Performance of Integrated Project Delivery (IPD)

For Mechanical and Electrical Contractors

By

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Abstract

Integrated Project Delivery (IPD) is a relatively new delivery system that is generating much interest in the construction industry today. IPD is characterized by a multiparty contract and the very early involvement of key participants including the owner, architect, general contractor, and important trade contractors such as mechanical and electrical contractors. Several organizations and publications have expressed great interest in IPD but very few studies statistically evaluated the benefits. Additionally, the few studies that have evaluated the impacts of IPD have focused on the general contractors’ perspective. No studies have focused solely on the effects that IPD may have on key trade contractors who typically represent 40-50% of the total cost of a project (Hanna 2001).

This research fills this gap by performing a comprehensive analysis of IPD from the perspective of mechanical and electrical contractors through a comparison of IPD with design-bid-build, construction management at risk, and design-build for many performance metrics. A literature review was conducted to gain an understanding of the prior research on IPD as well as insight into the trends and methodology of prior project delivery system literature. Then, a data collection tool was developed and sent to mechanical and electrical contractors in the U.S. and Canada. After data collection, a univariate analysis was performed comparing IPD to non-IPD for mechanical and electrical contractors using safety, cost, schedule, communication, quality, business, labor, and change metrics. Additionally, a comprehensive metric for collectively measuring overall project performance called the Project Quarterback Rating (PQR) was developed and analyzed. Finally, analyses were performed to determine other delivery characteristics that affect project performance for mechanical and electrical contractors.

The results from the study indicate that IPD outperforms non-IPD for mechanical and electrical contractors in six metrics related schedule, communication, quality, and change management. These metrics are the deficiencies per million dollars, resubmittals per million dollars,
change order processing time, schedule growth, rework cost, and change order effect on cost.

Additionally, after the PQR development, the study shows evidence that mechanical and electrical contractors on IPD projects have superior overall performance when compared with design-bid-build.

Finally, the study shows that, in addition to the selected project delivery system, increased involvement of owners and designers in the construction phase, earlier involvement of key subcontractors in the design phase, and the use of lean construction principles improve overall project performance for MEP contractors.
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Chapter 1 Introduction

Integrated Project Delivery (IPD) is a subject of great interest in the construction industry today. However, there is only one academic study that has attempted to prove that IPD outperforms traditional construction delivery (Cho and Ballard 2011). Several leading organizations have released publications devoted solely to the subject of IPD including the Construction Industry Institute, the American Institute of Architects, and the Construction Users Roundtable (CII 2005, 2007; AIA 2007, 2009, 2011; CURT 2004, 2007). However, these publications are mostly case studies that do not show statistically that IPD outperforms traditional construction delivery.

This chapter serves as an introduction to this Master’s thesis. It will introduce the concept of IPD and discuss how it compares with traditional construction project delivery systems. This chapter will also describe the motivation for this study followed by a discussion on the problem statement and methodology.

1.1 Definition of Terms

The definition of project delivery system is constantly changing. Ireland (1982) described a project delivery system as what defines the roles of participants and the timing of events. Sanvido and Konchar (1999) added to this definition saying that a project delivery system establishes an execution framework for sequencing design, procurement, and construction activities required to provide a facility. Recently, several sources have divided the project delivery system into three basic domains: commercial terms, operating system, and project organization (Cho et al. 2010; Smith et al. 2011). The commercial terms refer to the legal relationships between different parties. The operating system defines the project management techniques used on the project. Finally, the project organization refers to how the parties are organized. Even more recently, El Asmar (2012) defined a
project delivery system as “a system that determines the relationships between the different project stakeholders and their timing of engagement to provide a facility.”

The three most common project delivery systems used in the construction industry today are design-bid-build, construction management at risk, and design-build (Sanvido and Konchar 1999). Design-bid-build is the traditional method of construction delivery in the U.S. and involves the owner contracting with two separate parties, the designer and the general contractor. The contractual structure for this delivery system is shown in Figure 1-1. The designer fully completes the design documents before the owner selects the general contractor, usually based on lowest bid. For this reason, design-bid-build is a sequential process involving three phases: design, bid, and construction (see Figure 1-2). The designer and the general contractor may have various design consultants (structural, MEP) and subcontractors (mechanical, electrical, plumbing), respectively. Many have blamed this delivery system for the issues facing the construction industry today (Konchar and Sanvido 1998; Pocock et al. 1996; Rojas and Kell 2008). Much of this blame is because the designer and the general contractor have little collaboration, and the general contractor cannot provide input during the design process that could potentially increase constructability and reduce costs. The general contractor comes on board after the design is complete, when the influence on cost has diminished. Additionally, the focus on selecting the general contractor for the lowest price disregards the importance of complete life-cycle costs (Ballard 2008).

Figure 1-1: Contractual Relationship for Design-Bid-Build
Construction management at risk is different from the traditional design-bid-build process. The contractual structure for this delivery system is shown in Figure 1-3. The owner still signs separate contracts with the designer and the construction manager / general contractor but these two contractual engagements occur at relatively the same time. This gives the construction manager the ability to influence the design, allowing for increased constructability. Construction can start earlier, before the design phase is complete, allowing for faster overall project delivery as shown in Figure 1-4. After design completion, the construction manager will guarantee the maximum price of the project to the owner, which effectively shifts the risk from the owner to the construction manager. Similar to design-bid-build, both the designer and the construction manager will have consultants and subcontractors respectively.
In design-build, the owner contracts with only one entity to provide both design and construction services. The contractual structure for this delivery system is shown in Figure 1-5. Similar to the previously mentioned delivery systems, the design-builder may utilize design consultants and subcontractors. The phases for design-build are very similar to construction management at risk with portions of the design and construction occurring simultaneously, as shown in Figure 1-6.
shown that both construction management at risk and design-build result in improved project performance (Konchar and Sanvido 1998). Other studies show that, as integration increases, so does project success (Pocock et al. 1996).

Shown in *Figure 1-7*, the innovative project delivery system that is IPD furthers the integration of key stakeholders in construction projects. The key difference between IPD and other traditional delivery systems is that IPD involves a single multiparty contract (Smith et al. 2011). This multiparty contract will involve, at the least, the owner, the general contractor, and the architect. The multiparty contract may also include design consultants or subcontractors directly or these parties will sign joining agreements with the designer or general contractor respectively. The joining agreement will effectively make the design consultants and subcontractors a part of the multiparty contract. The multiparty agreement contractually requires collaboration, forcing project participants to think about overall project success and productivity instead of thinking about their individual success and productivity (Kent and Becerik-Gerber 2010). Other key principles of IPD include shared risk and reward and the early involvement of general and trade contractors. By having key participants involved earlier, the phasing of IPD is similar to that of construction management at risk and design-build as design and construction can occur simultaneously.

*Figure 1-7: Contractual Relationship for IPD*
1.2 Study Motivation

1.2.1 Problems in the AEC Industry

A troubling sign in the architecture-engineering-construction (AEC) industry is the productivity trend over the last few decades. From 1964-2004, productivity in construction has declined by 20%, even with the advancements made in technology (Teicholz 2004). Over that same time, all other non-farm industries in the U.S. have doubled their productivity, as shown in Figure 1-8. However, this figure only includes the productivity issues that occur in the construction phase and does not include similar problems that occur in the design phase through inefficiencies such as design rework (Love 2002).

![Construction & Non-Farm Labor Productivity Index (1964-2003)](Image)

*Figure 1-8: Productivity in Construction and Non-Farm Industries (Teicholz 2004)*

An updated version of this graph, utilizing data from the Bureau of Labor Statistics and the U.S. Department of Commerce, is shown in Figure 1-9, (BLS 2013; U.S. Department of Commerce 2013). The index of this graph is 1993, and it shows that while the increase in productivity in construction exceeded the productivity in all non-farm businesses from 2003-2008, the construction
industry dropped below all non-farm industries in the years 2008-2012. A similar productivity trend is shown below in Figure 1-10 for the Canadian construction industry from the years 1961-2011. This graph shows that, although the construction industry has increased productivity in Canada over the last five decades, it still lags behind all other businesses (Statistics Canada 2013).

Figure 1-9: Productivity in Construction and Non-Farm Industries from 1993-2012 (BLS 2013; U.S. Department of Commerce 2013)

Figure 1-10: Productivity Comparison of Construction and Other Business in Canada (Statistics Canada 2013)
Many attribute this productivity problem to inherent waste in the construction industry. Waste is defined as any activity that does not add value to the final product from the viewpoint of the customer (CII 2005). Several studies have commented on the amount of waste in the construction industry. Horman and Kenley (2005) estimated that 49.6% of time spent on projects is waste. Hanna (2010) had similar results, claiming that 59% of time on construction projects is wasteful activity including transporting materials, waiting for instructions, and locating materials.

The traditional project delivery system, design-bid-build, may be the source of much of the waste in the construction industry. Design-bid-build is a fragmented approach to construction with contractors having no input in design, ultimately resulting in a severe lack of collaboration. This in turn leads to problems such as design rework, which studies have shown can account for 52% of cost growth on capital projects (Love 2002). The other popular delivery methods, construction management at risk and design-build, have attempted to solve this problem through more integrated approaches. While these project delivery systems do demonstrate superior performance for certain aspects of construction, they are only incremental solutions and there are still many opportunities to improve in the construction industry. This is because project participants on design-bid-build, construction management at risk, and design-build do not act collaboratively, focusing only on their own productivity, even at the expense of overall project productivity (AIA 2007b).

There are still other problems in the construction industry. For example, interoperability between design software cost the AEC industry $15.8 billion in 2002 (Gallaher et al. 2004). Serious concerns involve schedules and budgets of construction projects as well. A study on transportation projects of more than $5 million showed that only 35% of these projects finished on time and only 20% finished under budget (NCHRP 2007). Another study estimated that 40-50% of projects are not delivered on time (NASFA et al. 2010). Smith et al. (2011) developed a list of problems in the construction industry including safety, litigation, design quality, too much risk for contractors, adversarial cultures, and owners losing too much money. El Asmar (2012) added a lack of
coordination between trades, lowered quality of design and construction caused by increased competition, latent defects, and lack of planning and tracking throughout the construction industry. With these trends in the construction industry, it is easy to see why many industry professionals are searching for ways to improve project performance.

Many of the previously discussed issues affect trade contractors, such as mechanical, electrical, plumbing, and fire protection (MEP) contractors, the most. Labor accounts for 40-60% of the total project cost for MEP contractors, making productivity extremely important for these industries (Hanna 2001). With labor being such a high portion of the MEP cost, a small change in productivity could completely eliminate an MEP contractor’s profit margin. Additionally, these trade contractors are especially susceptible to risk since they typically carry the delay caused by the trades working on the project before them. Furthermore, operating profit margin (gross profit minus overhead) is very volatile in both mechanical and electrical construction as indicated by Figure 1-11 below (RMA 1986-2011).

