schedule growth for all the projects was 5.7% with a standard deviation of 22.9%. The range of schedule growth was from -10% to 104%. More than 61% of the projects reported schedule growth between -5% and 5%.
Consistent with previous research by El Asmar (2012), each of the four metrics was considered equally important to the overall schedule performance area score and, therefore, given weighted values of 25%. The standard deviation for the overall schedule performance area score was 0.69 and was included as the denominator to standardize the performance area score. The standardized schedule performance area score is represented by:

$$Z_{Sc} = 0.25 \left( \frac{X_4 - 276}{429.6} + \frac{X_5 - 225.1}{398.3} + \frac{X_6 - 61,562}{95,504} - \frac{X_7 - .057}{.23} \right) / 0.69$$

Where: $Z_{Sc} =$ Standardized schedule performance area score

$X_4 =$ Construction speed $X_5 =$ Delivery speed

$X_6 =$ Schedule intensity $X_7 =$ Schedule growth

An analysis of the schedule performance area resulted in no statistically significant evidence of a difference in performance based on a test with a p-value of 0.53. The average scores for IPD/IPD-ish and Non-IPD projects were -0.18 and 0.07, respectively. Levene’s test did not suggest a difference in variance between the two groups with a p-value of 0.79. A 95% confidence interval for the differences in averages between IPD/IPD-ish and Non-IPD projects is -1.06 to 0.56. Comparative boxplots are provided in Figure 50.
5.4.3 PQR Performance Area III: Profit

The third most important success measure identified by survey respondents was profit. It is not surprising profit is an important metric for companies because it is certainly essential for the future health of a business. Some may find it surprising that it was not ranked higher. As described in subsection 4.2.3, overhead and profit data was provided on a five point scale from negative to >15% which were converted to ordinal values from zero to four. The average profit score for all the projects was two which related to 5-10% overhead and profit. The standard deviation was 0.77 and the range extended from one to four. None of the projects reported negative overhead and profit. This was the only performance metric included in the profit performance area, therefore, by normalizing the OH&P metric for each project, it becomes the standardized profit performance area such that:

$$Z_p = \frac{X_8 - 2.0}{0.77}$$

Where: $Z_p$ = Standardized profit performance area score
An analysis of the profit performance area resulted in no statistically significant evidence of a difference in performance based on a t-test with a p-value of 0.12. The average scores for IPD/IPD-ish and Non-IPD projects were 0.43 and -0.17, respectively. Levene’s test did not suggest a difference in variance between the two groups with a p-value of 0.74. A 95% confidence interval for the differences in averages between IPD/IPD-ish and Non-IPD projects is -0.17 to 1.37. Comparative boxplots are provided in Figure 51.

![Figure 51: Comparative Boxplots of the Profit Performance Area](image)

5.4.4 PQR Performance Area IV: Safety

The safety performance area is comprised of three metrics: 1) LTI per hundred million dollars, 2) OSHA RIs per hundred million dollars, and 3) Number of fatalities. The lost time and recordable incident rates based on project cost were used instead of the OSHA standard based on man-hours because more data was available for the former. The average number of LTI per hundred million dollars was 1.75 and the standard deviation was 4.84. The lowest number of LTI per hundred million dollars was zero and the highest was 22.1. The average number of recordable incidents per
hundred million dollars was 3.66 and the standard deviation was 9.83. The range of OSHA recordable incidents per hundred million dollars was from zero to 44.3. The average number of fatalities was 0.031 and the standard deviation was 0.177. Nearly every project had zero fatalities and the highest number reported for any project was one. Thankfully, the occurrence of fatalities in the dataset was exceptionally rare. Including the number of fatalities as a performance metric complicated the calculation of an overall safety score and minimized the effects of the LTI and OSHA recordable incidents metrics.

Indicator variables, A and B, were used to calculate the performance area score, $S_{sa}$, for each project. If a fatality occurred on a project it was considered to completely overshadow the effects of LTI and OSHA recordable incidents on safety performance. In that case variable A=10 and variable B=0. If there were zero fatalities on a project, the overwhelming majority from the dataset, then LTI and RIR were used to measure safety performance without including any effects of fatalities. In that case variable A=0 and variable B=1. Variable A was weighted higher than variable B to make the relative impact of fatalities far more significant than injuries. The LTI per hundred million dollars was determined to be more influential to safety performance because of the increased severity of the incidents and therefore given a coefficient of 75%. The score for recordable incidents per hundred million dollars was weighted at 25%. The relative weights of LTI and RI are consistent with previous research (El Asmar 2012). The negative signs associated with each metric represent an inverse relationship with the metric and safety performance. As the number of incidents increases, the safety performance score decreases. The resulting equation for the safety performance area, $S_{sa}$, is:

$$S_{sa} = -A \times (\frac{X_9 - 0.031}{0.177}) - B \times (0.75 \times \frac{X_{10} - 1.75}{4.84} + 25 \times \frac{X_{11} - 3.66}{9.83})$$

Where: $S_{sa} =$ Safety performance area score
The lowest safety performance score was -54.8 and the highest safety performance area score was 0.36. This skew in negative performance is attributed to the fact that the best any project can do is have zero incidents or fatalities while the worst performance could reach infinity for incidents and fatalities. The average of all the safety performance area scores was -1.71. Unlike the other performance areas this value is not centered on zero automatically because indicator variables were used, which created two pathways to derive the Tier II score. The sample standard deviation of all the projects’ safety performance area scores was 9.72 and is used as the denominator in the below equation. To obtain a standardized safety performance area score, $Z_{Sa}$, the following equation was used for each project:

$$Z_{Sa} = \frac{S_{Sa} - (-1.71)}{9.72}$$

An analysis of the safety performance area resulted in no statistically significant evidence of a difference in performance based on a t-test with a p-value of 0.55. The average scores for IPD/IPD-ish and Non-IPD projects were 0.17 and -0.068, respectively. Levene’s test did not suggest a difference in variance between the two groups with a p-value of 0.54. A 95% confidence interval for the differences in averages between IPD/IPD-ish and Non-IPD projects is -0.60 to 1.05. Comparative boxplots are provided in Figure 52.
A reduced dataset without the extreme Non-IPD observation was also analyzed and resulted in no evidence against the null hypothesis that there was a difference in means. The t-test resulted in a p-value of 0.93. The averages for each group were 0.17.

5.4.5 PQR Performance Area V: Budget

Project performance with respect to budget (or cost) consisted of two metrics: 1) Construction unit cost and 2) Construction cost growth. Both of these metrics were defined in section 4.2.4. The average construction unit cost was $347.42/ft$^2$ and the standard deviation was $215.73/ft$^2$. The highest cost per square foot was $1,059.16 and the lowest cost per square foot was $47.93. The average cost growth was 3.0% and the standard deviation was 9.6%. The largest cost growth was 41.3%; the lowest was -20.2%. The standard deviation for the overall cost performance area, $S_B$, was 0.69. Construction unit cost and cost growth were considered equally indicative of performance and given coefficients of 50% consistent with El Asmar (2012). Each metric was given a negative sign in the below equation because the metrics are inversely related to positive performance. The more
successful projects achieve a lower unit cost and less cost growth. The standardized budget
performance equation is represented by:

\[
Z_B = -0.5 \times \frac{X_{12} - 347.42}{215.73} - 0.5 \times \frac{X_{13} - 0.030}{0.096}
\]

Where: \( Z_B \) = Standardized budget performance area score

\( X_{12} \) = Construction unit cost \hspace{1cm} \( X_{13} \) = Construction cost growth

An analysis of the budget performance area resulted in no statistically significant evidence of
a difference in performance based on a t-test with a p-value of 0.20. The average scores for IPD/IPD-
ish and Non-IPD projects were 0.37 and -0.14, respectively. Levene’s test did not suggest a
difference in variance between the two groups with a p-value of 0.76. A 95% confidence interval for
the differences in averages between IPD/IPD-ish and Non-IPD projects is -0.29 to 1.30. Comparative
boxplots are provided in Figure 53.

![Figure 53: Comparative Boxplots of the Budget Performance Area](image-url)
5.4.6 PQR Performance Area VI: Quality

Quality was considered the sixth most important success measure. The quality performance area was comprised of five performance metrics: 1) Systems quality, 2) Number of deficiencies per million dollars, 3) Number of punchlist items per million dollars, 4) Warranty costs, and 5) Latent defect costs. Each of these five metrics was defined in subsection 4.2.5. Recall, systems quality data was provided on a five point scale from economy to high efficiency premium and converted to values from one through five. The average systems quality score for all projects was 3.1 which relates to a qualitative rating of high. The standard deviation is 0.93. The highest score was 4.81 and the lowest score was 1.50. The average number of deficiencies per million dollars was 4.1 and the standard deviation was 8.51. The number of deficiencies per million dollars on any particular project ranged from zero to 40.9. The average number of punchlist items per million dollars was 32.6 and the standard deviation was 41.3. The fewest punchlist items per million dollars was 2.4 and the most punchlist items per million dollars was 204.2. The average warranty score was 0.67 which relates to less than 0.5% warranty costs as a percentage of total project cost. The standard deviation was 0.56. The lowest score was a zero and the highest warranty score was two. The average latent defect score was 0.23 which relates to less than 0.5% of total project cost. The standard deviation was 0.53. The lowest latent defect score was zero and the highest score was two.

Systems quality was weighted as 60% of the overall quality metric because of its importance in representing the actual quality of the final project. Each of the other metrics was given a weight of 10% and considered to influence project quality equally. These weights are consistent with those used by El Asmar (2012). The overall standard deviation of the quality performance area was 0.65 which is the denominator in the below equation. It is important to note that only systems quality was
positively related to performance. The other four metrics were inversely related to quality which is why they are subtracted in the quality equation below.

\[
Z_Q = \frac{0.6 \times \frac{X_{14} - 3.1}{0.93} - 0.1 \left( \frac{X_{15} - 4.1}{8.51} + \frac{X_{16} - 32.6}{41.3} + \frac{X_{17} - 0.67}{0.56} + \frac{X_{18} - 0.23}{0.53} \right)}{0.65}
\]

Where: \( Z_Q \) = Standardized quality performance area score

\( X_{14} = \) Overall Systems Quality \hspace{1cm} \( X_{15} = \) Deficiencies per million dollars

\( X_{16} = \) Punchlist items per million dollars \hspace{1cm} \( X_{17} = \) Percent Warranty Costs

\( X_{18} = \) Percent Latent Defect Costs

An analysis of the quality performance area resulted in no statistically significant evidence of a difference in performance based on a t-test with a p-value of 0.47. The average scores for IPD/IPD-ish and Non-IPD projects were 0.21 and -0.08, respectively. Levene’s test did not suggest a difference in variance between the two groups with a p-value of 0.90. A 95% confidence interval for the differences in averages between IPD/IPD-ish and Non-IPD projects is -0.52 to 1.10. Comparative boxplots are provided in Figure 54.
5.4.7 PQR Performance Area VII: Change Management

The seventh most important success measure was change management. As previously described this performance area captures responses of “communication”, “collaboration” and “owner satisfaction with the design”. This performance area included seven performance metrics as follows: 1) Number of RFIs per million dollars, 2) RFI processing time, 3) Rework, 4) Number of resubmittals per million dollars, 5) Percentage of total absolute change, 6) Change order processing time, 7) PPC trend. Each of these metrics was defined in subsection 4.2.1 except for the percent of total change and CO processing time which were defined in subsection 4.2.2 and PPC trend which was defined in subsection 4.2.8.