![Figure 1-11: Operating Profit Margin for Mechanical and Electrical Contractors (RMA 1986-2013)](image-url)
1.2.2 **IPD: A Potential Solution**

Many in the construction industry believe that IPD will help reverse the negative trends seen in the industry through contractually required collaboration, shared risk and reward, and early involvement of general and trade contractors. Many studies provide estimated benefits of using IPD. An article from *Engineering News Record* cited benefits including more collaboration, higher quality, timely completion, and better budget performance (ENR 2010). Kent & Becerik-Gerber (2010) surveyed industry professionals for their perceptions on IPD and found that the majority believe IPD will result in fewer change orders, cost savings, and shorter schedules. A study by the United Kingdom’s Office of Government Commerce stated that integrated delivery can improve design, drive out inefficiency, and minimize risks of costly disputes while also creating savings of up to 30% when integrated teams work together for multiple projects (UKOGC 2007). Additionally, the American Institute of Architects have showcased several successful IPD projects in multiple publications (AIA 2010, 2011).

A few studies have attempted to statistically show that IPD outperforms non-IPD projects. One of these studies was done by Cho and Ballard (2011), which showed no significant improvement for IPD projects but considered a limited variety of performance metrics. Another study was done by El Asmar (2012), which demonstrated IPD outperforms non-IPD by analyzing a more comprehensive list of performance metrics.

1.3 **Problem Statement**

As mentioned earlier, IPD seems to be a potential solution to the many problems facing the construction industry. After an extensive literature review, it is clear that very few of the previous studies have quantitatively evaluated IPD projects. Most studies are case studies that show one or more situations in which IPD was successful, but with no scientific comparisons. Additionally, the perceptions of industry professionals, like in the study by Kent and Becerik-Gerber (2010), do not
offer any statistical data that show superior performance of IPD. The studies that have performed comprehensive analysis comparing IPD to non-IPD, like the Cho and Ballard (2011) study and the El Asmar (2012) study, have only focused on the general contractor perspective. There are no comprehensive studies that show the effects of IPD on construction project performance for trade contractors. This study will conduct a comprehensive study of the effects of IPD but from the perspective of MEP contractors.

1.4 Methodology

The methodology for this study is characterized by three distinct stages. Stage A involves the literature review, and variable development; Stage B involves the development of the data collection tool and data collection; and Stage C involves the analysis of the data. Figure 1-12 below displays the outline of the methodology. The following paragraphs will explain this outline in detail.
1.4.1 **Step A1: Literature Review**

The first step of this study was a thorough analysis of the previous literature. The reviewed literature consisted of journals, periodicals, published books, conference proceedings, and reports from major organizations such as the American Institute of Architects (AIA), the Construction Industry Institute (CII), the Construction Users Roundtable (CURT), and the Lean Construction Institute (LCI). The full literature review can be found in *Chapter 2*.

The literature review first considered the previous IPD literature. This section helped determine the definition of IPD and the possibilities it has of improving project delivery. As previously stated, very little of the prior IPD literature performed a quantitative analysis of the effects of IPD. Those that did include analysis only considered the general contractor’s perspective. This is in part due to the newness of IPD; much of the relevant literature is case studies. Publications from AIA were especially helpful in this phase for several reasons. The first is that it presented an adequate definition of IPD. The second reason is that it provided case studies of several projects that had utilized IPD. This study surveyed many of the MEP contractors from the projects showcased in these publications.

Next, the literature review considered the previous literature on construction delivery performance. There were two reasons for reviewing this literature. The first was to determine the trends of construction delivery research. Construction management at risk and design-build are two alternative delivery methods that have existed for many years and have been the subject of much more thorough research than IPD. The trends from this past research have shown that more integrated systems relate to superior project performance. The second reason for considering this literature is to examine the independent, control, and dependent variables used in these studies. Since this study strives to be as comprehensive as possible, it will consider many of these variables from previous studies.
Through the literature review, this study identified the relevant gaps in the previous IPD and project delivery research. The objectives include identifying the effects of IPD on a variety of performance metrics for MEP contractors, developing a comprehensive metric that will predict construction project success for MEP contractors, identifying the project delivery characteristics that lead to improved construction project performance for MEP contractors, and giving recommendations on IPD to the MEP construction industries. The literature review will discuss these gaps and the objectives that they led to in detail.

1.4.2 Step A2: Variable Development

As mentioned in the previous paragraphs, Step A1 was necessary in order to develop the variables for this study. This study requires a comprehensive set of independent, dependent, and control variables that are suited for MEP contractors. Of course, this step is necessary for the following stage, gathering data.

First, the study considered possible independent variables. Independent variables are the characteristics of a project, not a measured outcome. The first major independent variable is the project delivery system. The study will compare the performance of IPD and non-IPD delivery systems. The degree of implementation of IPD principles was also an independent variable considered. These principles include the use of a single multiparty contract, the use of incentives, risk allocation, team experience, early involvement of contractors, and the use of Building Information Modeling (BIM). Also considered as independent variables was the degree of implementation of lean construction principles. Lean construction principles include the Last Planner System, 5S, Set Based Design, Value Stream Mapping, Target Value Design, and Just in Time Delivery. This report will discuss these principles further in the literature review.

Next, the study considered possible control variables. Control variables include additional characteristics of the project that are not manageable. The study needs to account for these control
variables in order to avoid skewing the data. Examples of control variables were company information, the size of project, the program, the project type, and the type of work performed.

Finally, the study considered possible dependent variables or project performance metrics. These include quantitative and qualitative data measured at the end of the project. A comprehensive list is necessary as IPD may affect more than just cost and schedule. Examples of performance metric areas included safety, cost, schedule, changes, labor productivity, communication, and others.

1.4.3 Step B1: Survey Development

With the variables from the last step defined, the next step was to develop the data collection tool used for data collection. Before being sent to industry professionals, the data collection tool was reviewed by an expert panel.

The final version of the data collection tool was fifteen pages and can be found in Appendix C. The data collection tool contained five sections: Project Characteristics and Contract, Project Performance, Project Systems, Project Team and Collaboration, and Contractor Background and Success Measures. The questions in the Project Characteristics and Contract section included questions on the delivery system used, the type of contract used, the type of compensation used, the use of incentives, and the allocation of risk. The Project Performance section inquired about safety performance metrics, cost performance metrics, schedule performance metrics, change performance metrics, labor and productivity performance metrics, communication performance metrics, and various other performance metrics. The Project Systems section included questions on project complexity, project quality, and the use of BIM on specific building systems. The Project Team and Collaboration section inquired about the experience of project team members, subcontractor selection, project management structure, timing and collaboration, technology and tools used, and the specific uses of BIM functions. Finally, the Contractor Background and Success Measures section asked about how the individual contractors defined success for the project at interest.
1.4.4 Step B2: Data Collection

After finalizing the data collection tool by incorporating relevant comments from reviewers, it was sent to MEP contractors. Since IPD projects are still very rare, a random sample would be unlikely to have any IPD projects. Therefore, this study built on the previous UW-Madison IPD research by sending the data collection tool to the MEP contractors from projects surveyed in the prior study. The previous survey from El Asmar’s study asked the general contractors for the contact information of the MEP subcontractors including a phone number and email address for someone from the company who worked closely with the project at interest. Additional projects were added as the study progressed and other IPD projects were identified. Participants were first contacted by phone before sending the data collection tool through email. In order to make comparisons, this study sampled both IPD and non-IPD projects. Multiple notices were sent to non-responders in an effort to increase the sample size. Responses to the data collection tool occurred between April 2012 and February 2013.

1.4.5 Step C1: Univariate Analysis

After data collection, but before analysis, adjustments were necessary for some of the gathered data. For example, it was necessary to adjust all cost data for time and location through ENR Cost Indices. ENR has cost indices going back over thirty years for twenty U.S. cities and two Canadian cities. In most cases, it was necessary to use the closest city to the project for which ENR had indices such as Minneapolis or Chicago for projects in Wisconsin. Additionally, metrics such as OSHA recordable or lost-time incidents, number of punchlist items, and number of RFIs had to be normalized by project cost. It was also necessary to adjust the qualitative data based on scales (a lot, some, a little, none). These variables had to be coded to numerical values in order for analysis. Chapter 3 will discuss coding data further.
The purpose of the univariate analysis was to fulfill the first objective of identifying the effects of IPD on MEP contractors. In this analysis, the study compared construction project performance metrics with project delivery system as the only independent variable. The differences between IPD and non-IPD projects were tested for significance but IPD-ish projects were not included in these tests. However, IPD-ish projects were shown graphically with IPD and non-IPD projects through strip charts. IPD-ish projects were defined as using some IPD principles, but not all. This will be discussed in greater detail in Chapter 2. The study first tested for differences between IPD and non-IPD projects for individual metrics (cost growth, unit cost) using the t-test for data that was normally distributed and the Mann-Whitney-Wilcoxon test (MWW) for data that was not normally distributed. Most of the data gathered was not normally distributed so the MWW test was used for most of the metrics. For both the t-test and the MWW test, two-sided tests were utilized to stay conservative and to minimize bias towards an expected result. The null hypothesis for every test was that IPD does not affect the metric being tested. Both of these tests produced p-values for each metric that the study used to determine significance. The p-values were distinguished by three thresholds: p-values showing evidence against the null hypothesis at the 0.01 level of significance; p-values showing evidence against the null hypothesis at the 0.05 level of significance; and p-values showing evidence against the null hypothesis at the 0.1 level of significance. P-values greater than 0.1 were considered as no conclusive evidence against the null hypothesis. Software used for the univariate analysis included R for creating the strip charts and for testing significance with the t-test and the MWW test as well as Microsoft Excel for organizing the data. The population for these tests included mechanical contractors who performed HVAC, plumbing, and fire protection as well as electrical contractors. Therefore, the data from the MEP industries were analyzed together.

Table 1-1 displays the alternative hypotheses used in the univariate analysis. As mentioned before, all t-test and MWW tests were two-sided to stay conservative and to minimize bias. Therefore, all of the alternative hypothesis statements say that IPD “affects” the metric in question
instead of IPD “increases” or “decreases” the metric in question. Overall, thirty-eight hypotheses were tested. Metrics shown in the table will be explained in Chapter 3.

Table 1-1: Hypotheses for Univariate Analysis

<table>
<thead>
<tr>
<th>Performance Category</th>
<th>Hypothesis</th>
</tr>
</thead>
<tbody>
<tr>
<td>SAFETY</td>
<td>1. IPD affects the OSHA recordable incident rate</td>
</tr>
<tr>
<td></td>
<td>2. IPD affects the OSHA recordable incidents per million dollars</td>
</tr>
<tr>
<td></td>
<td>3. IPD affects the lost-time incident rate</td>
</tr>
<tr>
<td></td>
<td>4. IPD affects the lost-time incidents per million dollars</td>
</tr>
<tr>
<td>COST</td>
<td>5. IPD affects the construction cost growth (%)</td>
</tr>
<tr>
<td></td>
<td>6. IPD affects the budget factor (%)</td>
</tr>
<tr>
<td></td>
<td>7. IPD affects the total cost growth (%)</td>
</tr>
<tr>
<td></td>
<td>8. IPD affects the unit cost ($/SF)</td>
</tr>
<tr>
<td>SCHEDULE</td>
<td>9. IPD affects the construction speed (SF/day)</td>
</tr>
<tr>
<td></td>
<td>10. IPD affects the schedule growth (%)</td>
</tr>
<tr>
<td></td>
<td>11. IPD affects the schedule intensity ($/day)</td>
</tr>
<tr>
<td>COMMUNICATION</td>
<td>12. IPD affects the RFI processing time (weeks)</td>
</tr>
<tr>
<td></td>
<td>13. IPD affects the RFIs per million dollars</td>
</tr>
<tr>
<td></td>
<td>14. IPD affects the resubmittals per million dollar</td>
</tr>
<tr>
<td></td>
<td>15. IPD affects the rework cost</td>
</tr>
<tr>
<td>QUALITY</td>
<td>16. IPD affects the systems quality</td>
</tr>
<tr>
<td></td>
<td>17. IPD affects the deficiency issues per million dollars</td>
</tr>
<tr>
<td></td>
<td>18. IPD affects the warranty cost</td>
</tr>
<tr>
<td></td>
<td>19. IPD affects the latent defect cost</td>
</tr>
<tr>
<td></td>
<td>20. IPD affects the punchlist items per million dollars</td>
</tr>
<tr>
<td></td>
<td>21. IPD affects the punchlist cost</td>
</tr>
<tr>
<td>BUSINESS</td>
<td>22. IPD affects the overhead and profit</td>
</tr>
<tr>
<td></td>
<td>23. IPD affects the image and potential for return business</td>
</tr>
<tr>
<td>LABOR</td>
<td>24. IPD affects the PPC trend</td>
</tr>
<tr>
<td></td>
<td>25. IPD affects the absenteeism cost</td>
</tr>
<tr>
<td></td>
<td>26. IPD affects the turnover cost</td>
</tr>
<tr>
<td></td>
<td>27. IPD affects whether overmanning was experienced or not</td>
</tr>
<tr>
<td></td>
<td>28. IPD affects the man-hour growth</td>
</tr>
<tr>
<td></td>
<td>29. IPD affects the percent overtime hours</td>
</tr>
<tr>
<td></td>
<td>30. IPD affects the percent shiftwork hours</td>
</tr>
<tr>
<td></td>
<td>31. IPD affects the peak man-hours divided by the average man-hours</td>
</tr>
<tr>
<td></td>
<td>32. IPD affects the direct loss of productivity due to changes</td>
</tr>
<tr>
<td>CHANGE</td>
<td>33. IPD affects the percent shiftwork due to changes</td>
</tr>
<tr>
<td></td>
<td>34. IPD affects the change order impact on schedule</td>
</tr>
<tr>
<td></td>
<td>35. IPD affects the percent overtime due to changes</td>
</tr>
<tr>
<td></td>
<td>36. IPD affects the change order impact on cost</td>
</tr>
<tr>
<td></td>
<td>37. IPD affects the percent change</td>
</tr>
<tr>
<td></td>
<td>38. IPD affect the change order processing time</td>
</tr>
</tbody>
</table>
The next portion of the univariate analysis compared IPD to non-IPD with non-IPD divided into the three main delivery systems: design-bid-build, construction management at risk, and design-build. In this analysis, the IPD-ish projects were sorted into the construction management at risk, design-build, or IPD categories, depending on the contract type between the general contractor and the owner. Just as in the portion of the analysis where IPD was compared with non-IPD, the data was in most cases not normally distributed. For this reason, the usual ANOVA method of comparing more than two different groups was not effective since this method assumes the data is normally distributed. Instead, the Kruskal-Wallis test was used to compare the four different delivery systems as this is a non-parametric test that does not require normally distributed data. In the Kruskal-Wallis test and ANOVA, the null hypothesis is that the four different groups (design-bid-build, construction management at risk, design-build, and IPD) are all the same while the alternative hypothesis is that at least one of the groups is different. The p-values from the Kruskal-Wallis and F-test used in this section were distinguished again by three thresholds: p-values showing evidence against the null hypothesis at the 0.01 level of significance; p-values showing evidence against the null hypothesis at the 0.05 level of significance; and p-values showing evidence against the null hypothesis at the 0.1 level of significance.

1.4.6 Step C2: Project Quarterback Rating Development

The purpose of developing the Project Quarterback Rating (PQR) was to fulfill the second objective of developing a comprehensive metric to predict construction project success for MEP contractors. This step combined all performance metrics into one comprehensive value. The study developed the PQR through the company success factors gathered in the Contractor Background and Success Measures of the data collection tool, which asks the respondent how their companies measure success on construction projects.
The PQR provides a great tool for the MEP construction industries as companies could use this to measure the overall success of their projects. The study used the PQR to compare between IPD and non-IPD projects and to test for significance using the t-test and MWW test. Both tests were two-sided with the alternative hypothesis that IPD affects the PQR for MEP contractors. Additionally, the Kruskal-Wallis test and the F-test were performed testing for significant differences in the performance of MEP contractors on IPD projects compared to those on design-bid-build, construction management at risk, and design-build projects separately. Just as in the univariate analysis, there are three thresholds for significance: p-values showing evidence against the null hypothesis at the 0.01 level of significance; p-values showing evidence against the null hypothesis at the 0.05 level of significance; and p-values showing evidence against the null hypothesis at the 0.1 level of significance.

1.4.7 Step C3: Input Analysis

The purpose of the input analysis was to fulfill the third objective of determining the characteristics of project delivery that lead to improved performance of the studied projects. This analysis used regression to compare the developed PQR with individual characteristics such as lump sum compensation, percent design complete when subcontractors are involved, and involvement scores. These metrics will be discussed in greater detail in Chapter 3. The regression analysis had outputs of slope coefficient, confidence intervals, and R-squared values. The slope coefficient explains the degree of impact a delivery characteristic has on the PQR with negative values indicating an indirect relationship and positive values indicating a direct relationship. The confidence intervals determine if there is a significant relationship. If the confidence interval for the slope coefficient does not include zero, there is a significant relationship between PQR and the delivery characteristic.

The delivery characteristics did include some binary variables such as yes/no questions. Instead of using regression for these binary independent variables, MWW tests were once again used
to determine if there were any differences in PQR between the two groups. These tests were two-sided with a null hypothesis that the delivery characteristic in question has no effect on the PQR and an alternative hypothesis that the delivery characteristic has an effect on the PQR. The same three significance thresholds used in earlier portions are applied to the binary delivery characteristics as well.

Additionally, the input analysis included MWW tests and t-tests to determine whether the implementation rate of the input variable by MEP contractors on IPD projects was different from those on non-IPD projects. These tests were also two-sided with a null hypothesis that the implementation rate of the delivery characteristic in question was not different between IPD and non-IPD and the alternative hypothesis that the implementation rate of the delivery characteristic was different between IPD and non-IPD.

1.5 *Research Contributions*

This research offers four contributions to the overall literature on construction and the MEP contracting industries:

1. A demonstration of the effects of IPD and other project delivery systems on a comprehensive list of individual performance metrics for MEP contractors;
2. A demonstration of the effects of IPD on overall construction project performance for MEP contractors;
3. An understanding of how several project delivery characteristics affect overall construction project performance for MEP contractors;
4. A guide for specific use by MEP contractors working on IPD projects.
1.6 Thesis Organization

Chapter 1 of this thesis acted as an introduction to the topic of IPD, the problems facing the construction industry, the motivation for this study, and the methodology used. Next, Chapter 2 will discuss a thorough review of the previous IPD literature, the previous project delivery literature, and the metrics used in these studies. Following the literature review, Chapter 3 will further discuss the variables used in this study including the 3Ts (terms, tones, and tools), performance metrics, combined variables, the coding of non-numerical variables, and dataset characteristics. Next, Chapter 4 will discuss the univariate analysis and results used to compare IPD and non-IPD projects. Then, Chapter 5 will discuss the development of the PQR and compare PQR values for IPD and non-IPD projects. Next, Chapter 6 will discuss the regression analysis and the characteristics of project delivery that result in improved construction project performance. Finally, Chapter 7 will present the conclusions and recommendations of the study. Appendix A displays the bibliography used for this study followed by Appendix B, which has a list of definitions and acronyms found in this study. Appendix C presents the data collection tool used to gather data for the study. Finally, Appendix D presents the outputs of selected functions used in the R Statistical Package.
Chapter 2 Literature Review

This chapter will discuss a thorough review of the previous literature on IPD and project delivery system comparisons. The review is divided into three main sections: (1) Integrated Project Delivery (IPD), (2) Comparing Project Delivery Systems, and (3) Key Variables. This chapter will also discuss research opportunities, research objectives, and research scope.

2.1 Integrated Project Delivery (IPD)

The American Institute of Architects (AIA) defines Integrated Project Delivery as the following (AIACC 2011):

“IPD is 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.”

The most recent definition of IPD is “a delivery system distinguished by a multiparty agreement and the very early involvement of the key participants.” (El Asmar 2012). IPD is a new approach to project delivery with a focus on an enhanced collaborative contract structure through relational contracting (Smith et al. 2011). Relational contracts are different from traditional transactional contracts in that they provide for improved communication between all participants.

Nelson (2011) offers a good example of how IPD improves communication. In traditional construction, if a surgeon at a hospital under construction needs a specific requirement for the temperature in the operating room, he or she would first need to talk to the owner representative, who would then need to talk to the architect, who would then need to talk to the MEP designer. After approval from the MEP designer, the architect would then talk to the general contractor, who would
then talk to the mechanical contractor, who would then finally talk to the contractor in charge of controls who must meet this need from the surgeon (see Figure 2-1). This complicated chain of command can be simplified if all project participants can communicate directly with each other (if the surgeon and owner representative could directly talk to the MEP designer and the controls contractor like in IPD projects).

![Figure 2-1: Complicated Communication with Traditional Transactional Contracts (Nelson 2011)](image)

Relational contracts aim to align the goals of team members while providing incentives for working together that are based on the amount of value generated for the end user (Kent and Becerik-Gerber 2010; O’Conner 2009). Essentially, if one participant earns a profit, all participants on the project will earn a profit. Examples of relational contracts used in the construction industry include the Integrated Form of Agreement (IFOA) and ConsensusDOCS300 (Smith et al. 2011).

IPD allows for better workflow throughout all phases of a project. *Figure 2-2* shows how workflow in IPD compares with the workflow in traditional construction. The main takeaway from
this figure is that with IPD, the WHO, or those doing the work (general or trade contractors), are involved very early on in the project allowing for early collaboration (Smith et al. 2011).