The average number of RFIs per million dollars was 6.83 and the standard deviation was 7.28. The fewest number of RFIs on a project was 0.83 per million dollars and the highest number of RFIs was 36.8 per million dollars. The average RFI processing time was 1.48 which represents about a week and a half. The standard deviation was 0.63. The fastest RFI processing time was one week and the slowest was three weeks. The average rework score for all the projects was 1.29 which
related to approximately 0-1.5% of the total project cost. The standard deviation was 0.46. The
lowest rework percentage reported was 0-1%; the highest rework percentage was 1-2%. The average
number of resubmittals per million dollars was 1.99 and the standard deviation was 2.22. The fewest
number of resubmittals reported was zero; the highest number of resubmittals on a project was 10.84.
The average absolute value of total project change was 8.72% and the standard deviation was 9.1%.
The range of total project changes was from zero to 41%. The average time to process a change order
was 4.07 weeks and the standard deviation was 1.98. The fastest processing time of a change order
was one week and the longest processing time was greater than six weeks. The average percent plans
complete (PPC) trend was zero which indicated a stable trend throughout a project. The standard
deviation was 0.45. PPC trends for all the projects ranged from -1 (decreased) to 1 (increased).

The standard deviation of the overall communication performance area was 0.80 and is
included as the denominator in the below equation. The RFI and change order processing times were
each weighted as 25% of the total communication success measure. Their combined weight
represents half of the performance area. This weighting is reasonable since those metrics are most
indicative of the quality of communication between stakeholders during construction. Each of the
remaining five metrics was weighted equally at 10% each. The change management performance
area metrics, and their weights, used in this research are consistent with the metrics used by El Asmar
(2012) for communication/collaboration. The resulting equation for the change management
performance area is represented by:

\[
Z_C = \frac{0.1 \times \frac{X_{19} - 0}{0.45} - 0.5 \times \left( \frac{X_{20} - 1.48}{0.63} + \frac{X_{21} - 4.07}{1.98} \right) - 0.1 \times \left( \frac{X_{22} - 1.29}{0.46} + \frac{X_{23} - 1.99}{2.22} \right) + \frac{X_{24} - 0.087}{0.091} + \frac{X_{25} - 6.83}{7.28}}{0.80}
\]

Where: \( Z_C = \) Standardized change management performance area score
An analysis of the change management performance area resulted in evidence of a statistically significant difference in performance based on a t-test with a p-value of 0.03. The average scores for IPD/IPD-ish and Non-IPD projects were 0.60 and -0.24, respectively. Levene’s test did not suggest a difference in variance between the two groups with a p-value of 0.68. A 95% confidence interval for the differences in averages between IPD/IPD-ish and Non-IPD projects is -0.087 to 1.59. Comparative boxplots are provided in Figure 55.

![Figure 55: Comparative Boxplots of the Change Management Performance Area](image)

### 5.5 PQR Analysis of Full Dataset

Now that a comprehensive performance factor, the PQR, has been developed it begs the question: Do IPD/IPD-ish projects have different overall performance compared to Non-IPD
projects? A PQR value was calculated for each of the 32 projects in the dataset and statistical analysis was performed to answer the previous question. Comparative boxplots of IPD/IPD-ish and Non-IPD, shown in Figure 56, suggest IPD/IPD-ish outperforms Non-IPD as evidenced by having higher median PQR scores. The median PQR for IPD/IPD-ish projects was 0.83 compared to 0.18 for Non-IPD. Formal analysis was performed to validate what the boxplots infer.

![Figure 56: Comparative Boxplots of IPD/IPD-ish and Non-IPD for PQR](image)

The mean PQR for IPD/IPD-ish was 0.58 compared to a mean of -0.23 for Non-IPD projects. The t-test (two-sided) was used to test the null hypothesis and resulted in a p-value of 0.037. There was statistically significant evidence of a difference in means between the IPD/IPD-ish and Non-IPD projects. Levene’s test resulted in a p-value of 0.33 indicating there was no evidence of a difference in variances between the two groups. The data were determined to be normally distributed by evaluating the Q-Q plots for each group as shown in Figure 57.
In order to understand the relative performance of each project compared to the absolute best and worst case scenarios, theoretical PQRs were calculated for each extreme. For each finite performance metric (i.e. systems quality on a scale of -2 to 2) the most extreme possible value was assigned to each scenario. When the performance metric was infinite in at least one direction (i.e. number of resubmittals per million dollars) the best and worst observed values from the dataset were used to calculate the best and worst possible theoretical PQRs, respectively. The analysis resulted in a best possible PQR score of 4.44 and a worst possible PQR score of -9.58. There is more opportunity for a project to have a negative PQR because many of the metrics are unidirectional (i.e. LTI, RFI per million dollars, etc.) and cannot be less than zero. Those metrics all adversely affect PQR thus shift the theoretical worst PQR scores further from zero.

This subsection provided statistically significant evidence at a 0.05 threshold of superior overall IPD/IPD-ish performance compared to Non-IPD projects. By analyzing overall performance of a completely independent data set this research reached similar conclusions as the groundbreaking findings of El Asmar (2012).
5.6 **PQR Analysis of Reduced Dataset**

The previous section provided statistically significant evidence that integrated projects outperformed non-integrated projects. This section takes an alternative approach to account for potential bias in the dataset because of an unequal number of projects from a few contractors. Although the dataset contains projects from twelve contractors, two contractors provided nearly half of the projects with the remaining contractors providing the other half of the projects. To minimize potential bias from the larger influence of these two contractors, all but three of their projects were randomly eliminated from the dataset. Other than these two contractors, each of the other contractors provided data on between one and three projects. Random number generation was performed using R statistical software to determine which projects would be removed. The reduced dataset contained 22 projects and the PQR equation was re-calculated using only those projects. Statistical analysis was performed to compare PQR scores for IPD/IPD-ish* and Non-IPD* projects (the asterisk indicates a reduced dataset). The comparative boxplots, shown in Figure 58, suggest the IPD/IPD-ish* group outperformed the Non-IPD* group. In fact, the IPD/IPD-ish* median (0.85) is higher than the median for the full IPD/IPD-ish dataset and the Non-IPD* median (-0.26) is lower than the full Non-IPD dataset.
Formal statistical analysis revealed that comparison of the reduced groups mirrored the findings from the analysis of the full groups. Statistically significant evidence of superior integrated project performance was found based on a t-test with a p-value of 0.042. Based upon the reduced dataset, in fact, the difference between the IPD/IPD-ish* and Non-IPD* averages is larger than what was found for the full dataset. IPD/IPD-ish* averaged 0.62 and Non-IPD* averaged -0.29 compared to 0.58 and -0.22, respectively, for the full dataset.

This section took an alternative analysis approach to account for potential bias from the influence of a minority of contractors by equalizing the number of projects for all twelve contractors. The dataset was reduced so that each contractor had between one and three projects included in the sample. The results provided evidence that there is no undue bias from the two companies that provided nearly half of the data by replicating the results of the analysis of the full dataset.
5.7 **PQR Validation**

The PQR model was validated through factor analysis and multi-dimensional scaling (El Asmar 2012). A comparison of PQRs using El Asmar’s equation and the equation developed in this research was done since each study utilized different Tier II coefficients based on each dataset. The below equation uses the numerator from El Asmar (2012) divided by the standard deviation of all the PQR_{El Asmar} scores calculated for this dataset.

\[
PQR_{El Asmar} = \frac{0.23 \times \text{Satisfaction} + 0.17 \times \text{Safety} + 0.16 \times \text{Schedule} + 0.13 \times \text{Budget}}{+0.12 \times \text{Quality} + 0.11 \times \text{Profit} + 0.09 \times \text{Communication}} \div 0.57
\]

The PQR scores calculated using El Asmar’s equation and the PQR scores calculated using the enhanced PQR equation developed in this research were plotted together as show in Figure 59.

![Figure 59: Graph of project PQRs compared to PQRs calculated using El Asmar (2012)’s equation](image)

Overall, the two different PQR equations result in very similar PQR values. The safety performance area score, Z_{Sa}, was very sensitive to the fatality data yet the overall relative impacts on
PQR were not significant since the overall trend of the two lines is very similar. When the project(s) with a fatality were removed the two different PQR equations yielded very similar results as shown below in Figure 60.

![Figure 60: Graph of Project PQRs compared to PQRs calculated using El Asmar (2012’s) Equation for a Reduced Dataset without any fatalities](image)

Chapter 5 described the Project Quarterback Rating and its components and tested overall project performance of IPD/IPD-ish and Non-IPD projects. In order to assess possible bias from an unequal influence of a few contractors a reduced dataset, where all contractors provided a maximum of three projects, was analyzed. This resulted in a larger difference in the average performance of the IPD/IPD-ish and Non-IPD projects. Even with a smaller dataset statistically significant evidence at a 0.05 threshold of superior integrated project performance was found. The analysis of the reduced dataset increased the confidence that the sample was not unduly biased by a disproportionate representation of a minority of contractors. Chapter 6 will test other project attributes that were identified in the literature review as variables that may affect project performance to determine their effects on PQR.
Chapter 6. Evaluation of Other Project Attributes

As mentioned in Chapter 3 other key project attributes besides IPD/IPD-ish and Non-IPD were evaluated as independent variables. Specifically, seven independent variables were evaluated to determine how each of them affected overall performance measured by the PQR. The project attributes assessed were:

- Unconventional Key Stakeholder Involvement
- Project Leadership Team
- Use of Building Information Modeling (BIM)
- Use of Incentives
- Utilization of Lean Construction Principles
- Co-location
- Past Team Experience

Three of these characteristics, BIM, Lean Construction, and Co-location, are considered to be catalysts for IPD (NASFA et al. 2010).

Except for the binary data, simple linear regression was used to evaluate the effects of each attribute on overall performance. The binary data was analyzed using hypothesis tests as described in Chapter 4. The assumptions for linear regression were validated for each of the analyses. The four assumptions applicable to simple linear regression, in order of importance, are: 1) data follow a line, 2) independence of errors, 3) equal variances for the errors, and 4) normally distributed errors (Clayton and Zhu 2012). Independence of the errors was checked by assessing the randomness of a plot of residuals versus fitted values of PQR. If the errors are independent the plot will appear to be random and not follow any patterns. The assumption of equal variances for the errors was also tested
using a plot of the residuals and fitted PQR values and was satisfied if the magnitude of the errors was consistent for increasing fitted PQR values. Normality was assessed by looking at the Q-Q plot.

In addition to testing the assumptions of linear regression, tests for outliers and their influence were also performed to ensure the results of each analysis were not negatively affected by a single observation. The formal Bonferonni outlier test was conducted at a significance level of 0.05. If the test resulted in a p-value greater than 0.05, then there were no concerns of outliers. Lastly, the influence of each observation was assessed using Cook’s distance. Any Cook’s distance values greater than 1.0 were considered influential and looked at more closely. The diagnostics for linear regression are provided in Appendix E for each of the attributes evaluated. The following sections describe each of the project attributes and provide the results of the statistical analyses.

6.1 Unconventional Key Stakeholder Involvement

Early stakeholder involvement is a key premise of the IPD philosophy. The biggest influence on a project can be realized for the lowest cost early on as depicted in Figure 61 (CURT 2004).
Additionally, having key stakeholders remain consistently involved throughout the duration of the project lending support to a unified team seems intuitive to positively affect project outcomes. The survey included various questions pertaining to the timing and collaboration of stakeholders specifically:

- *How familiar was the contractor with the owner’s objectives and expectations?*
- *Did the owner’s staff actively participate in the construction process?*
- *Did the architect/engineer give adequate support during construction?*
- *How involved was the CM/GC in the design/preplanning stage of the project?*
- *How involved were the key subcontractors in the design/preplanning stage of the project?*
- *Did the project team have a formal risk review process to identify and accept project risks before starting construction?*
- *Did the key subcontractors participate in the risk assessment process?*

Responses to the first five questions above were provided on Likert scales of *Very familiar/Very actively/Very Involved* (9), *Somewhat familiar/Some participation/Some involvement* (3), *A little familiar/participation/support involvement* (1), or *Not familiar/None* (0). The remaining two questions; whether a project had a formal risk review process and if subcontractors were involved in a risk review process, had binomial responses with *yes* = 6 and *no* = 0. A value of six was given for *yes* responses so they would have similar influence compared to the other five questions. The seven scores were summed together resulting in a single “Unconventional Stakeholder Involvement” factor. A graphic of the Involvement factor is provided below in Figure 62.
Figure 62: Components of the Independent "Unconventional Stakeholder Involvement" Variable

A scatterplot of the relationship between Unconventional Stakeholder Involvement (x-axis) and PQR (y-axis), shown in Figure 63, depicts a positive correlation suggesting the higher the involvement on a project the better the overall performance. Also of interest, the IPD/IPD-ish projects (identified by circles) tend to have higher scores for stakeholder involvement than the Non-IPD projects (identified by triangles). This is not surprising because of the higher degree of integration among the project stakeholders in the IPD/IPD-ish project construct.
All regression assumptions are satisfied and there are no outliers or data points with high leverage. The summary regression output indicates there is a very strong relationship between a project’s PQR and involvement with a p-value of 0.000098. The slope of the least squares line is 0.055 indicating for each unit increase along the x-axis PQR increases by 0.055. The 95% confidence interval for the slope is from 0.030 to 0.081. The fit of the line is fairly good with an $R^2$ value of 0.40. The results of this regression analysis provide statistically significant evidence that projects with higher unconventional stakeholder involvement at the beginning, and throughout, a project have better overall performance.

6.2 **Project Leadership Team**

The *project leadership team* variable is a composite variable consisting of nine direct input responses from the PMs. Every project, except one that did not complete this portion of the survey,
had a project leadership team; however, they varied in their makeup, level of authority, and timing and frequency of engagement. The *project leadership team* variable includes:

- the number of stakeholders represented in the team;
- the authority of the team to make necessary decisions to manage and lead the project on a daily basis (No (0), Somewhat (1), Absolutely (3));
- whether the team jointly developed project target criteria and goals (No (0), Somewhat (1), Absolutely (3));
- whether the team made decisions collaboratively (No (0), Somewhat (1), Absolutely (3));
- periodic project reviews were performed (Yes (1), No (0));
- frequency of team meetings during the planning phase (None (0), Monthly (1), Biweekly (2), Weekly (3), Daily (4));
- frequency of team meetings during the construction phase (None (0), Monthly (1), Biweekly (2), Weekly (3), Daily (4));
- frequency of team meetings during the commissioning phase (None (0), Monthly (1), Biweekly (2), Weekly (3), Daily (4));
- If lessons learned were captured by the team (Never (0), At completion (1), Throughout the project (3)).

The numbers in parenthesis represent the values that each qualitative score was converted to in order to directly combine all nine responses. The scatterplot shows a positive relationship between project performance and *project leadership team* scores, see Figure 64.
All linear regression assumptions are satisfied and there are no outliers or highly influential data points. The regression analysis finds a p-value of 0.00205 and an $R^2$ value of 0.28. The slope of the least squares line is 0.11 with a 95% confidence interval from 0.044 to 0.18. The analysis provides statistically significant evidence at a threshold of 0.05 that projects with a highly engaged and collaborative project leadership team have higher overall performance.

### 6.3 Building Information Modeling (BIM)

The effects of BIM on project performance were analyzed in two different ways. First, a hypothesis test was performed with the null hypothesis that the use of BIM did not affect overall performance. Comparative boxplots do not show any substantial differences in performance between projects that used BIM and those that did not use BIM, see Figure 65. A two-tailed t-test was
performed to formally test the null hypothesis and resulted in a p-value of 0.89. Therefore, there was no evidence against the null hypothesis.

Figure 65: Comparative Boxplots for Use of BIM and PQR

The second approach to analyze the effects of BIM on performance was done based upon the extent that BIM was used. Only projects that used BIM were included in this portion of the analysis. Survey respondents identified the degree BIM was used for each of the major building systems and also identified the functional uses of BIM employed, see Figure 66. For each of the building systems (foundation, structure, interior finishes, exterior enclosures, roofing, mechanical systems, electrical systems, site, process equipment, conveying systems, and specialties) BIM was either not used (0), moderately used (1), or extensively used (3). For each functional use of BIM it was employed none (0), a little (1), some (3), or a lot (9). The value in parenthesis was the converted value used in the statistical analysis. The total score for the extent of BIM use was a combination of each of these elements with a total possible score of 177.

<table>
<thead>
<tr>
<th>Visualization</th>
<th>A lot</th>
<th>Some</th>
<th>A little</th>
<th>None</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vision</td>
<td></td>
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</tbody>
</table>
The scatterplot suggests a positive correlation between projects that had a higher degree of BIM utilization and performance, see Figure 67.

Figure 66: Excerpt From the Data Collection Tool used to determine the Functional Uses of BIM on a Project

Figure 67: Scatterplot of the Extent of BIM Use regressed on PQR
The linear regression assumptions are satisfied and there are no outliers. It appears that one observation may have high influence but none of the observations had a Cook’s distance greater than one so that is not the case. The formal regression analysis resulted in a p-value of 0.115 and an $R^2$ value of 0.19 so there was no evidence that projects using BIM more extensively achieved better performance. The slope of the least squares line was 0.022 with a 95% confidence of -0.0063 to 0.051 which confirmed there is no conclusive evidence at a 0.05 threshold of superior performance of projects that use a higher degree of BIM.

### 6.4 Use of Incentives

Incentive clauses are often used to promote collaboration between contracting parties. Incentives can be based on any number of performance metrics including cost, schedule, quality, and safety. IPD projects usually include incentives funded with project savings that are split between key stakeholders. This research analyzed whether the existence of an incentive clause resulted in higher performing projects. Only seven projects included an incentive clause and five of them were IPD/IPD-ish. The data was binary with the existence of an incentive clause given a value of one and projects without an incentive clause given a value of zero. A comparative boxplot suggests that projects that contain an incentive clause have higher average performance than those that did not contain an incentive clause (see Figure 68). There is also a much smaller range of performance when contracts contained an incentive clause. The average PQR for projects with an incentive clause was 0.87 while projects without an incentive clause averaged -0.24. Levene’s test resulted in a p-value of 0.07 and confirmed unequal variances between the two groups. Welch’s two-sample test resulted in a p-value of 0.00015 on 24.8 degrees of freedom. There was statistically significant evidence at a 0.05 threshold of superior performance of projects that had contracts containing an incentive clause.
6.5 **Utilization of Lean Construction Tools**

Lean construction is focused on eliminating waste and maximizing value and can be implemented in conjunction with any PDS to varying degrees. Although not the primary focus of this research, a portion of the data collection tool was dedicated to capturing the extent that Lean techniques were implemented on a project. Figure 69 is an excerpt from the data collection tool. An overall Lean Construction score was developed to measure the effect of Lean techniques on performance and included the principles listed in Figure 69 as well as co-location and pull planning.

<table>
<thead>
<tr>
<th>Last Planner System for production control</th>
<th>A lot</th>
<th>Some</th>
<th>A little</th>
<th>None</th>
</tr>
</thead>
<tbody>
<tr>
<td>5S - A policy that requires cleanliness, organization and orderly storage and movement plans. Gang boxes, tools and consumable supplies should be stocked and organized so that no time is spent searching for or retrieving common tools or materials.</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Set-Based Design - Set-Based Design requires carrying forward multiple alternatives to allow more time for analysis, only narrowing alternatives at the last responsible moment.</td>
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<td></td>
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<tr>
<td>Value Stream Mapping - to clearly identify and eliminate waste throughout the project.</td>
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<td></td>
<td></td>
<td></td>
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<tr>
<td>Proactive dynamic Target Costing or Target Value Design</td>
<td></td>
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<tr>
<td>Daily Huddles – meeting with the field crews on a daily basis</td>
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to review the schedule and plan the work.

| JIT - bulk materials are delivered just prior to installation |
| Point Cloud technology such as Total Station |
| Visual Management Devices |
| Mock-ups for repetitive construction systems |
| Constructability reviews |

Figure 69: Excerpt From the Data Collection Tool for the use of Lean Construction Principles

The qualitative input from Figure 69 was converted to numerical values of nine, three, one, and zero corresponding to responses of a lot, some, a little, and none, respectively. Survey respondents indicated the perceived level of effectiveness of co-location on their project on a scale from none, limited, good, exceptional which were converted to values of zero, one, three, and nine, respectively. Pull planning was measured based upon the frequency of pull planning sessions and their perceived effectiveness. Respondents indicated how often pull planning sessions were conducted; daily, weekly, monthly, or never and their responses were converted to numerical values of three, two, one, and zero, respectively. The effectiveness of the pull planning was measured from very, some, little, or none which were converted to scores of nine, three, one, and zero, respectively. The two pull planning sub-factors were multiplied for a total possible score of 27. To avoid weighting the influence of pull planning, the score was divided by three.

An average of the sum of the thirteen IPD technique scores was calculated to create an overall Lean Construction score. It was beneficial to calculate an average value because occasionally survey respondents did not respond to some of the Lean related questions which would have inappropriately affected a project’s Lean Construction Score. Therefore, the highest possible score was nine.
As depicted in Figure 70, a larger proportion of IPD/IPD-ish projects had higher Lean Construction Scores than Non-IPD projects. IPD and Lean Construction are mutually supportive of each other and strive to each achieve similar goals.

The linear regression assumptions are satisfied for this analysis. A formal test for outliers, see Appendix E, results in a p-value of 0.031 confirming there is an outlier at a 0.05 significance level. However, the Cook’s distance for this observation is less than 0.5 indicating it is not influential on the regression analysis and therefore is not overly concerning.

The regression analysis concluded that there is a significant positive relationship (p-value of 0.00061) between utilizing Lean construction tools and overall project success. The goodness of fit is acceptable with an $R^2$ of 0.33. The slope of the least squares line was 0.36 with a 95% confidence interval between 0.17 and 0.55. This research provides evidence that using Lean tools and techniques
will positively affect project performance which is consistent with results from previous case studies (Andersen et al. 2012).

### 6.5.1 Co-location

Co-location was analyzed as an independent variable separately from the other Lean construction tools because of specific interest to evaluate its effects on project performance. As part of their case study analysis in 2012, AIA found mixed responses concerning the benefits and effectiveness of co-location. For this research survey respondents indicated the perceived level of effectiveness of co-location on their project on a scale from *none, limited, good, exceptional* which were converted to values of zero, one, three, and nine, respectively. The scatterplot in Figure 71 suggests a slightly positive slope of the least squares line.

![Scatterplot of Co-location regressed on PQR](image)

*Figure 71: Scatterplot of Co-location regressed on PQR*

The linear regression assumptions were satisfied and there were no outliers or highly influential data points. Formal analysis resulted in a p-value of 0.184 and an $R^2$ value of 0.06. The
slope of the least squares line was 0.083 with a 95% confidence interval from -0.042 to 0.21. Therefore, there was no statistically significant evidence of a relationship between co-location and performance. The results of this research entice further study of this Lean technique because it has been perceived as beneficial to project performance in other studies.

### 6.6 Past Team Experience

A logical hypothesis would be that teams with more experience together will outperform teams with less experience. In fact, previous research has found that the stakeholders’ experience is an important factor that affects performance (Konchar and Sanvido 1998). For this research *Past Team Experience* included experience with the type and size of construction, project delivery system, experience with other stakeholders, and experience as a team unit (see Figure 72).