Figure 2-2: Workflow Comparison between IPD and Traditional Construction (Smith et al 2011)

Traditional construction (design-bid-build) has several other major issues in addition to those mentioned in the Introduction section (Matthews and Howell 2005). The first of these is that project team members, especially trade contractors, hold back good ideas when consulted during the design process. This is because they are trying to gain a competitive advantage against other trade contractors bidding for the same project. When the selected contractors arrive on the project, there is lost time when trying to implement these ideas after the design has been finalized. The second issue is that the contracting structure of traditional construction limits cooperation and innovation. When the scope of work is very specifically defined, it inhibits innovation across contract boundaries, which hurts overall performance for the project. The third issue is that there is little ability to coordinate because there is no effort to foster collaboration between different trade contractors. Finally,
traditional construction puts pressure on local optimization instead of focusing on the project as a whole. When subcontractors focus on their individual productivity at the expense of project, the overall project productivity suffers.

Several characteristics of IPD help mend these problems with traditional construction. The first of these characteristics is a multiparty relational contract. The purpose of a multiparty contract is to foster collaboration and coordination across all phases of a project (Kent and Becerik-Gerber 2010). The multiparty contract aligns the goals of all project participants by awarding financial incentives for overall performance, not individual project performance (Tommelein et al. 1999). In this way, key subcontractors are much more open to collaboration and getting the project done. As mentioned, a multiparty relational contract improves communication among all project participants (AIACC 2007b). Usually, the multiparty contract will define a core team in charge of making project decisions. This core team includes representatives from the owner, designer, general contractor, and key subcontractors (Matthews and Howell 2005).

A second characteristic of IPD projects is the early involvement of key subcontractors. Having subcontractors involved in the design of a project decreases the fragmentation between design and construction (Kent and Becerik-Gerber 2010). This is because having contractors involved in the design process makes information sharing less difficult and increases cooperation (CURT 2004). Less fragmentation helps to improve decision making in design that can increase the constructability of the facility (AIACC 2007b). This also allows subcontractors to feel free to share any ideas they have without holding information back to gain a competitive advantage (Matthews and Howell 2005).

Finally, a third characteristic of IPD is shared risk and reward. This includes shared profit pools and contingency pools (Singleton and Hamzeh 2011). All profits from the project go into a profit pool and are distributed at the end of the project based on previously arranged agreements. Along with the multiparty contract, the shared profit pool helps to align the goals of the project participants. Project participants will be looking to improve overall project performance instead of
their individual performance. Similar to the profit pool, project participants put money into a contingency pool to cover the risk before the project starts. The project participants will then share any remaining contingency at the end of the project based on previous agreements. This creates a culture in which team members are not afraid to test new and innovative ideas (Matthews and Howell 2005).

In addition to these major characteristics of IPD projects, four additional elements contribute to the integration of project delivery (Kim and Dossick 2011). The first of these is the culture of the project participants. When the cultures between project participants are in alignment, the teams’ effectiveness increases and the team is more likely to resist regressing back to traditional construction methods. The second element is the organization of the project team. Many IPD projects utilize the “Big Room” concept or co-location where all project team members work in the same space in order to build teamwork and improve collaboration. This eliminates project participants from working in their functional silos of architecture, engineering, and construction. The third element is the use of lean construction principles such as Target Value Design, Set Based Design, and Last Planner. The fourth and final element that contributes to integration is the use of Building Information (BIM) to help ease the processes of collaboration and communication between participants.

While these characteristics and elements define true IPD projects, many projects utilize some but not all of the IPD principles. Recently, a joint effort of the National Association of State Facilities Administrators (NASFA), Construction Owners Association of America (COAA), APPA: The Association of Higher Education Facilities Officers, Associated General Contractors of America (AGC) and American Institute of Architects (AIA) defined the three levels of collaboration shown in Table 2-1 below (NASFA et al. 2010). Collaboration Level 1 is where collaboration is not contractually required. Collaboration Level 2 is where some contractual collaboration is required through early participation and the use of BIM. However, a multiparty contract is not required for Collaboration Level Two. These first two levels define IPD as a philosophy and typically use
traditional project delivery methods. Collaboration Level 3 is where collaboration is required through a multiparty contract. Collaboration Level 3 is true IPD while Collaboration Level 2, where IPD principles exist but without a multiparty contract, is IPD-ish. Other notable IPD research has also defined a project that uses some IPD principles but not a multiparty contract as IPD-ish (El Asmar 2012).

### Table 2-1: Levels of Collaboration Descriptions (NASFA et al 2010)

<table>
<thead>
<tr>
<th>Level of Collaboration</th>
<th>Level One “Typical” Collaboration</th>
<th>Level Two “Enhanced” Collaboration</th>
<th>Level Three “Required” Collaboration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Philosophy or Delivery Method?</td>
<td>IPD as a Philosophy</td>
<td>IPD-ish; IPD Lite; Non Multi-Party IPD, Technology Enhanced Collaboration; Hybrid IPD; Integrated Practice</td>
<td>Multi-Party Contracting; “Pure” IPD; Relational Contracting; Alliancing; Lean Project Delivery System</td>
</tr>
<tr>
<td>Also known as…</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Delivery Approaches</td>
<td>CMR or DB</td>
<td>CMR or DB</td>
<td>IPD</td>
</tr>
</tbody>
</table>

Much of the previous IPD research has commented on the benefits of IPD and IPD-ish projects. These benefits include cost savings and early completion (Bendewald and Franta 2010; Matthews and Howell 2005; Singleton and Hamzeh 2011; Thomsen 2009) as well as other benefits such as easier application of lean construction principles (Kim and Dossick 2011; Singleton and Hamzeh 2011). Other comments on the benefits of IPD include the minimization of conflicting interests and easier problem resolution (Kim and Dossick 2011; Matthews and Howell 2005). A survey of industry professionals revealed that IPD is perceived to produce fewer change orders, more cost savings, and shorter schedules (Kent and Becerik-Gerber 2010). Finally, one source commented on characteristics of projects that make them more suitable for IPD. These characteristics include projects that are unique, projects that are apt to face changes during project delivery, and projects for which the owner is a knowledgeable and hands-on manager (Thomsen 2009). It is notable that all of these sources used IPD case studies to display the benefits of IPD but none of these sources quantitatively evaluated IPD performance.
In the last few years, a small number of studies have attempted quantitative analysis on the performance of IPD. The first of these studies showed no significant difference in performance between non-IPD projects and IPD projects, but, as will be discussed later, this study did not analyze a thorough set of project performance metrics (Cho and Ballard 2011). Another study that this paper has already discussed and will discuss in further detail later analyzed a more comprehensive set of performance metrics and showed that IPD outperforms non-IPD in terms of quality, schedule, change management, communication, and general contractor profit performance (El Asmar 2012).

2.1.1 Challenges for IPD

Even with the proven and perceived benefits mentioned on the previous pages, there are challenges for the widespread implementation of IPD. These challenges include cultural, financial, legal and technological barriers (Ghassemi and Becerik-Gerber 2011). In addition to these challenges, IPD faces opposition from organizations in the construction industry such as the Design-Build Institute of America (DBIA 2010).

Cultural barriers refer to the unwillingness of the AEC community to vary from traditional methods (AIACC 2008). Cultural barriers include cognitive impairments and adaptive challenges (Tradeline 2009). Cognitive impairments are preexisting biases of individual mindsets in the AEC industry. IPD presents a great challenge to individuals who have worked in the AEC industry for many years under the traditional method of design-bid-build (AIACC 2007b). In some cases, these individuals cannot grasp the IPD concept and are disruptive to the process. Often times peer pressure can remedy this situation but in some cases, the participant will need to be removed from the project (AIACC 2009). Adaptive challenges, on the other hand, refer to the difficulties that institutions face in implementing the large shift in philosophy that is necessary for IPD. What is required for institutions to succeed in IPD implementation is more than just applying a few IPD principles or lean construction tools. Instead, organizations need systemic cultural change to implement IPD.
successfully (Koskela et al. 2003). Institutional and political challenges are also adaptive challenges (Beck 2009). In the past, political interests have influenced efforts to modify project delivery methods in the public sector of construction. For example, many states were against the use of design-build project delivery for the public sector. Methods to break through cultural barriers include integrating project personnel by involving all contractors early, and by providing training at the project and organizational level to overcome cognitive impairments and adaptive challenges respectively (Ghassemi and Becerik-Gerber 2011). Another cultural challenge is the belief that design-bid-build is the best choice financially. As one architect said about IPD, “Dancing together and singing Kumbaya doesn’t get my client the best price … I just don’t get it,” (ENR 2010). The problem with this statement is, while design-bid-build delivers the best initial cost, IPD is better at providing value to the owner in the form of improved lifecycle costs (Ballard 2008).

Less of an issue than cultural barriers, financial barriers refer to the challenge of selecting compensation and incentive structures that align with the distinguishing traits of a project and its participants (AIACC 2010). Budgeting the team effort can be a challenge for project teams on IPD projects (AIACC 2011). Project teams struggle with how to quantify the efforts of contractors in the design phase so that they can be appropriately compensated (Matthews and Howell 2005). IPD team members typically only gain incentives for cost reductions after the budget is developed, so much of the contractors’ efforts in the design phase go unrewarded, although the owner still reaps the benefits of this process. Another financial barrier to lean construction and IPD is the incorrect mindset that design-bid-build will result in lower costs. As mentioned in the previous paragraph, design-bid-build may result in lower initial costs, but it does not reduce complete lifecycle costs (Ballard 2008). A method to overcome financial barriers to IPD is to use compensation structures such as profit pooling and contingency pooling (Ghassemi and Becerik-Gerber 2011). By sharing profits, it insures that contractors are fairly compensated for their efforts in the design phase as long as those efforts help
lead to cost savings for the project. Additionally, education of owners on cost and other benefits of IPD versus design-bid-build will surely pave the way for further implementation.

A serious barrier to the widespread implementation of IPD is the issue of IPD in public sector projects. In most instances, laws restrict the use of IPD for public construction projects since public projects bid competitively to avoid misuse of public funds (Ghassemi and Becerik-Gerber 2011). Since projects are awarded on a low bid basis after the design is complete, there is no chance for the early involvement of key contractors. Laws also forbid the use of multiparty contracts in public sector construction. A solution to this issue is to use design-build (where design-build is allowed in public projects) while still implementing many IPD principles (DBIA 2010; Ghassemi and Becerik-Gerber 2011). By using design-build, owners could still be involved in the project. Additionally, many important factors from the Integrated Form of Agreement can still be included such as risk and reward sharing, lean processes, and collaboration (Darrington 2011). This method has worked in the past for projects such as the St. Olaf College Fieldhouse Project (Ballard and Reiser 2004).