<table>
<thead>
<tr>
<th>Past experience with this <em>type</em> of construction:</th>
<th>A lot</th>
<th>Some</th>
<th>A little</th>
<th>None</th>
</tr>
</thead>
<tbody>
<tr>
<td>CM/GC</td>
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<td></td>
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<tr>
<td>Subcontractors</td>
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<td>Owner</td>
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<td>A/E</td>
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<td>DB firm (if applicable)</td>
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<tr>
<th>Past experience with this <em>size</em> of construction:</th>
<th>A lot</th>
<th>Some</th>
<th>A little</th>
<th>None</th>
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<tbody>
<tr>
<td>CM/GC</td>
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<td>Subcontractors</td>
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<td>Owner</td>
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<td>A/E</td>
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<td>DB firm (if applicable)</td>
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<thead>
<tr>
<th>Past experience with this <em>project delivery system</em>:</th>
<th>A lot</th>
<th>Some</th>
<th>A little</th>
<th>None</th>
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<td>CM/GC</td>
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<td>Subcontractors</td>
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<td>A/E</td>
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<tr>
<td>DB firm (if applicable)</td>
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<td></td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Your past experience with the <em>other stakeholders</em>:</th>
<th>A lot</th>
<th>Some</th>
<th>A little</th>
<th>None</th>
</tr>
</thead>
<tbody>
<tr>
<td>Subcontractors</td>
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</table>
Each qualitative response was converted to a numerical value of zero (*none*), one (*a little*), three (*some*), or nine (*a lot*). The overall *Past Team Experience* score is the average of all the responses. The scatterplot in Figure 73 does not suggest there is a relationship between performance and past team experience.

![Figure 73: Scatterplot of Past Team Experience regressed on PQR](image)

The linear regression assumptions are mostly satisfied. It does appear that there may be a slight pattern of a plot of the residuals versus fitted values. There are no outliers or highly influential data points. Formal regression analysis resulted in a p-value of 0.98 and an $R^2$ of 0.000033. There was no evidence of a relationship between past team experience and overall performance.
6.7 Testing Control Variables

Another approach used to validate the effectiveness of the PQR model as a tool to compare performance of different projects was an analysis of control variables and their effects on PQR scores. The control variables tested included project cost, project size, site access, type of construction, and type of owner.

6.7.1 Project Cost

Recall for this dataset project costs ranged from slightly over one million dollars to in excess of $700M. With the high variation in project costs there was concern that the smaller projects may be at a disadvantage using the PQR model even though many of the metrics are normalized based on project cost. For example, a one million dollar project that has 5 RFIs ends up with 5 RFIs per million dollars. A$700M project could have 3,500 RFIs and achieve the same normalized score of 5 RFIs per million dollars. A regression analysis was performed to determine if there was a difference in performance between high and low cost projects. A scatter plot including the least squares line of project cost regressed on PQR is shown below in Figure 74. It appears there is a slightly positive relationship between project cost and PQR however, this assertion requires formal analysis.
Figure 74: Scatterplot of Project Cost and PQR

A regression analysis resulted in a p-value of 0.28 and an $R^2$ value of 0.038; therefore, there was no statistically significant evidence of a relationship between a project’s cost and its PQR score. The estimated slope was $1.55 \times 10^{-9}$ with a 95% confidence interval of $-1.35 \times 10^{-9}$ to $4.43 \times 10^{-9}$. The linear regression assumptions were satisfied. A formal test for outliers resulted in a Bonferonni p-value of 0.09 therefore there is no evidence of outliers. From the scatterplot it is evident that there is a highly influential data point. This was confirmed in the diagnostics graphs shown in Appendix E with a Cook’s distance greater than 1.0 for one of the observations. To address this concern a reduced dataset was analyzed where the influential data point was eliminated. The resulting scatterplot and least squares line is shown below in Figure 75.
Regression analysis of the reduced dataset still found there was no evidence of a relationship between project cost and PQR with a p-value of 0.21 and an $R^2$ value of 0.05. The estimated slope of the least squares line was $5.84 \times 10^{-9}$ with a 95% confidence interval of $-3.5 \times 10^{-9}$ to $1.5 \times 10^{-8}$. For the reduced dataset there were no highly influential variables or evidence of outliers as shown in Appendix E.

### 6.7.2 Project Size

Similar to project cost, there was a question of whether project size, based on gross area, was related to PQR. Again linear regression was used to evaluate this question. A scatterplot of project size regressed on PQR shows a slightly positive relationship between PQR and project size, see Figure 76. Again, it appears there is a highly influential data point.
Regression analysis resulted in a p-value of 0.23 and an $R^2$ value of 0.05. Therefore, there was no evidence of a relationship between project size and PQR. The estimated slope of the least squares line was $4.7 \times 10^{-7}$ with a 95% confidence interval of $-3.2 \times 10^{-7}$ to $1.3 \times 10^{-6}$. There were no outliers with a Bonferonni p-value of 0.10. However, there was a data point with a Cook’s distance greater than one so it was highly influential.

To account for the highly influential observation, project size was regressed on PQR for a reduced dataset with the highly influential observation removed. The scatterplot for this regression is shown below in Figure 77.
With the influential observation eliminated, the regression analysis resulted in a p-value of 0.19 and an $R^2$ value of 0.060. The estimated slope of the least squares line was $1.2 \times 10^{-6}$ with a 95% confidence interval of $-6.4 \times 10^{-7}$ to $3.0 \times 10^{-6}$. There was no evidence of a relationship between project size and PQR.

### 6.7.3 Site Access

A potential criticism of comparing various projects using the PQR could be that project performance is affected significantly by the access to each project site. The suggestion may be that projects in a “greenfield” would usually perform better than projects in dense urban environments with limited access. Thirty-one of the 32 survey respondents indicated whether they had unlimited, limited, restricted, or severely restricted site access of their project. Comparative boxplots of each of the levels of access is shown below in Figure 78. It does not appear there is a relationship between
site access and PQR. In fact, most of the high PQR scores came from projects with something other than unlimited access; however, the variability of the performance for restricted and severely restricted projects is considerable.

The average PQR for projects with unlimited, limited, restricted, and severely restricted access was -0.15, 0.39, -0.07, and -0.02, respectively. One-way ANOVA resulted in a p-value of 0.76 suggesting there is no evidence of any differences between any of the four groups. There is no evidence of site access impacting a project’s overall performance.

6.7.4 Type of Construction

The dataset was not homogeneous with respect to the type of construction for each project. As discussed in Chapter 3, more than half of the projects were mostly or entirely new construction with the remainder being additions and/or renovation type projects. It could be thought that the type
of construction would impact comparing overall project performance of different projects. In order to test this suggestion, a comparison of new construction, additions, and renovations was done. Projects that included multiple types of construction were grouped according to their predominant type of construction. One project was 50% new construction and 50% addition and was considered as new construction. Another project was half addition and half renovation and was grouped with the additions. Comparative boxplots of the three groups does not show a discernible trend (see Figure 79). The variability of project performance of new construction projects is much less than for additions and somewhat less than for renovations. The average PQR for additions, new construction, and renovations was -0.56, -0.013, and 0.23, respectively. Formal statistical analysis using ANOVA resulted in a p-value of 0.41. Therefore, there was no evidence of any of the types of construction having different PQR scores.

Figure 79: Comparative Boxplots of PQR for Construction Type
6.7.5 Type of Owner

The last control variable tested was the type of owner; public or private. Public owners are unable to utilize pure IPD. However; there were public projects in this dataset that were considered IPD-ish. To test whether projects with different owners achieved different PQRs a hypothesis test was performed with the null hypothesis that the PQRs for each type of owner were the same.

Comparative boxplots show a slightly lower median PQR for public owners but formal hypothesis testing is required to make a conclusion (see Figure 80). The average PQR for public projects was 0.02 and for private projects was -0.02. Levene’s tested resulted in a p-value of 0.79 so an independent t-test was used to test the hypothesis. The t-test resulted in a p-value of 0.90 so there is no evidence against the null hypothesis. There is nothing to suggest that the type of owner affects a projects overall performance.

![Figure 80: Comparative Boxplots of PQR for Type of Owner](image-url)
Chapter 6 analyzed other project attributes to determine their influence on overall project performance. Statistically significant evidence of positive impacts on project performance at a 0.05 threshold was found for unconventional stakeholder involvement, a strong project leadership team, use of an incentive clause, and utilization of Lean construction techniques. The analysis suggests that incorporating these principles into future projects will improve the opportunity to realize success. This chapter also confirmed there is no evidence of the control variables, project cost, size, site access, type of construction, or type of owner, affecting overall performance. These findings suggest the PQR is a robust tool to compare delivery of various projects with different uncontrollable characteristics. This chapter concludes the statistical analyses performed in this research. Chapter 7 will provide a summary of the significant findings as well as discuss some closing points before concluding this report.
Chapter 7. Conclusion

7.1 Summary of Results

This research will contribute to the AEC community’s body of knowledge on IPD. It has accomplished the objectives set forth at the beginning of this report.

1. IPD/IPD-ish performance across 24 metrics was compared to performance of Non-IPD. Statistically significant evidence of superior IPD/IPD-ish performance at a 0.05 threshold was found for three metrics from the communication, change management, and business performance areas.

2. The research found statistically significant evidence of overall superior IPD/IPD-ish measured by a comprehensive performance metric, the PQR. The PQR previously developed at the University of Wisconsin-Madison was enhanced by adding two additional metrics to better reflect overall performance. This offers a model for the AEC community to utilize and further adapt as desired.

3. Other project attributes were analyzed and statistically significant evidence of superior performance was found when there is a high degree of stakeholder involvement throughout a project, a strong project leadership team, use of an incentives clause, or utilization of Lean construction techniques.

Owners need to drive the demand to achieve faster, more efficient, and more cost effective projects (CURT 2004). They may be able to increase the opportunities to achieve optimum performance by selecting the ideal PDS that maximizes early collaboration and incentivizes project goals over individual performance. When feasible, IPD may be best able to accomplish these desired
outcomes. However, in some cases, IPD may not be desired by an owner, or may be precluded by regulations (i.e. public owners), and the next best option may be to undertake an IPD-ish approach.

### 7.2 Research Limitations

This research only analyzed the benefits of IPD from the perspective of construction contractors. Their viewpoints may not be entirely consistent with the viewpoints from the other project stakeholders. The dataset included mostly institutional and commercial type projects but the dataset was not perfectly homogeneous. The diversity of project types makes comparing some of the performance metrics difficult and the interpretation of the results not indicative of any specific sector. Challenges of evaluating Lean construction principles, very much similar to evaluating IPD, of different projects result from variations of objectives, resources, and project specific conditions and situations unique to each project (Andersen et al. 2012).

### 7.3 Future Research Opportunities

The opportunities for future IPD research are substantial. This research provides one of the few thorough quantitative analyses of IPD and integrated principles on project performance from a contractor’s perspective. Additional research is already underway at the University of Wisconsin-Madison to evaluate the performance of IPD from an owner and mechanical and electrical subcontractor perspectives. Further research would be beneficial to evaluate the performance of IPD from the perspective of architects and engineers. Understanding the effects of IPD for all project stakeholders may promote the wider adoption of IPD. Future research could also be done to compare the performance of IPD and IPD-ish projects to determine whether or not a multi-party contract is beneficial to overall performance. Many industry professionals indicated owners are still not willing to pursue multi-party contracts; however, they insist upon using IPD.
7.4 Applicability to Federal Government Contracting

At this time the Federal Acquisition Regulation (FAR) does not allow the Federal Government to enter into a pure-IPD contract. As the use of multi-party, relational agreements evolves, and becomes more widely accepted in the construction industry, there may be a possibility at some point in the future that the FAR will allow for pure-IPD contracting. Today, IPD techniques are being used on Government projects in conjunction with traditional delivery methods and may continue to be utilized even more often as the benefits of IPD continues to be studied and validated. By using appropriate source selection criteria, Government contracting currently allows for the following integrated approaches (Singleton, Michael and Hamzeh 2011):

- Relational contracting where owner is not included in the multi-party contract
- Integrated governance
- High performing, cross-functional teams that form early in the design process
- Multiple Lean construction techniques

Other IPD techniques such as incentives and awards can be applied using specific contract methods such as Fixed Price Incentive (or Award) Fee. A transition for the Government to require more integrated delivery techniques is not far-fetched based on the evolution of Government contracting in recent years. As an example, Naval Facilities Engineering Command, the United States Navy’s entity responsible for execution of construction services on Navy and other Department of Defense installations world-wide, has significantly increased the use of Design-Build contracts on MILCON projects compared to the previously predominant approach of using Design-Bid-Build.

Other government entities have already aggressively leaned forward with adopting an IPD-ish approach. According to the AIA and University of Minnesota (2012) case study, the GSA
Contracting Officer for the Edith Green Wendell Wyatt Federal Building Modernization does not believe a multi-party contract is required to achieve the benefits of integrated delivery and believes the legislation to allow multi-party contracting is an unnecessary and difficult pursuit. Using award terms and milestone payments within existing contracting regulations is sufficient to realize the benefits of IPD. GSA used a “CMc+6” PDS approach where the “+6” refers to six requirements for increased collaboration:

1) GSA provide on-site management,
2) First tier subcontractors on team prior to development of contract documents,
3) Key first tier subcontractors selected as part of the solicitation process,
4) Integrated document development,
5) Shared collocation facilities,
6) Optimized BIM.

True commitment from an owner is necessary to successfully implement IPD according to the GSA Contracting Officer. GSA used a time and material contract for the planning phases of the work in lieu of their traditional fixed fee approach. This increased their risk in that particular phase but benefited the overall project by reducing schedule costs and providing better value. GSA mitigated the increased risk by having frequent meetings with the project team. As the private construction industry transitions to wider adoption of IPD it is very possible that more public entities will follow.

7.5 Barriers and Challenges to implementing IPD

A transformational change for widespread adoption of IPD has yet to reach a “tipping point” and its use is not prevalent throughout the construction industry. In their 2011 survey AIA identified 46 projects using, or planning to use, IPD agreements (AIA 2012). More recently, it has been suggested that IPD, including a multi-party contract, is still only being used in less than 1% of vertical
building projects (CMAA 2012). According to a presentation from the 2013 AIA Center for Integrated Practices Symposium approximately 150 projects have used, or are currently using, a multi-party IPD contract (Dierks 2013).

As it stands today, IPD is still not fully understood throughout the AEC community. According to a recent AIA study, although 84% of members are aware of IPD, only 40% understand IPD and even fewer, only 13%, are implementing IPD philosophies as depicted below in Figure 81 (AIA 2011).

![Figure 81: AIA Member Awareness of Integrated Project Delivery](image)

Even so, there are still significant barriers impeding wide spread utilization of IPD. Integrated philosophies are being applied to construction projects to varying degrees; however, adoption of pure IPD has been extremely limited. The fact that pure IPD has not become more commonly applied is a testament to the remaining challenges within the AEC to accept such an untested and modern approach.

Fish (2012) asserts the three major obstacles to IPD implementation as structure for facilitation, contracts, and insurance. Fish states that ideally the core group, as established by a
contractual agreement, can facilitate IPD; however, often times a dedicated facilitator is a good alternative if the members of the core group are not experienced with IPD.

It was evident in many of the case studies by AIA and U of MN (2012) that reluctance to cultural change had to be overcome to implement IPD contractually and behaviorally. Selecting a team willing to make the necessary adjustments was paramount, and when individual team members are unable, or unwilling, to do so, they have even been removed from the project team. IPD is dramatically different from traditional project delivery and requires an owner to rethink their entire approach to construct capital facilities.

7.6 Closing Remarks

This research endeavor has been extremely rewarding. I have dedicated an unparalleled amount of time and effort in this work compared to any previous academic endeavors. This opportunity has allowed me to gain a keen awareness of the current state of the construction industry and provided a glimpse of what it may become in the future. The interaction with many leading industry professionals was one of the most rewarding aspects of this research. Again, I extend a huge thank you for their support providing data for this research.
Appendix A – Bibliography


AIA, and AGC. (2011). *Primer on Project Delivery*.


Appendix B – Glossary of Terms

Definitions were identified from multiple sources (AIA and AGC 2011; El Asmar 2012; Forbes and Ahmed 2011; Halpin 2006; Hanna 2010; LCI 2013b; NASFA et al. 2010; Womack and Jones 2003).

**Building Information Modeling (BIM):** The process of generating and managing building data during its life cycle. It is a model-based technology linked with a database of project information. A BIM carries all information related to a facility, including its physical and functional characteristics and project life cycle information, in a series of smart objects.

**Change orders:** A compensable change to the drawings, specifications, or any other contract document.

**Five Ss:** Five terms beginning with S utilized to create a workplace suited for visual control and lean production. *Seiri* means to separate needed tools, parts, and instructions from unneeded material and to remove the latter. *Seiton* means to neatly arrange and identify parts and tools for ease of use. *Seiso* means to conduct a cleanup campaign. *Seiketsu* means to conduct *seiri, seiton,* and *seiso* at frequent (daily) intervals to maintain a workplace in perfect condition. *Shitsuke* means to form the habit of always following the first four Ss.

**Integrated Form of Agreement (IFOA):** A legal agreement that seeks to align the commercial relationships of a construction project’s design and construction participants that are assembled as a temporary production system. It also requires collaborating through planning, design, construction, and managing the project as a network of commitments. As a result it optimizes the project as a whole, rather than any particular piece. The agreement also calls
for a combination of learning with action and promoting continuous improvement throughout
the life of the project.

**Integrated Project Delivery**: A method of project delivery distinguished by a contractual
arrangement among a minimum of owner, constructor and design professional that aligns
business interests of all parties. IPD motivates collaboration throughout the design and
construction process, tying stakeholder success to project success.

**Just-in-Time Production**: A system of production that makes and delivers just what is needed, just
when it is needed, and just in the amount needed. One of the two pillars of the Toyota
Production System. The key elements of JIT are flow, pull, standard work, and *takt* time.

**Last Planner System (LPS)**: The LPS is an important subset of The Lean Project Delivery System™
and is critical to its effective deployment. The LPS accommodates project variability and
levels out workflow so that labor and material resources can be maximally productive. It
uses lean methods to provide improved project control.

**Lean Project Delivery System™**: The LPDS is a lean technique that integrates phases to facilitate
the design and delivery of construction projects. These phases are: project definition, lean
design, lean supply, lean assembly, and use. The LPDS is based on a close collaboration
between the members of the project delivery team. They are bound by codes of conduct, both
written and unwritten, that focus on the success of the overall project rather than their
individual success.

**Overtime**: Work performed on a project that exceeds eight hours a day and 40 hours a week.

**Percent Plans Complete (PPC)**: In lean construction, work accomplishment is recorded as a
graphical plot of PPC; it shows the percentage of the assigned plans (i.e., commitments that
were completed, fractional completion is not considered). Some lean construction practitioners refer to PPC as commitment reliability.

**Prefab**ration: The process of producing and pre-assembling systems and materials. The prefabricated parts can be produced on-site or off-site in a specialty shop.

**Project Delivery System:** The organization or the development of the framework relating the organizations required to complete or deliver a project and the establishment of the formal (i.e., contractual) and the informal relationships between the organizations.

**Pull:** A system of cascading production and delivery instruction from downstream to upstream activities in which nothing is produced by the upstream supplier until the downstream customer signals a need.

**Request for Information (RFI):** A written request to clarify some aspect of the project scope, specifications, or requirements.

**Rework:** Work that, due to change orders or inadequate quality, must be repeated.

**Value stream:** The entire flow of information and material flow that make up a process and include identification of the Value Added, Non-Value Added but Required, and Non-Value Added activities within the process.

**Value Stream Mapping:** Identification of all the specific activities occurring along a value stream for a product.

**Quality Control:** The review of project services, construction work, management, and documentation for compliance with contractual and regulatory obligations and accepted industry practices.
Relational Contracting: A transaction or contracting mechanism that apportions responsibilities and benefits of the contract fairly and transparently, based on trust and partnership between the parties. It provides a more efficient and effective system for construction delivery in projects that require close collaboration for execution. The relationship between the parties transcends the exchange of goods and services and displays the attributes of a community with shared values and trust-based interaction.

Set-Based Design: A design management approach that defers design decisions to the “last responsible moment” to allow for the evaluation of alternatives that improve constructability.

Stacking of trades: Overcrowding where multiple trades are working simultaneously in a single work area, thereby decreasing productivity.

Submittals: Items that the contractor must submit to the engineers for review and approval prior to inclusion in a project; this may include such items as drawings, product data, samples, etc.

Target Value Design (TVD): TVD involves designing to a specific estimate instead of estimating based on a detailed design.

Toyota Production System (TPS): The production system developed by Toyota Motor Corporation to provide best quality, lowest cost, and shortest lead time through the elimination of waste. TPS is comprised of two pillars, JIT production and Jidoka. TPS is maintained and improved through iterations of standardized work and Kaizen, following the scientific method of the plan-do-check-act cycle.

Waste: Any activity that consumes resources but creates no value for the customer.
Abbreviations

BIM: Building Information Modeling

CM/GC: Construction Manager / General Contractor

CMR: Construction Manager at Risk (project delivery system)

DB: Design-Build (project delivery system)

DBB: Design-Bid-Build (project delivery system)

GMP: Guaranteed Maximum Profit

JIT: Just-in-Time

IFOA: Integrated Form of Agreement

IPD: Integrated Project Delivery

LPDS: The Lean Project Delivery System™

LPS: Last Planner System

MEP: Mechanical, Electrical, Plumbing

PPC: Percent Plans Complete

PDS: Project Delivery System

RFI: Request for Information

SBD: Set Based Design
**TVD:** Target Value Design

**TPS:** Toyota Production System

**VSM:** Value Stream Mapping
## Appendix C – Data Collection Tool

### Survey on Project Delivery Systems Performance

<table>
<thead>
<tr>
<th>SECTION I: PROJECT CHARACTERISTICS &amp; CONTRACT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Project name __________________________________</td>
</tr>
<tr>
<td>Project location ________________________________</td>
</tr>
<tr>
<td>Your Company name ________________________________</td>
</tr>
<tr>
<td>For this project, your company acted as a:</td>
</tr>
<tr>
<td>☐ General Contractor</td>
</tr>
<tr>
<td>☐ Construction Manager</td>
</tr>
<tr>
<td>☐ Design-Build</td>
</tr>
<tr>
<td>1. Project type:</td>
</tr>
<tr>
<td>☐ Commercial (banks, retail, office buildings, etc.)</td>
</tr>
<tr>
<td>☐ Institutional (hospitals, correctional facilities, schools, etc.)</td>
</tr>
<tr>
<td>☐ Industrial or Manufacturing</td>
</tr>
<tr>
<td>☐ Residential</td>
</tr>
<tr>
<td>☐ Heavy Civil/Highway</td>
</tr>
<tr>
<td>☐ Other (please specify) __________________________</td>
</tr>
<tr>
<td>2. Planned Building gross square footage</td>
</tr>
<tr>
<td>__________ sqft</td>
</tr>
<tr>
<td>Final Building gross square footage</td>
</tr>
<tr>
<td>__________ sqft</td>
</tr>
<tr>
<td>Number of floors __________ floors</td>
</tr>
<tr>
<td>Site size __________ sqft</td>
</tr>
<tr>
<td>3. Project Program:</td>
</tr>
<tr>
<td>Examples: number of beds, for hospitals</td>
</tr>
<tr>
<td>number of student/pupils, for schools</td>
</tr>
<tr>
<td>4. What type of construction was this project?</td>
</tr>
<tr>
<td>☐ New construction __________ %</td>
</tr>
<tr>
<td>☐ Addition or expansion __________ %</td>
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<tr>
<td>☐ Renovation __________ %</td>
</tr>
<tr>
<td>Sum = 100%</td>
</tr>
<tr>
<td>5. Total project manhours: ______________</td>
</tr>
<tr>
<td>White collar __________ %</td>
</tr>
<tr>
<td>Blue collar __________ %</td>
</tr>
</tbody>
</table>