The final barrier impeding the widespread adoption of lean construction and IPD is technological barriers. Technological barriers refer to the legal challenges of ownership and the interoperability concerns for integrated use of technology on IPD projects (Ghassemi and Becerik-Gerber 2011). Even with the benefits that BIM brings to IPD projects, there are major concerns. The first is ownership of the model. These concerns involve who (architect, engineer, or contractor) has the right to make changes to the model. Some BIM software, such as Autodesk Revit, already has solutions to ownership issues through worksets. Through worksets, project participants can claim certain elements in a model (such as a structural column, window or ductwork), which will then not allow anyone else to make changes to those elements. A second issue involves interoperability concerns (Bendewald and Franta 2010). These concerns arise from small trade contractors not yet having BIM and 3D modeling capabilities, but instead, still using 2D modeling such as AutoCAD. When some of the subcontractors do not have BIM capabilities, it makes collaboration more difficult.
This is a major concern for the industry since in 2002, the U.S. AEC industry suffered $15.8 billion in interoperability costs (Gallaher et al. 2004). Interoperability concerns remain an issue that BIM users must work through on IPD projects. Research that shows how BIM has positively affected MEP construction may be instrumental in leading trade contractors to pursue BIM capabilities (Boktor et al. 2013).

For pure IPD to become more common in the construction industry, these hurdles must be addressed. If not, owners will continue to choose traditional or IPD-ish approaches without reaping the full benefits of IPD.

2.1.2 IPD and Lean Construction

One cannot give a complete summary of IPD without mentioning lean construction as the two go hand-in-hand. From the Lean Construction Institute (LCI) website, lean construction is a management based approach to project delivery that extends from the objectives of lean production, which are to maximize value and minimize waste (LCI 2012). Lean principles were developed in the manufacturing industry of Japan, but quickly spread to other geographic locations and to other fields such as business, education, and construction (Koskela 1992). Manufacturers implemented lean principles through a five step process: (1) specify value through the eyes of the customer; (2) identify the value stream; (3) make the value adding activities flow; (4) allow customers to pull; (5) pursue perfection (Womack and Jones 1996). Table 2-2 below shows the eight forms of waste that exist in traditional manufacturing and construction processes (Liker 2004; Niesen 2012).
Table 2-2: Eight Wastes (Liker 2004; Niesen 2012)

<table>
<thead>
<tr>
<th>Waste</th>
<th>Definition</th>
<th>Traditional AEC Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>Overproduction</td>
<td>• Producing items for which there are no orders</td>
<td>In DBB, the entire design is complete before the contractor is brought on board. This is overproduction since the contractor does not need 100% complete design documents to start construction.</td>
</tr>
<tr>
<td></td>
<td>• Not using pull</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• The principle waste</td>
<td></td>
</tr>
<tr>
<td>Waiting</td>
<td>• Workers not using time effectively</td>
<td>Workers waiting for the previous step to finish or waiting for a response to an RFI.</td>
</tr>
<tr>
<td></td>
<td>• Waiting for next process, shipment, etc.</td>
<td></td>
</tr>
<tr>
<td>Unnecessary Transportation of Materials</td>
<td>• Carrying work in progress (created from overproduction) across plant or site</td>
<td>When materials for a construction project are ordered in large bulks, not all of the material will be installed immediately. The remaining material must be stored somewhere. Workers waste time transporting materials in and out of storage.</td>
</tr>
<tr>
<td></td>
<td>• Moving materials in and out of storage</td>
<td></td>
</tr>
<tr>
<td>Incorrect Processing</td>
<td>• Any effort that does not add value in the eyes of the customer</td>
<td>For foundations, all the owner is worried about is if it is structurally sound. Any effort spent on making the foundation aesthetically pleasing is waste since it does not add value from the customer’s perspective.</td>
</tr>
<tr>
<td>Excess Inventory</td>
<td>• Producing more than what is necessary</td>
<td>If a downstream process takes longer to complete than a prerequisite activity, many times the first activity will produce more than what is necessary. Instead, the two activities should balance their workload so they take the same amount of time to complete.</td>
</tr>
<tr>
<td>Unnecessary Movement of Employees or Equipment</td>
<td>• Usually caused by poor plant or site layout</td>
<td>Workers walking across a construction site to use the restroom or look for a set of plans.</td>
</tr>
<tr>
<td></td>
<td>• Similar to waiting waste</td>
<td></td>
</tr>
<tr>
<td>Defects</td>
<td>• Result from any rework or inspection</td>
<td>Punchlist items or rework in the design process.</td>
</tr>
<tr>
<td></td>
<td>• Lean focuses on getting the job done right the first time</td>
<td></td>
</tr>
<tr>
<td>Underutilization of People</td>
<td>• Not utilizing the physical, mental, and creative abilities of employees</td>
<td>Designers not valuing the opinion of contractors during the design phase.</td>
</tr>
</tbody>
</table>

Lean in the construction industry accomplishes the goals of maximizing value and minimizing waste through a set of lean tools shown in Figure 2-3 below. Last Planner is a production planning control system implemented to improve planning performance (Cho and Ballard 2011). The primary principles of Last Planner are pull scheduling (only completing tasks that are required by downstream tasks), reliable promising (measured by percent plan complete or PPC), and continuous learning (Ballard and Howell 2003). Target Value Design, as defined by AIA, is “the process of establishing early financial targets for the project and then designing to an associated
detailed estimate rather than estimating a detailed design. Iterative in nature, ” (AIACC 2007b). Target Value Design includes the target cost as a design constraint and eliminates rework in design (Ballard and Reiser 2004; CII 2007). Set Based Design examines multiple design alternatives while keeping the design space open for as long as possible allowing for a more informed decision (Deshpande et al. 2012). When using Set Based Design, it is important to make design decisions at the last responsible moment (Hansen and Olsson 2011). Value Stream Mapping involves creating a map of all activities required to create a product or service (Yu et al. 2009). Value Stream Mapping makes it simple to recognize the activities that add value and the activities that do not add value (CII 2005). Just In Time Delivery delivers the right items at the right time in the right amount (CII 2007). By using pull philosophy, upstream activities only produce when the next activity needs it to (Womack and Jones 1996). This creates shorter lead times and the elimination of work in progress (Koskela 1992; Liker 2004). However, not all work in progress can be eliminated. Small buffers are necessary between activities in construction in order to be reliable (Sakamoto et al. 2002). 5S is an approach to achieve organization, cleanliness, and standardization on a construction site (CII 2007). This includes five steps (Salem et al. 2005): (1) Sort, or separating needed tools or parts from unneeded materials; (2) Set in Order, or arranging tools and materials for ease of use; (3) Shine, or make sure the workplace is always in good condition through use of a cleaning plan; (4) Standardize, or create steps to maintain the first three elements; (5) Sustain, or never letting the job site regress back to the norm. At the center of all the previously mentioned lean tools, is continuous improvement (Liker 2004). Just like IPD, lean construction requires more than applying a set of tools; a large shift in philosophy is necessary.
Lean Construction and IPD go hand-in-hand because lean construction and IPD strive for the same outcome of maximizing value and minimizing waste (Kim and Dossick 2011; NASFA et al. 2010). IPD can minimize waste in several ways. IPD can reduce litigation by promoting resolution of disputes internally instead of in courts. This reduces the amount of overhead needed for liability insurance, which does not add value to a project but is still something the customer has to pay for (Thomsen 2009). The early involvement of general contractors and trade contractors required by IPD reduces the waste of rework and underutilized people. If trade contractors come to the project late, any ideas they have to improve design and constructability will have to be added to the design after its completion, resulting in rework (Matthews and Howell 2005). If the design team instead decides not to rework the design, then they are underutilizing the skills and knowledge of the trade contractors. In addition to removing waste, IPD can also add value to a project. With IPD, the
project team stays focused on overall project goals instead of individual performance, causing overall improved project performance. This is because the integrated agreement creates financial incentives aligned with overall project performance instead of individual performance, as is the practice in a traditional contract agreement (Matthews and Howell 2005). IPD can also add value to the customer through improved risk allocation. When trade contractors bear most of the risk on projects, as they do with traditional risk allocation, they lose their ability to try new and innovative methods. Poor risk allocation prevents designers from creating innovative designs or builders from using new building methods. Furthermore, risk aversion in the traditional delivery methods drive non-collaborative behavior (CURT 2004). If the project team shares the risk, like in IPD, participants feel more comfortable with trying new and innovative methods.

### 2.2 Comparing Project Delivery Systems

The previous section of the literature review highlighted prior research on the subject of IPD. However, most of this prior IPD literature did not attempt a quantitative evaluation of IPD performance. This next section will examine previous construction literature that compared different project delivery systems. Most of the studies in this section compared design-bid-build with design-build and/or construction management at risk. These studies used a variety of different metrics to make comparisons.

Pocock et al. (1996) hypothesized that projects perform better with increased interaction between project participants. The authors of this study developed a formula for Degree of Interaction (DOI) based on the following variables: phase when designers and builders first had direct contact, the number of persons involved in the interaction, the job title for each person involved in the interaction, approximate hours per month each person spent in interaction, how many months the interaction occurred, and whether the interaction was planned or in response to a problem. The authors analyzed three metrics, cost growth, schedule growth, and number of modifications. The
study examined design-bid-build, design-build, partnering, and combination projects (which consisted of a combination of the other three methods). The results showed that the combination projects had the highest DOI, partnering had the second highest DOI, design-build had the third highest DOI, and design-bid-build had an extremely low DOI. Regression analysis showed that with a higher DOI, average cost growth remained the same, average schedule growth decreased, and the number of modifications per million dollars decreased. The results of this study showed that projects with more integration should expect better performance in schedule and change metrics.

Konchar and Sanvido (1998) followed this study with a study of their own comparing design-bid-build, design-build, and construction management at risk delivery systems in terms of cost, schedule, and quality metrics. The univariate results for this study showed that design-build performed best in all cost and schedule metrics while design-bid-build performed worst. Construction management at risk outperformed design-build in most quality metrics but design-build still performed better than design-bid-build projects for all quality metrics. *Table 2-3* below shows a multivariate analysis for the same study. The results showed design-build performed the best for all metrics, while design-bid-build performed the worst in all metrics except for cost growth. The results from this study validate the previous research by Pocock et al. (1996) since design-build and construction management at risk are more integrated delivery methods than design-bid-build.