### Special project conditions:

Were there any special circumstances that significantly impacted the project? ☐ Yes ☐ No
Examples: abnormal weather, labor or material unavailability, etc.
Please specify:

a. LEED rating? ☐ None ☐ Certified ☐ Silver ☐ Gold ☐ Platinum
b. Seismic Zone Concerns? ☐ Yes ☐ No
c. Site Access: ☐ Unlimited ☐ Limited ☐ Restricted ☐ Severely Restricted
d. Other (please specify) ____________________________

Survey on Project Delivery Systems Performance

Delivery and Contract
1. What was the Project Delivery System used on this project?
   - Design Bid Build “hard money” single prime (DBB)
   - Multiple Prime Contractors
   - Agent Construction Management
   - Construction Management at Risk (CMR)
   - Design Build (DB)
   - Integrated Project Delivery (IPD) – if IPD, please fillout box below:
     - Was a single multiparty contract used? □ No □ Yes, which? ______
     - How many parties were part of the multiparty contract? ______
     - Liability waivers between participants to protect from litigation? □ No □ Yes
   - Other (specify) ___________

2. What was the compensation type for this project? Please check ALL that apply.

<table>
<thead>
<tr>
<th>Prime Contractor</th>
<th>Sub-Contractors</th>
<th>Architect/Designer</th>
<th>Design-Builder (if Applicable)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>□ Lump sum</td>
<td>□ Lump sum</td>
<td>□ Lump sum</td>
</tr>
<tr>
<td></td>
<td>□ Cost + fee</td>
<td>□ Cost + fee</td>
<td>□ Cost + fee</td>
</tr>
<tr>
<td>□ % or □ fixed</td>
<td>□ % or □ fixed</td>
<td>□ % or □ fixed</td>
<td>□ % or □ fixed</td>
</tr>
<tr>
<td>□ GMP</td>
<td>□ GMP</td>
<td>□ GMP</td>
<td>□ GMP</td>
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<td>□ Unit price</td>
<td>□ Unit price</td>
<td>□ Unit price</td>
<td>□ Unit price</td>
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<td>□ Time &amp; Mat</td>
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<td>□ Time &amp; Mat</td>
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<td>□ Negotiated</td>
<td>□ Negotiated</td>
<td>□ Negotiated</td>
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<tr>
<td>□ Fee</td>
<td>□ Fee</td>
<td>□ Fee</td>
<td>□ Fee</td>
</tr>
<tr>
<td>□ Other:</td>
<td>□ Other:</td>
<td>□ Other:</td>
<td>□ Other:</td>
</tr>
</tbody>
</table>

3. What percentage of the overall design time was completed when the GMP was established?
   - Not GMP □ ___________________________________________ % of design time

4. How much contingency did the CM/GC (or DB) contract include to account for unknown project risk? ______ %

5. Which of these parties were involved in the design phase?
   - CM/GC □
   - Major subcontractors, specify: ____________________________
   - None (SKIP to Incentives) □
   - Other: ______

6. How were the parties compensated during preplanning/preconstruction? Please check all that apply.
   - CM/GC: □ Lump sum □ GMP □ Cost + % fee □ Cost + fixed fee □ Other: __________
   - Subs: □ Lump sum □ GMP □ Cost + % fee □ Cost + fixed fee □ Other: __________
   - Other: □ Lump sum □ GMP □ Cost + % fee □ Cost + fixed fee □ Other: __________
Survey on Project Delivery Systems Performance

Incentives
1. Did the contract include an incentive clause to incentivize collaboration by sharing risk and reward?  □ Yes, please continue □ No (SKIP to Risk Allocation)

2. Were the incentives based on:
   a. Value, by offering a bonus linked to adding value to the project?  □ Yes □ No
   b. Profit sharing, where each party’s profit is determined collectively? □ Yes □ No
   c. Project performance? □ Yes □ No

Metrics to determine performance: □ Cost □ Schedule □ Quality □ Safety □ Other

   e. An “incentive pool,” which reserves a portion of the team’s fees into a pool that can increase or decrease based on various criteria? □ Yes □ No

3. Were the incentives funded with project savings as compared to the GMP? □ Yes □ No

4. What was the value of the incentives? _______ % or $ ______

5. How was it distributed: Owner ______ % CM/GC ______ % Subs ______ % A/E ______ % DB ______ % Other ______ %

Risk Allocation
1. Did the project team have a formal risk review process to identify and accept project risks before starting construction? □ Yes □ No

2. Did the key subcontractors participate in the risk assessment process? □ Yes □ No

3. How were the risks allocated?
   □ Shifted to other parties
   □ Shared equally
   □ Assumed by owner
   □ Other: ______

4. Did the owner buy a single insurance for the whole project? □ Yes □ No

5. Rate the existence of onerous contract clauses: □ Many □ Few □ None
   How problematic were they, on average? □ Very □ Somewhat □ Not at all

6. Rate the existence of regulatory/legal constraints: □ Many □ Few □ None
   How problematic were they, on average? □ Very □ Somewhat □ Not at all
Survey on Project Delivery Systems Performance

SECTION II: PROJECT PERFORMANCE

Safety Performance
1. Number of OSHA recordables: _______
2. Number of lost-time-injuries: _______
   (Injuries and/or Illnesses Resulting in Lost Workdays or Restricted Work Activity)
3. Number of fatalities: _______

Cost Performance
1. Please specify the following project costs. *For Design and Construction costs, please make sure to deduct all costs that are not costs of the base building, i.e., property costs, owner costs, costs of installed manufacturing equipment, furnishings and others.

<table>
<thead>
<tr>
<th>Timeline</th>
<th>Design Costs$</th>
<th>Construction Costs$</th>
<th>Total Project Costs$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bid / Initial GMP / Target Value</td>
<td>$</td>
<td>$</td>
<td>$</td>
</tr>
<tr>
<td>Contract Value or Target, including changes/GMP increase</td>
<td>$</td>
<td>$</td>
<td>$</td>
</tr>
<tr>
<td>Final Actual Costs</td>
<td>$</td>
<td>$</td>
<td>$</td>
</tr>
</tbody>
</table>

2. Please estimate the cost of the site work (outside the footprint of the building) as a percentage of final construction cost: _______%

Schedule Performance
Please provide the following schedule information:

<table>
<thead>
<tr>
<th></th>
<th>(Month&amp;Year OK)</th>
<th>Target (mm/yy)</th>
<th>Actual (mm/yy)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Date Project was Advertised</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Design Start Date (Notice to Proceed)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Design End Date</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Construction Start Date (Notice to Proceed)</td>
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</tr>
<tr>
<td>Construction End Date (Substantial Completion)</td>
<td></td>
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<tr>
<td>End of Commissionning</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Occupancy</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Changes
1. What was the overall percent change on the project? +____ or -_____%
   a. How much of it was for added/deleted program? (approx.) ______% of changes
   b. How much of it was for increased/decreased quality/value? ______% of changes
   c. How much of it was for risk mitigation (unforeseen conditions etc.) ______% of changes
2. In percentage of total changes, please approximate the percent of
   a. Modifications due to owner-initiated change orders ______% 
   b. Modifications due to design issues / deficiency ______% 
   c. Modifications due to major regulatory agencies ______% 

Survey on Project Delivery Systems Performance

3. How did the changes impact the OVERALL schedule?
   - [ ] Created an extension of time
   - [ ] Created a compression of work
   - [ ] Did not affect the schedule

4. How did the changes impact the OVERALL project cost?
   - [ ] Decreased the project cost
   - [ ] Increased the project cost
   - [ ] Did not affect the cost
   - Was the budget adjusted accordingly? [ ] Yes  [ ] No

5. On average, the change order processing time (the period of time between initiation of the change order and the owner's approval of the change order) was:
   - [ ] 1-7 days
   - [ ] 22-28 days
   - [ ] Greater than 42 days
   - [ ] 8-14 days
   - [ ] 29-35 days
   - [ ] 15-21 days
   - [ ] 36-42 days

Labor Performance / Productivity (Please provide your best guess)
1. The total amount of overtime labor, in percentage of total labor hours for this project:
   - [ ] none  [ ] 0 – 5%
   - [ ] 6 – 10%  [ ] 11 – 15%
   - [ ] 16 – 20%  [ ] 21 – 25%
   - [ ] 26 – 30%  [ ] 31 – 35%
   - [ ] 36 – 40%  [ ] 41 – 45%
   - [ ] 46 – 50%
   - [ ] 51 – 55%
   - [ ] 56 – 60%
   - [ ] 61 – 65%
   - [ ] 66 – 70%
   - [ ] 71 – 75%
   - [ ] 76 – 80%
   - [ ] 81 – 85%
   - [ ] 86 – 90%
   - [ ] 91 – 95%
   - [ ] 96 – 100%

2. The total amount of shift-work, in percentage of total labor hours for this project:
   - [ ] none  [ ] 0 – 5%
   - [ ] 6 – 10%  [ ] 11 – 15%
   - [ ] 16 – 20%  [ ] 21 – 25%
   - [ ] 26 – 30%  [ ] 31 – 35%
   - [ ] 36 – 40%  [ ] 41 – 45%
   - [ ] 46 – 50%
   - [ ] 51 – 55%
   - [ ] 56 – 60%
   - [ ] 61 – 65%
   - [ ] 66 – 70%
   - [ ] 71 – 75%
   - [ ] 76 – 80%
   - [ ] 81 – 85%
   - [ ] 86 – 90%
   - [ ] 91 – 95%
   - [ ] 96 – 100%

3. Think about the average jobsite area available per worker. Was the jobsite for this particular project more or less crowded than average?
   - [ ] more crowded than average
   - [ ] about average
   - [ ] less crowded than average

*** What was the average number of workers of all trades on the site? ________

Self performed work (if none, SKIP to the RFI subsection)
1. What was the self performed labor cost? $ ________
2. What was the self performed total cost (labor, equip., material)? $ ________
3. Please provide the following information for self-performed work:

<table>
<thead>
<tr>
<th>Self-performed Activity</th>
<th>Quantity (CY, Ton, etc.)</th>
<th>Duration</th>
<th>Cost</th>
<th>Labor Productivity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Concrete</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Steel</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Carpentry</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Other</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Other:

Request for Information (RFI)
1. What was the total number of RFI's on the project? ________ Classify: % early % field

2. The RFI processing time (the period of time between your submittal of a RFI and the response by the appropriate party - closure), on average, was:
   - [ ] 1-7 days
   - [ ] 8-14 days

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☐ 15-21 days
☐ 22-28 days
☐ 29-35 days
☐ Greater than 35 days

3. Was a work-around used to avoid RFI’s (such as phone, email, etc.)?
   ☐ No ☐ A few times ☐ Many times

Other Performance Metrics

1. What is the total number of re-submittals on the project? __________ re-submittals

2. What is the total number of deficiency issues on the project? __________ deficiency issues
   (Field inspection/report, A/E, jurisdiction/code, etc. during the course of construction)

4. What is the total number of punchlist items? __________ items

5. What is the value associated with punchlist items, in percentage of total construction cost?
   ☐ 0-0.25 % ☐ 0.25 - .5% ☐ .5 - 1% ☐ 1 - 2% ☐ >2%

6. What is the percentage of rework on the whole project, including subcontracted work?
   ☐ 0% ☐ 0 – 1% ☐ 1 – 2% ☐ 2 – 3% ☐ 3 – 4% ☐ >4%

7. How many claims were there on this project, if any? __________ cases

8. What was the total cost of claims (from subs / others)? $_________
   For a project of this type and size, do you consider this value: ☐ below average ☐ average ☐ above average

9. What was the total weight of material waste?
   a. How much of it was recycled? __________ tons
   b. How much of it was sent to landfills? __________ tons

10. What are the warranty costs (measured one year after occupation date)?
    ☐ 0 % ☐ 0 – .5% ☐ .5 – 1% ☐ 1 – 2% ☐ 2 – 3% ☐ >3%

11. What are the latent defect costs (measured AFTER the end of the one-year warranty period)?
    ☐ 0 % ☐ 0 – .5% ☐ .5 – 1% ☐ 1 – 2% ☐ 2 – 3% ☐ >3%

12. Your project OH&P on the project was: __________ % (job overhead, not company OH)
    ☐ negative ☐ <5% ☐ 5-10% ☐ 11-15% ☐ >15%

13. Overall, how would you rate the effect of this project on your company image and/or potential for return business?
    ☐ very negative ☐ negative ☐ neutral ☐ positive ☐ very positive

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#### SECTION III: PROJECT SYSTEMS – Complexity and Quality Factors

1. For each major building system, please rate each of the following:
   1. The complexity of the system,
   2. The as-built quality of the system, and
   3. Whether BIM was used to model the system.