<table>
<thead>
<tr>
<th>Multivariate Model</th>
<th>DB versus CMR (%)</th>
<th>CMR versus DBB (%)</th>
<th>DB versus DBB (%)</th>
<th>R²</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unit Cost</td>
<td>4.5 less</td>
<td>1.5 less</td>
<td>6 less</td>
<td>0.99</td>
</tr>
<tr>
<td>Construction Speed</td>
<td>7 faster</td>
<td>6 faster</td>
<td>12 faster</td>
<td>0.89</td>
</tr>
<tr>
<td>Delivery Speed</td>
<td>23 faster</td>
<td>13 faster</td>
<td>33 faster</td>
<td>0.87</td>
</tr>
<tr>
<td>Cost Growth</td>
<td>12.6 less</td>
<td>7.8 more</td>
<td>5.2 less</td>
<td>0.24</td>
</tr>
<tr>
<td>Schedule Growth</td>
<td>2.2 less</td>
<td>9.2 less</td>
<td>11.4 less</td>
<td>0.24</td>
</tr>
</tbody>
</table>

Thomas et al. (2002) continued the research on differing project delivery systems by comparing performance of design-bid-build and design-build projects from the perspective of both
owners and contractors in terms of cost, schedule, safety, changes, and rework metrics. The results showed that design-build performed better than design-bid-build for both owners and contractors in terms of cost, changes, and rework metrics. For schedule metrics, design-build was preferred for owners while contractors preferred design-bid-build. Safety metrics yielded no significant results. This study further validated the work of Pocock et al. (1996) and Konchar and Sanvido (1998).

Ibbs et al. (2003) also compared design-build and design-bid-build projects in terms of cost, schedule, and productivity performance metrics. The results from this study showed that design-build performed significantly better in schedule metrics but not significantly better for cost and productivity metrics. The authors of this study concluded that design-build did not perform as well as expected but this study still validated previous studies that determined design-build performed better for schedule metrics.

Debella and Ries (2006) compared public school construction projects that used multi-prime systems and single prime systems. The authors studied quantitative metrics such as schedule, cost, change orders, and number of litigation cases as well as various qualitative metrics. The only significant result from this study was that single prime systems had much smaller number of litigation cases when compared with multi-prime systems.

Similar to the prior study, Rojas and Kell (2008) studied school construction projects in the Pacific Northwest. This study compared design-bid-build and construction management at risk but only considered cost metrics. The results showed that change order performance did not significantly improve from design-bid-build. Other results showed that only 25% of construction management at risk projects finished at or below the guaranteed maximum price (GMP) and that construction management at risk was not effective at minimizing cost growth. The study concluded that expected benefits of construction management at risk were not materializing.

The comparisons of different project delivery systems continued with Hale et al. (2009). This study compared design-bid-build and design-build projects for U.S. Navy Bachelor Enlisted Quarters
projects considering cost and schedule metrics. The results showed that design-build performed significantly better than design-bid-build in one cost metric (cost growth) and all of the schedule metrics.

In another project delivery comparison for military construction projects, Rosner et al. (2009) compared design-build and design-bid-build for Air Force construction projects. The study considered cost, schedule and modification performance metrics. The results from this study showed that design-build outperformed design-bid-build in cost and modification metrics but not in schedule metrics. This result does not agree with the previous research, most of which found that design-build performed significantly better in schedule performance than design-bid-build.

Korkmaz et al. (2010) studied important metrics for sustainable building project delivery. The study concluded that the timing of contractor involvement in projects is a strong process indicator affecting many performance outcomes. Once again, this follows the previous research, which has shown that projects with a higher level of integration and collaboration between designer and builder result in superior project performance.

Up until this point, the review of the literature has not mentioned comparisons of IPD with other delivery systems. Furthermore, the IPD literature that did exist before 2012 did not demonstrate superior performance for IPD projects. Cho and Ballard (2011) was the first study that attempted to quantitatively evaluated IPD performance. The authors had three hypotheses. The first was that if a project implements Last Planner, it achieves better project performance. The independent variable for this hypothesis was the degree of implementation of Last Planner. The authors determined this variable by examining the project’s use of pull planning, the project’s lookahead process, how well the project team learned from breakdowns, the project’s use of phase scheduling, and the amount of distributed control for the project. The dependent variable was determined through cost and schedule performance metrics. The second hypothesis stated that if a project adopts IPD, its performance is different from other projects. The independent variable for this hypothesis was the degree of
implementation of IPD while the dependent variable used the same project performance metrics as the dependent variable for the first hypothesis. Finally, the third hypothesis stated that if a project adopts IPD, its degree of implementation of Last Planner is different from other projects. The independent variable for this hypothesis was the degree of implementation of IPD (same as the independent variable from the second hypothesis) and the dependent variable was the degree of implementation of Last Planner (same as the independent variable from the first hypothesis). The results from this study showed the first hypothesis was significant but the second and third hypotheses were not. The authors concluded that IPD did not have significant effect on the variables studied but suggested that future research should continue to study this claim.

El Asmar (2012) followed in the footsteps of Cho and Ballard (2011). While Cho and Ballard (2011) only considered two project metrics, the author of the more recent study realized that IPD had the potential to affect many project performance metrics. Metrics included in this study were cost, schedule, safety, changes, productivity, communication, and many other performance metrics. The author found that IPD performed significantly better than non-IPD projects for quality metrics (quality of building systems, number of deficiency issues, number and cost of punchlist items, and cost of warranty), one schedule metric (delivery speed), change performance metrics (reductions in design-related changes and reduction in change order processing time), communication metrics (less resubmittals, less RFIs, and faster processing time for RFIs) and the metric of general contractor profit. The author also developed a comprehensive performance metric for general contractors to gauge construction project success. The author called this the Project Quarterback Rating (PQR) and it included customer satisfaction, safety, budget, profit, quality, schedule, and communication metrics. The research showed that IPD projects tend to have higher values of PQR. Further research showed that of the non-IPD projects surveyed (DBB, CMR, and DB), the more integrated projects had higher values of PQR. Figure 2-4 shows this comparison of PQR values between different project deliver systems.
Table 2-4 below summarizes the previous literature that compared different project delivery systems. The table shows the delivery systems compared, the type of metrics studied, and the results. From the table, the previous literature shows that more integrative and collaborative delivery systems, design-build, construction management at risk, and IPD tend to perform better.
Table 2-4: Summary of Literature Comparing Different Project Delivery Systems

<table>
<thead>
<tr>
<th>Study</th>
<th>PDS Compared</th>
<th>Performance Metric Categories</th>
<th>Findings</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pocock et al. 1996</td>
<td>DBB, DB, Partnering</td>
<td>Cost, Schedule, Changes</td>
<td>Projects with higher DOI, performed better for schedule and modification metrics.</td>
</tr>
<tr>
<td>Konchar and Sanvido 1998</td>
<td>DBB, DB, CMR</td>
<td>Cost, Schedule, Quality</td>
<td>DB performed best in all cost and schedule metrics and most quality metrics. DBB performed worst in all cost and schedule metrics.</td>
</tr>
<tr>
<td>Thomas et al. 2002</td>
<td>DBB, DB</td>
<td>Cost, Schedule, Safety, Changes, Rework</td>
<td>DB performed best for owners and contractors in cost, changes and rework metrics. DB performed best for owners in schedule metrics. DBB performed best for contractors in schedule metrics.</td>
</tr>
<tr>
<td>Ibbs et al. 2003</td>
<td>DBB, DB</td>
<td>Cost, Schedule, Productivity</td>
<td>DB performed better than DBB in schedule metrics.</td>
</tr>
<tr>
<td>Debella and Ries 2006</td>
<td>Multiple Prime, Single Prime</td>
<td>Schedule, Cost, Changes, Litigation Cases</td>
<td>Single prime performed significantly better for litigation metrics.</td>
</tr>
<tr>
<td>Rojas and Kell 2008</td>
<td>DBB, CMR</td>
<td>Cost</td>
<td>Only 25% of CMR projects finished at or below GMP. DBB was better in cost performance.</td>
</tr>
<tr>
<td>Hale et al. 2009</td>
<td>DBB, DB</td>
<td>Cost, Schedule</td>
<td>DB performed better for all schedule metrics and some cost metrics.</td>
</tr>
<tr>
<td>Rosner et al. 2009</td>
<td>DBB, DB</td>
<td>Cost, Schedule, Changes</td>
<td>DB was better in cost and change metrics while DBB was better in schedule metrics.</td>
</tr>
<tr>
<td>Korkmaz et al. 2010</td>
<td>General Study</td>
<td>Cost, Schedule, Quality, Safety, LEED</td>
<td>Determined that timing of contractors’ involvement was significant in improving metrics.</td>
</tr>
<tr>
<td>Cho and Ballard 2011</td>
<td>IPD, non-IPD</td>
<td>Cost, Schedule</td>
<td>IPD did not perform significantly better than non-IPD metrics.</td>
</tr>
<tr>
<td>El Asmar 2012</td>
<td>IPD, non-IPD</td>
<td>Cost, Schedule, Safety, Changes, Productivity, Communication, Quality</td>
<td>IPD performed better in quality, schedule, changes, and communication metrics</td>
</tr>
</tbody>
</table>

2.3 Key Variables

The previous section of the literature review summarized the findings of previous studies comparing different project delivery systems. This section will take a closer look at the metrics used in these studies as well as the metrics from a few additional studies. The section will begin with a discussion on the previous performance metrics or dependent variables used followed by a discussion of the independent and control variables considered in previous research.
2.3.1 Performance Metrics

Revisiting Pocock et al. (1996), this study analyzed cost, schedule, and modification metrics to compare design-bid-build, design-build, and partnering. This study did not consider multiple metrics within these categories, but only analyzed cost growth, schedule growth, and modifications per million dollars.

Konchar and Sanvido (1998) studied more metrics under the cost, schedule, and quality categories to compare design-bid-build, design-build, and construction management at risk delivery systems. The cost metrics considered were unit cost (per area), cost growth measured by the percent difference between the final project cost and the contract project cost, and cost intensity, which is essentially the unit cost per time. Schedule metrics considered were construction speed (area per unit time) and schedule growth measured by the percent difference between total duration and the total planned duration. Finally, quality included turnover quality measures (high, medium, or low coded to ten, five, or zero respectively) and system quality measures (did not meet expectations, met expectations, or exceeded expectations coded to zero, five, or ten respectively).

Chan et al. (2002) did not compare different project delivery systems, but the authors did examine all previous literature on construction project performance metrics used for design-build projects. The authors divided the metrics into objective measures, which included schedule, cost, safety, and profitability, as well as subjective measures, which included quality, technical performance, functionality, satisfaction of all participants, and environmental sustainability. Schedule metrics included schedule overrun in units of time, construction time, and construction speed. Cost metrics included cost overrun in dollars and unit cost. Safety and profitability categories only included one metric each, injury/accident rate per 1,000 workers and net revenue divided by total costs respectively. Quality metrics included conformity with expectations, administrative burden, and overall satisfaction. Technical performance included clearly defined project scope while functionality included conformance to technical performance. This study was essentially repeated by Lam et al.
(2008). The more recent study added quality metrics to the objective criteria and added aesthetics and reduction in disputes to the subjective criteria.