<table>
<thead>
<tr>
<th>Building Systems</th>
<th>(1) Complexity</th>
<th>(2) Quality as built</th>
<th>(3) BIM</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Low</td>
<td>Avg.</td>
<td>High</td>
</tr>
<tr>
<td>Foundation</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Structure</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Interior Finishes</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Exterior Enclosure</td>
<td></td>
<td></td>
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<tr>
<td>Roofing</td>
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<td></td>
<td></td>
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<tr>
<td>Mechanical Systems</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Electrical Systems</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Site</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Process Equipment, if applicable</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Conveying Systems, if applicable</td>
<td></td>
<td></td>
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<tr>
<td>Specialties, if applicable</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

2. Rate average project complexity, as a whole:
   - [ ] Low
   - [ ] Average
   - [ ] High

3. Rate average project as-built quality, as a whole:
   - [ ] Economy
   - [ ] Standard
   - [ ] High
   - [ ] Premium
   - [ ] High Eff Premium

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SECTION IV: PROJECT TEAM AND COLLABORATION

Experience

1. Please tell us about the prior experience of the stakeholders before the start of this project. Example: is the CM/GC experienced with building hospitals?

<table>
<thead>
<tr>
<th>Past experience with this type of construction:</th>
<th>A lot</th>
<th>Some</th>
<th>A little</th>
<th>None</th>
</tr>
</thead>
<tbody>
<tr>
<td>CM/GC</td>
<td></td>
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<td></td>
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<tr>
<td>Subcontractors</td>
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<tr>
<td>Owner</td>
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<td></td>
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<tr>
<td>A/E</td>
<td></td>
<td></td>
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<tr>
<td>DB firm (if applicable)</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Past experience with this size of construction:</th>
<th>A lot</th>
<th>Some</th>
<th>A little</th>
<th>None</th>
</tr>
</thead>
<tbody>
<tr>
<td>CM/GC</td>
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<tr>
<td>Subcontractors</td>
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<td>Owner</td>
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<tr>
<td>A/E</td>
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<tr>
<td>DB firm (if applicable)</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Past experience with this project delivery system:</th>
<th>A lot</th>
<th>Some</th>
<th>A little</th>
<th>None</th>
</tr>
</thead>
<tbody>
<tr>
<td>CM/GC</td>
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<tr>
<td>Subcontractors</td>
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<tr>
<td>Owner</td>
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<tr>
<td>A/E</td>
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<tr>
<td>DB firm (if applicable)</td>
<td></td>
<td></td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Past experience with BIM:</th>
<th>A lot</th>
<th>Some</th>
<th>A little</th>
<th>None</th>
</tr>
</thead>
<tbody>
<tr>
<td>CM/GC</td>
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<tr>
<td>Subcontractors</td>
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<tr>
<td>Owner</td>
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<tr>
<td>A/E</td>
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<tr>
<td>DB firm (if applicable)</td>
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<td></td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Your past experience with the other stakeholders:</th>
<th>A lot</th>
<th>Some</th>
<th>A little</th>
<th>None</th>
</tr>
</thead>
<tbody>
<tr>
<td>Subcontractors</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Owner</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A/E</td>
<td></td>
<td></td>
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<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Past experience of the team as a unit:</th>
<th>A lot</th>
<th>Some</th>
<th>A little</th>
<th>None</th>
</tr>
</thead>
</table>

2. Now looking back, what is your overall satisfaction working with this project team? In other words, rate your current experience working as a team for this project:

Project team with Architect and Owner: ☐ Excellent ☐ Very Good ☐ Good ☐ Fair ☐ Poor
Construction team with Subcontractors: ☐ Excellent ☐ Very Good ☐ Good ☐ Fair ☐ Poor
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Team Selection
1. The project owner is:  □ Public (government)  □ Private
2. The owner organization is:     □ Non-Profit  □ For profit
3. CM/GC selection:
   □ Open Bidding
   □ Prequalified Bidding
   □ Negotiated Contract
   □ Voting of key people
   □ Other: __________
4. Was there competition from other qualified general contractors?  □ Yes  □ No
5. Subcontractors selection:
   □ Open Bidding
   □ Prequalified Bidding
   □ Negotiated Contract
   □ Voting of key people
   □ Other: __________
6. Was there competition from other qualified subcontractors?  □ Yes  □ No

Project Management Structure
In this subsection, we are trying to understand your project management structure. The questions are specifically geared to test how many levels of project management were established, and how they function together. Though different models exist, we commonly see up to three major levels, from the details cluster level, to the project leadership team, and finally the executive level.

1. Project leadership team
a. Was there a dedicated leadership team for this project? □ Yes  □ No (Skip & go to #2)
b. How frequently did the leadership team meet during each of the following stages:
   Preplanning: □ Daily  □ Weekly  □ Every other week  □ Monthly  □ Other: __________
   Construction: □ Daily  □ Weekly  □ Every other week  □ Monthly  □ Other: __________
   Commissioning: □ Daily  □ Weekly  □ Every other week  □ Monthly  □ Other: __________
c. How many stakeholder representatives were on the leadership team?
   Owner: __________ Reps.
   A/E: __________ Reps.
   CM/GC: __________ Reps.
   MEP Subs: __________ Reps. Total: ____ Representatives
   Suppliers: __________ Reps.
   Other, __________: ___ Reps.
d. Did this leadership team have all the authority needed to make the necessary decisions to manage and lead the project on a daily basis?  □ Absolutely  □ Somewhat  □ No
e. Did the project leadership team jointly develop project target criteria and goals?
   □ Absolutely  □ Somewhat  □ No
f. Did the project leadership team make decisions collaboratively?
   □ Absolutely  □ Somewhat  □ No
g. Did the project leadership team perform periodic project reviews?  □ Yes  □ No
h. Did the team meet to discuss and capture “lessons learned”? Check all that apply.
   □ at project completion  □ throughout the project  □ never

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2 – Cluster level
a. Were there clusters of multidisciplinary working teams responsible for specific parts or aspects of the project (e.g. enclosure)?
   □ For most of the project  □ For parts of the project (specify __% ) □ No (SKIP b)
b. How frequently did the cluster teams meet during each of the following stages:
   Preplanning  □ Daily  □ Weekly  □ Every other week  □ Monthly  □ Other: ________
   Construction  □ Daily  □ Weekly  □ Every other week  □ Monthly  □ Other: ________
   Commissioning  □ Daily  □ Weekly  □ Every other week  □ Monthly  □ Other: ________

3 – Executive level team
a. Was there an executive management team (to which the leadership team reports) that also acts as a dispute resolution board when needed?  □ Yes  □ No (SKIP b)
b. How frequently did the executive management team meet during each of the following stages:
   Preplanning  □ Weekly  □ Monthly  □ Quarterly  □ Other: ________
   Construction  □ Weekly  □ Monthly  □ Quarterly  □ Other: ________
   Commissioning  □ Weekly  □ Monthly  □ Quarterly  □ Other: ________

4. In case of conflicts, which party has the final decision-making authority?
   □ Owner  □ A/E  □ CM/GC  □ Voting of project leadership group  □ Other: ________

Timing and Collaboration
1. What percentage of the design was complete prior to the award of the construction contract?  ______%  
2. How familiar was the contractor with the owner’s objectives and expectations (firsthand)?
   □ Very familiar  □ Somewhat familiar  □ A little familiar  □ Not familiar
3. Did the owner’s staff actively participate in the construction process?
   □ Very actively  □ Some participation  □ A little participation  □ None
4. Did the architect/engineer give adequate support during construction?
   □ Very adequate  □ Some support  □ A little support  □ None
5. How involved was the CM/GC in the design/preplanning stage of the project?
   □ Very involved  □ Some involvement  □ Limited involvement  □ None
6. How involved were the key subcontractors in the design/preplanning stage of the project?
   □ Very involved  □ Some involvement  □ Limited involvement  □ None
7. Rate the project parties’ physical Co-location, or use of the “Big Room” concept
   □ Exceptional  □ Good  □ Limited  □ None

Technology and Tools
1. How frequently was Pull Planning / Pull Scheduling used on the project?
   □ Never (Skip a)  □ Daily  □ Weekly  □ Monthly  □ Other: ________
   a. How effectively was Pull Planning / Pull Scheduling used on the project?
   □ Very effectively  □ Some effectiveness  □ Little effectiveness  □ Not used
2. Which contractors used off-site prefabrication, if any?
   Concrete  □ Sheet Metal  □ Plumbing  □ Mech. Sub  □ Elec. Sub  Others: ________

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3. Did you use the following tools / techniques on this project?

<table>
<thead>
<tr>
<th>Tool Description</th>
<th>A lot</th>
<th>Some</th>
<th>A little</th>
<th>None</th>
</tr>
</thead>
<tbody>
<tr>
<td>Last Planner System for production control</td>
<td></td>
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</tr>
<tr>
<td>Did you track weekly commitments from the project teams?</td>
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<tr>
<td>Did you track reliable promises / Percent Plan Complete PPC</td>
<td></td>
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</tr>
<tr>
<td>5S - A policy that requires cleanliness, organization and orderly storage and movement plans. Gang boxes, tools and consumable supplies should be stocked and organized so that no time is spent searching for or retrieving common tools or materials.</td>
<td></td>
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</tr>
<tr>
<td>Set-Based Design - Set-Based Design requires carrying forward multiple alternatives to allow more time for analysis, only narrowing alternatives at the last responsible moment</td>
<td></td>
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</tr>
<tr>
<td>Value Stream Mapping - to clearly identify and eliminate waste throughout the project</td>
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<tr>
<td>Proactive dynamic Target Costing or Target Value Design</td>
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<tr>
<td>Daily Huddles - meeting with the field crews on a daily basis to review the schedule and plan the work</td>
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<tr>
<td>JIT - bulk materials are delivered just prior to installation</td>
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<tr>
<td>Point Cloud technology such as Total Station</td>
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<tr>
<td>Visual Management Devices</td>
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<tr>
<td>Mock-ups for repetitive construction systems</td>
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<tr>
<td>Open Books - fiscal transparency between key participants, with respect to:</td>
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<td></td>
</tr>
<tr>
<td>• Change orders</td>
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</tr>
<tr>
<td>• Bidding and procurement</td>
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<td></td>
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<tr>
<td>• Contingency usage</td>
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</tr>
<tr>
<td>• All project costs</td>
<td></td>
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<tr>
<td>Project training sessions - to enhance team working ability, clarify Pull Scheduling and/or the Last Planner System, etc.</td>
<td></td>
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<tr>
<td>Constructability reviews</td>
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<tr>
<td>Safety trainings/awareness/commitment</td>
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<tr>
<td>Think about this project. How cutting edge do you think this project was, based on materials, latest technologies, state-of-the-art equipment, and/or modern construction methods?</td>
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</tbody>
</table>

4. Just In Time delivery (if used); on average, which best describes JIT on this project?

- Material off the truck and on the building
- Minor storage (small batches for a short period)
- Site Warehouse (long batches for a long period)
- Other: ____________________________

5. How was the PPC trend throughout the project? □ Stable □ Increased □ Decreased

6. Did you track project percentage complete? □ Yes □ No (Skip a)
   a. How? □ By earned value □ Actual installed quantities □ Actual manhours □ Other: ____________________________

7. Did you use a formal comprehensive change order management process? □ Yes □ No
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Building Information Modeling (BIM)
1. Was BIM used on this project? □ Yes □ No (Skip and go to Project Team Contacts)
2. Was a BIM protocol manual used/developed? □ Yes □ No
3. Did the contract allow the right of reliance on the 3D models? □ Yes □ No
4. Were the project parties using joint servers for the building model? □ Yes □ No

Rate the use of the BIM model for the following tasks. Please check the appropriate box to answer if BIM was used a lot, if there was some BIM use, only little BIM use, or not BIM use at all for the respective tasks.