Revisiting Thomas et al. (2002), the authors considered cost, schedule, safety, changes, and rework metrics to compare design-bid-build and design-build. Cost metrics included cost growth and budget factor, the latter of which is the ratio of actual cost to estimated cost. Schedule metrics included project schedule growth, schedule factor (ratio of actual duration to estimated duration), total duration, and construction duration. Safety metrics included the recordable incident rate and lost workday incident rate. Changes and rework consisted of one metric each, change cost factor (ratio of total cost of changes to actual construction cost) and total field rework factor (ratio of total direct cost of field rework to actual construction cost) respectively.

Ibbs et al. (2003) also compared design-bid-build and design-build and considered cost, schedule, and productivity metrics. Cost metrics included change in total cost, change in design cost, and change in construction cost, all measured in percent. Schedule metrics were very similar and included change in total schedule duration, change in design duration, and change in construction duration all measured in percent difference from planned. The only productivity metric studied was earned labor hours divided by expected labor hours.

Hanna et al. (2004) did not compare different project delivery systems, but the authors studied the effect of project changes for MEP construction. The authors defined delta as the difference between actual labor hours to complete the project and the estimated base hours, plus approved change order hours. The authors identified several performance metrics that led to higher delta, including high peak manpower, long change order processing time, high absenteeism, high turnover, and the use of overmanning. The authors also identified performance metrics that led to a lower delta. These included more change orders initiated by owners and more change order hours approved by owners. A similar study repeated the same methodology but for small, labor intensive projects and led to similar results (Hanna and Gunduz 2004).
Debella and Ries (2006) considered quantitative and qualitative metrics for comparing single prime and multi-prime systems. Quantitative metrics included construction speed, unit cost, cost growth, construction schedule growth, percent change order (total change order cost divided by actual total cost), and number of litigation cases. Qualitative metrics included length of punchlist, difficulty of facility startup, level of callbacks after owner occupancy, level of administrative burden, project team communication, and project team chemistry.

Menches and Hanna (2006) surveyed project managers to study the performance metrics that project managers thought were most important in determining construction project success. These important metrics included actual percent profit, percent schedule overrun, time given to complete work, communication between team members, budget criteria, and percent change measured with work hours.

Rojas and Kell (2008) only used cost metrics in their comparison of design-bid-build and construction management at risk projects. The cost metrics considered were unit cost (per unit area), bid growth in dollars and percent, change order growth in dollars and percent, and project growth in dollars and percent. Obviously, the change order growth metrics would fall under the change category that much of the previous literature has studied.

Rankin et al. (2008) considered a vast number of metrics for determining construction project performance in a proposal to the Canadian Construction Industry. These metrics include cost, schedule, quality, safety, scope, innovation, and sustainability metrics. Cost metrics included design cost growth in percent, construction cost growth in percent, unit cost, cost of defects, and cost in use (operating expenses). Schedule metrics included design schedule growth in percent, construction schedule growth in percent, time per unit, and time spent defects. Quality metrics included client satisfaction with product, client satisfaction with design, client satisfaction with construction, quality issues at end of construction, and warranty issues. The authors asked survey participants to rank quality metrics one through seven with one being extremely dissatisfied and seven being extremely
satisfied. Safety metrics included the reportable incident rate and the lost-time accident rate. Scope metrics involved change order metrics, which included percent cost for an owner initiated change order, percent cost for changes from the contract, the percent time change for an owner initiated change order, and the percent time change for a change in the contract. The innovation metrics included deviations from the normal procurement, technological, and management processes. The authors asked survey participants to measure innovation metrics on a scale from one to five, with one being incremental and five being radical. Finally, sustainability metrics included design and construction sustainability.

Hale et al. (2009) used cost and schedule metrics to compare design-bid-build and design-build projects for Navy projects. Cost metrics included a unit cost (cost per bed) and cost growth in percent. Schedule metrics included total project duration, construction duration, unit time (time per bed), and time growth measured in percent.

Rosner et al. (2009) compared design-bid-build and design-build for Air Force projects using cost, schedule, and change performance metrics. Cost metrics included unit cost and cost growth. Schedule metrics included schedule growth and total project duration. Modifications per million dollars was the only change performance metric studied.

Cho et al. (2010) did not complete a comparison but determined several metrics to use to compare project delivery systems including IPD. These metrics included cost performance, schedule performance, safety factors, defects, and subjective satisfaction. However, when Cho and Ballard (2011) made their comparison between IPD and non-IPD projects, they only considered cost reduction ratio and duration reduction ratio (essentially cost growth and schedule growth in percent).

El Asmar (2012) included a wide range of metrics for his comparison of IPD and non-IPD projects. These included cost, quality, safety, labor, material waste, business, communication, schedule, and change metrics. Cost metrics included unit cost, construction cost growth, budget factor (percent change of initial construction cost to original estimate – essentially bid growth used in
Rojas and Kell (2008), and overall project cost growth. Quality metrics included systems quality (foundation, structure, mechanical systems, etc.), deficiencies per million dollars, and punchlist items per million dollars. Safety measures included recordable incident rate and lost-time incident rate. For labor metrics, the author used labor factor, which is self-total cost divided by self-labor cost. For a material waste metric, the author used material waste in tons per million dollars. The author measured business metrics by the percent of overhead and profit, as well as the company’s image after project completion. Communication metrics included RFI s per million dollars, RFI processing time, and resubmittals per million dollars. Schedule metrics included construction speed, delivery speed, construction schedule growth, delivery schedule growth, and schedule intensity (the average dollar value of construction work completed per day, same as cost intensity in Konchar and Sanvido (1998)). Finally, changes metrics included the total number of modifications and the change order processing time. Recall that the author also developed a comprehensive performance metric for general contractors to gauge construction project success called the Project Quarterback Rating or the PQR. The author used many of the metrics mentioned earlier in this paragraph to develop the formula for this comprehensive metric including customer satisfaction, project safety, project schedule, project cost, project quality, financial metrics, and communication and collaboration.

Table 2-5 shows the summary of metrics used in previous literature to determine construction project performance. Studies that included IPD projects are shown in bold. It is clear that much of the literature to date has focused heavily on cost and schedule metrics but El Asmar (2012) considered a full, comprehensive list of performance metrics.
### Table 2-5: Summary of Previous Project Performance Literature

<table>
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</thead>
<tbody>
<tr>
<td><strong>Cost Metrics</strong></td>
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<tr>
<td>Cost Growth (%)</td>
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<tr>
<td>Unit Cost</td>
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<td>Cost Intensity</td>
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2.3.2 Independent and Control Variables

The previous section described the construction project performance metrics or dependent variables of earlier studies. This section will discuss the independent and control variables found in previous literature. Clearly, many of the previous studies identified project delivery system as an independent variable but there are other independent and control variables important for consideration.

Chan et al. (2004) considered the factors affecting the success of a construction project. The authors divided these factors into five categories: project related factors, procurement related factors, project management factors, project participants related factors, and external factors. Figure 2-5 below gives a description of the many factors in each of these categories. Research from other studies considered project size, percent design complete before construction entity joins team, and project participant (owner, designer, contractor, and subcontractor) experience with similar facilities (Konchar and Sanvido 1998; Korkmaz et al. 2010).

![Figure 2-5: Factors Affecting Project Success (Chan et al 2004)](image)
The most recent research on the subject divided independent and control variables into three categories, terms, tones, and tools or the 3Ts (El Asmar 2012). The motivation for these categories came from the triple bottom line (Elkington 1998), which includes the following factors: social (tone), or the culture of the project team; economic (terms), or the financial and legal terms for the project; physical (tools), or the management of a project on day-to-day basis. El Asmar used this for the basis of the independent and control variables in his study. The terms included variables such as the project delivery system, the compensation structure, incentives, risk allocation, fiscal transparency and team selection. The tone included team experience (with construction type, construction size, delivery system, and BIM), the experience of the general contractor / construction manager with all stakeholders, the project management structure, and stakeholder involvement. Finally, tools included lean construction principles and BIM.

Section 2.3 of the literature review discussed the many variables that previous research used in their studies of construction performance. The independent, dependent, and control variables used in this study will be discussed in the next chapter.

2.4 Research Opportunities

The literature review was helpful in gaining an understanding of IPD and previous project delivery comparisons. The literature review was also helpful in identifying gaps that this research will fill. Through a thorough review of the literature, it is apparent that there is a lack of studies that quantitatively evaluated IPD performance. Most IPD literature has discussed the benefits and challenges of IPD through case studies, which do not show any statistical evidence of superior construction project performance. The majority of the literature that does actually compare differing project delivery systems typically only compares design-bid-build, design-build, and construction management at risk through cost and schedule metrics. There are, of course, exceptions. Cho and Ballard 2011 was the first study to statistically compare IPD and non-IPD projects, but this study was
extremely limited in construction project performance metrics. El Asmar (2012) considered a very comprehensive list of performance metrics to compare IPD and non-IPD projects and showed that IPD does outperform non-IPD in certain metrics from the general contractor or construction manager perspective. Therefore, there is a gap in the literature concerning the effects of IPD on trade contractors, specifically MEP trade contractors. Additionally, no previous studies have shown which project delivery characteristics affect overall performance for MEP contractors.

2.5 Research Objectives

This study will evaluate the performance of IPD projects in comparison with design-bid-build, construction management at risk, and design-build projects from the perspective of MEP contractors. The research will consider a comprehensive list of performance metrics as well as independent and control variables. Specific objectives are as follows:

1. Compare performance of IPD projects and IPD-ish projects to non-IPD projects from the perspective of MEP contractors. This research will show if IPD provides MEP contractors with superior performance that is worth the efforts to implement IPD;

2. Use a comprehensive measure of construction project performance to compare IPD to non-IPD for MEP contractors. MEP construction companies will be able to use this metric on their own projects;

3. Determine which project delivery characteristics are responsible for improved construction project performance for MEP contractors through regression analysis and;

4. Provide recommendations on IPD to the MEP construction industries.
2.6 **Research Scope**

The scope for this study is constrained by the data gathered. The projects surveyed for this research were mostly private sector projects. As mentioned earlier, legal issues prevent public projects from utilizing IPD in some cases. Private owners are much more willing to try innovative processes for their built facilities, especially in the healthcare industry (Lichtig 2005). An exception to this is that some data came from projects on public universities, which may have received funding from private sources.

For similar reasons, much of the data gathered came from vertical construction projects. This is because IPD projects are typically high-scale, complex building construction projects. This research did not target horizontal construction since they are mostly concerned with roads and bridges. These types of projects often fall under the public sector, and, for reasons described in the previous paragraph, cannot deliver projects using IPD in most cases.

This research gathered data from projects completed within the last seven years in order to make a fair comparison between IPD and non-IPD projects. Of course, the analysis of the cost data used cost adjustments to consider projects from different years and locations. Additionally, the data gathered for this study was strictly from the MEP contractors’ perspective.