<table>
<thead>
<tr>
<th>Task</th>
<th>A lot</th>
<th>Some</th>
<th>A little</th>
<th>None</th>
</tr>
</thead>
<tbody>
<tr>
<td>Visualization</td>
<td></td>
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<tr>
<td>Space Validation</td>
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<tr>
<td>Site Logistics</td>
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<tr>
<td>Environmental Analysis</td>
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<tr>
<td>Early Design Coordination</td>
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<tr>
<td>MEP Coordination</td>
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<tr>
<td>Design Collaboration</td>
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<tr>
<td>Clash Detection</td>
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<tr>
<td>Submittals</td>
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<tr>
<td>Estimating / Quantity Take-off</td>
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<tr>
<td>4D Scheduling</td>
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<tr>
<td>Digital Fabrication / Prefab</td>
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<tr>
<td>Construction Simulation / Virtual Mock-ups</td>
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<tr>
<td>Proj. Turnover and Closeout</td>
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<tr>
<td>Facilities Management, O&amp;M</td>
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<tr>
<td>Rule / Code Checking</td>
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<tr>
<td>Other:</td>
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<tr>
<td>Other:</td>
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Project Team Contact Information

<table>
<thead>
<tr>
<th></th>
<th>Contact Person</th>
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<tbody>
<tr>
<td>Project Owner E-mail</td>
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</tr>
<tr>
<td>Architect E-mail</td>
<td></td>
</tr>
<tr>
<td>Mechanical Sub. E-mail</td>
<td></td>
</tr>
<tr>
<td>Electrical Sub. E-mail</td>
<td></td>
</tr>
</tbody>
</table>

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Survey on Project Delivery Systems Performance

**SECTION V: CONTRACTOR BACKGROUND & SUCCESS MEASURES**

Success measures: Please list the criteria your organization uses to measure project success, starting with the most important criterion, and then use these criteria to rate what was achieved on this project.

1. □ Excellent □ Very Good □ Good □ Fair □ Poor
2. □ Excellent □ Very Good □ Good □ Fair □ Poor
3. □ Excellent □ Very Good □ Good □ Fair □ Poor
4. □ Excellent □ Very Good □ Good □ Fair □ Poor
5. □ Excellent □ Very Good □ Good □ Fair □ Poor

Individual that completed the survey:
Name ____________________________________________
Address _________________________________________
Telephone __________________ Fax ___________ Email _______________________

What position do you hold within your company?
□ Owner □ Superintendent □ President
□ Project manager □ Vice president □ Other (specify) ______________________

What is the percentage of each type of delivery your company has used over the last 5 years?
□ Design Bid Build “hard money” ______ %
□ Pure Construction Management (Agent) ______ %
□ Construction Management at Risk ______ %
□ Design Build ______ %
□ Integrated Project Delivery ______ %
□ Other (specify) ______ %

What is the percentage of self-performed work for your company, on average? ______ %

Does your company assign more talented/experienced personnel to more collaborative projects, as opposed to projects using traditional delivery systems such as DBB? □ Yes □ No

**You have completed the questionnaire. Thank You.**
We truly appreciate all your time and effort. Your responses will be kept confidential and will further the research process and allow for the development of findings that will be useful for the success of your future projects.

Appendix D – Quantile-Quantile Plots

The following Q-Q plots were used to determine normality of a few select metrics. Similar plots were constructed for each of the metrics analyzed.

Chapter 4

Number of RFIs per Million Dollars (Communication)

Change Order Processing Time (Change Management)

Company Image / Return Business Potential (Business)
Appendix E – PQR Regression Diagnostics

Project Attributes Affecting Overall Performance (Chapter 6)

Unconventional Key Stake holder Involvement

lm(mod_PQR ~ Involvement)

Outlier Test
No Studentized residuals with Bonferonni p < 0.05
Largest lrstudent:
\[
\text{rstudent unadjusted p-value Bonferonni p} \\
7 -2.395773 \quad 0.023261 \quad 0.74435
\]
No Studentized residuals with Bonferonni p < 0.05
Largest |rstudent|:

<table>
<thead>
<tr>
<th>rstudent</th>
<th>unadjusted p-value</th>
<th>Bonferonni p</th>
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</thead>
<tbody>
<tr>
<td>-2.293261</td>
<td>0.029548</td>
<td>0.916</td>
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</tbody>
</table>

Project Leadership Team

Im(mod_PQR ~ Core_Team)
No Studentized residuals with Bonferroni $p < 0.05$

Largest $|r_{student}|$

<table>
<thead>
<tr>
<th>$r_{student}$</th>
<th>unadjusted $p$-value</th>
<th>Bonferroni $p$</th>
</tr>
</thead>
<tbody>
<tr>
<td>-2.631168</td>
<td>0.023358</td>
<td>0.32702</td>
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</tbody>
</table>

**Extent of BIM Use**

$$\text{lm(mod}_{-}\text{PQR} \sim \text{BIM}_{-}\text{Ext}_{-}\text{Use})$$
Utilization of Lean Construction Tools

\[ \text{lm(mod\_PQR} \sim \text{Lean\_Tools\_Use}) \]

**OutlierTest**

```r
> outlierTest(RegModel.1)
  rstudent unadjusted p-value Bonferonni p
31 -3.677017 0.00095419 0.030534
```

![Residuals vs Fitted](image1)
![Normal Q-Q](image2)
![Scale-Location](image3)
![Residuals vs Leverage](image4)
Co-location

\text{lm(mod\_PQR ~ Colocation)}

No Studentized residuals with Bonferonni \( p < 0.05 \)
Largest \( \text{rstudent} \):
\[
\begin{array}{ccc}
\text{rstudent} & \text{unadjusted \( p \)-value} & \text{Bonferonni \( p \)} \\
31 & -0.054538 & 0.0047973 & 0.15351 \\
\end{array}
\]
> outlierTest(experience)
No Studentized residuals with Bonferonni p < 0.05
Largest |rstudent|:

<table>
<thead>
<tr>
<th>rstudent</th>
<th>unadjusted p-value</th>
<th>Bonferonni p</th>
</tr>
</thead>
<tbody>
<tr>
<td>-3.269289</td>
<td>0.0028557</td>
<td>0.088527</td>
</tr>
</tbody>
</table>

\[
\text{lm}(\text{mod}_{\text{PQR}} \sim \text{Avg}_{\text{Past Exp}})
\]
Control Variables (Chapter 6)

Project Cost

\[ \text{lm(mod_PQR \sim Project\_Cost)} \]

No Studentized residuals with Bonferroni p < 0.05
Largest \( r_{\text{student}} \) unadjusted p-value Bonferroni p
31 -3.269289 0.0028557 0.088527

Project Size
No Studentized residuals with Bonferonni \( p < 0.05 \)
Largest \( r_{\text{student}} \):

<table>
<thead>
<tr>
<th>( r_{\text{student}} )</th>
<th>unadjusted ( p )-value</th>
<th>Bonferonni ( p )</th>
</tr>
</thead>
<tbody>
<tr>
<td>31</td>
<td>-3.200955</td>
<td>0.1053</td>
</tr>
</tbody>
</table>

\( \text{lm}(\text{mod}_{\text{PQR}} \sim \text{Project\_Size}) \)
Appendix F – Sample R Code

Below are examples of R code used to perform each type of the statistical analyses used in this research. The code presented here is representative of the code used to analyze the other variables throughout this research.

Chapter 4: Analysis of Construction Unit Cost

Boxplot(ConstUnitCost~ProjDel, data=Thesis, id.method="identify", col=c("green", "red"), ylab="Construction Unit Cost")

leveneTest(Thesis$ConstUnitCost, Thesis$ProjDel, center=median)

t.test(ConstUnitCost~ProjDel, alternative='two.sided', conf.level=.95, var.equal=TRUE, data=Thesis)
tapply(Thesis$ConstUnitCost, Thesis$ProjDel, median, na.rm=TRUE)

wilcox.test(ConstUnitCost ~ ProjDel, alternative="two.sided", data=Thesis)

numSummary(Thesis[, "ConstUnitCost"], groups=Thesis$ProjDel, statistics=c("mean", "sd"), quantiles=c(0,.25,.5,.75,1))

Chapter 5: Analysis of PQR

Boxplot(mod_PQR~ProjDel, data=Thesis, id.method="identify", col=c("green", "red"), ylab="PQR")

leveneTest(Thesis$mod_PQR, Thesis$ProjDel, center=median)

t.test(mod_PQR~ProjDel, alternative='two.sided', conf.level=.95, var.equal=TRUE, data=Thesis)
tapply(Thesis$mod_PQR, Thesis$ProjDel, median, na.rm=TRUE)

wilcox.test(mod_PQR ~ ProjDel, alternative="two.sided", data=Thesis)

numSummary(Thesis[, "mod_PQR"], groups=Thesis$ProjDel, statistics=c("mean", "sd"), quantiles=c(0,.25,.5,.75,1))

qqPlot(Thesis$mod_PQR[Thesis$ProjDel=="IPD/IPD-ish"], dist="norm", ylab="PQR (IPD/IPD-ish)")

qqPlot(Thesis$mod_PQR[Thesis$ProjDel=="non-IPD"], dist="norm", ylab="PQR (non-IPD)")

Chapter 6: Linear Regression of Unconventional Stakeholder Involvement

Involvement <- lm(mod_PQR~Involvement, data=Thesis)

summary(Involvement)
showData(Thesis, placement='-'20+200', font=getRcmdr('logFont'), maxwidth=80,maxheight=30)
scatterplot(mod_PQR~Involvement | ProjDel, reg.line=lm, smooth=FALSE,spread=FALSE,
boxplots=FALSE,ylab="PQR", span=0.5, by.groups=FALSE, data=Thesis)

Thesis$fitted.Involvement <- fitted(Involvement)
Thesis$rstudent.Involvement <- rstudent(Involvement)

oldpar <- par(oma=c(0,0,3,0), mfrow=c(2,2))
plot(Involvement)
par(oldpar)

scatterplot(rstudent.Involvement~fitted.Involvement | ProjDel, reg.line=FALSE, smooth=FALSE,
spread=FALSE,boxplots=FALSE, span=0.5, by.groups=FALSE, data=Thesis)

outlierTest(Involvement)
library(lmtest, pos=4)