The literature review helped to understand the previous research completed on IPD and project delivery systems as well as identify gaps that this research can fill. *Chapter 3* will discuss the independent variables, control variables, and performance metrics used for this study on MEP contractors. Additionally, *Chapter 3* will present the characteristics of the data gathered.
Chapter 3  Variables Based on the 3Ts and Dataset

Characteristics

Chapter 2 discussed the previous literature on IPD and construction project performance noting the different performance metrics used by the authors in those studies. With the literature review completed in Chapter 2 as a foundation, Chapter 3 will discuss the performance metrics used in this study as well as the independent variables in terms of the 3Ts: tone, terms, and tools. The last section of Chapter 3 will describe the characteristics of the data gathered for this study.

3.1 Independent Variables

The independent variables in this study are based on the 3Ts as defined by El Asmar (2012). The 3Ts are tone, terms, and tools. The tone refers to the social aspects of the project and the culture of the project team including team experience, vocabulary used, accountability, and the timing and degree of stakeholder involvement. The terms refer to the economic aspects of the project including procurement, contract type, compensation, incentives, and risk management. Finally, the tools refer to the physical aspects of the project and the management of the project on a day-to-day basis including the use of BIM and lean construction principles.

Shown in Table 3-1 through Table 3-3 are the independent variables included under tone, tools, and terms respectively. The tables are divided into three columns: the 3T (tone, tools, or terms), the intermediate level, and the survey level. The survey level column refers to the questions asked in the data collection tool that can be found in Appendix C.
<table>
<thead>
<tr>
<th>3T</th>
<th>Intermediate Level</th>
<th>Survey Level</th>
</tr>
</thead>
<tbody>
<tr>
<td>Past Team Experience: Construction Type</td>
<td>CM/GC</td>
<td>Subcontractors</td>
</tr>
<tr>
<td></td>
<td>Owner</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Architect/Engineer</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Design-Build (if applicable)</td>
<td></td>
</tr>
<tr>
<td>Past Team Experience: Construction Size</td>
<td>Same as Above</td>
<td></td>
</tr>
<tr>
<td>Past Team Experience: Project Delivery System</td>
<td>Same as Above</td>
<td></td>
</tr>
<tr>
<td>Past Team Experience: BIM</td>
<td>Same as Above</td>
<td></td>
</tr>
<tr>
<td>Past Experience with Stakeholders</td>
<td>CM/GC</td>
<td>Subcontractors</td>
</tr>
<tr>
<td></td>
<td>Owner</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Past Experience as a Unit</td>
<td></td>
</tr>
<tr>
<td>Sub’s Current Experience with Stakeholders</td>
<td>Owner and Designers</td>
<td>Construction Team</td>
</tr>
</tbody>
</table>

**Project Management Structure:**

- **Project Leadership Team**
  - Number of Representatives
  - Parties Represented
  - Jointly Developed Goals
  - Collaborative Decisions
  - Periodic Reviews
  - Opinion Respected
  - Lessons Learned
  - Preplanning Meetings
  - Construction Meetings
  - Commissioning Meetings

- **Cluster Teams**
  - Portion of Project
  - Preplanning Meetings
  - Construction Meetings
  - Commissioning Meetings

- **Executive Teams**
  - Meetings
  - Conflict Authority

**Stakeholder Involvement**

- % Design Complete When Involved
- Subcontractor Familiarity
- Owner Participation
- Involvement of CM/GC in Design
- Involvement of Subcontractors in Design
- Use of Co-location
## Table 3-2: The 3Ts - Tools

<table>
<thead>
<tr>
<th>3T</th>
<th>Intermediate Level</th>
<th>Survey Level</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Lean: Pull Planning</strong></td>
<td>Frequency</td>
<td>Effectiveness</td>
</tr>
<tr>
<td><strong>Lean: Last Planner</strong></td>
<td>Frequency</td>
<td>Weekly Commitments</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Percent Plan Complete (PPC)</td>
</tr>
<tr>
<td><strong>Lean: Just-in-Time Delivery (JIT)</strong></td>
<td>Frequency</td>
<td>JIT Definition</td>
</tr>
<tr>
<td><strong>Other Lean Construction Tools</strong></td>
<td>5S</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Set Based Design (SBD)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Value Stream Mapping (VSM)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Target Value Design (TVD)</td>
<td></td>
</tr>
<tr>
<td><strong>TOOLS</strong></td>
<td><strong>Use of Building Information Modeling (BIM)</strong></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Visualization</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Space Validation</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Site Logistics</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Environmental Analysis</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Early Design Coordination</td>
<td></td>
</tr>
<tr>
<td></td>
<td>MEP Coordination</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Design Collaboration</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Clash Detection</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Submittals</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Estimating</td>
<td></td>
</tr>
<tr>
<td></td>
<td>4D Scheduling</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Digital Fabrication</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Construction Simulation</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Project Turnover</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Facilities Management</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Rule/Code Checking</td>
<td></td>
</tr>
<tr>
<td><strong>BIM Effectiveness</strong></td>
<td><strong>BIM used</strong></td>
<td></td>
</tr>
<tr>
<td></td>
<td>BIM Protocol Manual</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Right of Reliance</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Joint Servers</td>
<td></td>
</tr>
</tbody>
</table>
Table 3-3: The 3Ts - Terms

<table>
<thead>
<tr>
<th>3T</th>
<th>Intermediate Level</th>
<th>Survey Level</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Project Delivery System</td>
<td>Type of PDS</td>
</tr>
<tr>
<td></td>
<td></td>
<td>If IPD, type of IPD Contract</td>
</tr>
<tr>
<td></td>
<td></td>
<td>If IPD, Multiparty Contract</td>
</tr>
<tr>
<td></td>
<td></td>
<td>If IPD, Joining Agreement</td>
</tr>
<tr>
<td></td>
<td></td>
<td>If IPD, Number of Parties</td>
</tr>
<tr>
<td></td>
<td>Compensation</td>
<td>Type of Compensation for Subs</td>
</tr>
<tr>
<td></td>
<td></td>
<td>GMP Establishment Time</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Design Compensation</td>
</tr>
<tr>
<td></td>
<td>Incentives</td>
<td>Incentives</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Based on</td>
</tr>
<tr>
<td></td>
<td>Risk</td>
<td>Special Circumstances</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Subcontractor Participation</td>
</tr>
<tr>
<td></td>
<td>Fiscal Transparency</td>
<td>Change Orders</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Bidding and Procurement</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Contingency Usage</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Project Costs</td>
</tr>
</tbody>
</table>

3.2 Control Variables

In addition to the data gathered for the independent variables, data was also gathered for the control variables. The control variables include the general information on the project. Control variables are similar to the independent variables since they are both inputs to the project performance variables but, unlike independent variables, they are inherent to the project scope. Therefore, control variables need to be accounted for in the construction project performance metrics. For example, the size of the project in square feet is not controllable for the MEP contractor but it will affect the final cost. Therefore, the cost of the MEP portions of the project must be normalized by the gross square footage. This normalized variable is the unit cost of construction in terms of square feet. Other performance metrics that require normalization include the safety metrics, schedule metrics, and change metrics. Table 3-4 below displays all of the control variables gathered in this study.
Table 3-4: Control Variables

<table>
<thead>
<tr>
<th>High Level</th>
<th>Intermediate Level</th>
<th>Survey Level</th>
</tr>
</thead>
<tbody>
<tr>
<td>CONTROL VARIABLES</td>
<td>Project Name</td>
<td>Work Performed</td>
</tr>
<tr>
<td></td>
<td>Location</td>
<td>Project Type</td>
</tr>
<tr>
<td></td>
<td>General Information</td>
<td>Final Square Footage</td>
</tr>
<tr>
<td></td>
<td>Type of Construction</td>
<td>New</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Addition</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Renovation</td>
</tr>
<tr>
<td></td>
<td>MEP System Complexity</td>
<td></td>
</tr>
<tr>
<td></td>
<td>MEP System Quality</td>
<td></td>
</tr>
</tbody>
</table>

3.3 Performance Metrics

Finally, Table 3-5 displays the performance metrics included in this study. The metrics that are not italicized are metrics directly from the data collection tool while the italicized metrics are calculated using the collected data. Additionally, the metrics in bold are the metrics actually analyzed in the study. Many of these variables were introduced earlier in the literature review as they were used on past studies on project delivery systems.
### Table 3-5: Performance Metrics

<table>
<thead>
<tr>
<th>Performance Category</th>
<th>Performance Metric</th>
<th>Performance Category</th>
<th>Performance Metric</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>SAFETY</strong></td>
<td>OSHA Recordable Incidents</td>
<td><strong>COST</strong></td>
<td>Bid / Initial GMP / Target Value</td>
</tr>
<tr>
<td></td>
<td>Lost Time Incidents</td>
<td></td>
<td>Contract Value / Target Value Including Changes</td>
</tr>
<tr>
<td></td>
<td>Fatalities</td>
<td></td>
<td>Final Value</td>
</tr>
<tr>
<td></td>
<td><strong>Recordable Injury Rate</strong></td>
<td></td>
<td>Unit Cost ($/SF)</td>
</tr>
<tr>
<td></td>
<td><strong>Lost Time Incident Rate</strong></td>
<td></td>
<td>Cost Growth (%)</td>
</tr>
<tr>
<td></td>
<td><strong>Recordable Injuries per $1 Million</strong></td>
<td></td>
<td>Budget Growth (%)</td>
</tr>
<tr>
<td></td>
<td><strong>Lost Time Incidents per $1 Million</strong></td>
<td></td>
<td>Total Growth (%)</td>
</tr>
<tr>
<td><strong>SCHEDULE</strong></td>
<td>Estimated Duration at Award</td>
<td><strong>QUALITY</strong></td>
<td>MEP Systems Quality</td>
</tr>
<tr>
<td></td>
<td>Actual Duration</td>
<td></td>
<td>Deficiency Issues</td>
</tr>
<tr>
<td></td>
<td><strong>Construction Speed (SF/day)</strong></td>
<td></td>
<td>Deficiencies per $1 Million</td>
</tr>
<tr>
<td></td>
<td><strong>Schedule Growth (%)</strong></td>
<td></td>
<td>Number of Punchlist Items</td>
</tr>
<tr>
<td></td>
<td><strong>Schedule Intensity ($/day)</strong></td>
<td></td>
<td>Punchlist % Cost</td>
</tr>
<tr>
<td><strong>COMMUNICATION</strong></td>
<td><strong>Number of RFIs</strong></td>
<td></td>
<td><strong>Punchlist per $1 Million</strong></td>
</tr>
<tr>
<td></td>
<td><strong>RFI Processing Time</strong></td>
<td></td>
<td>Warranty Costs %</td>
</tr>
<tr>
<td></td>
<td><strong>RFI per $1 Million</strong></td>
<td></td>
<td>Latent Defects Cost %</td>
</tr>
<tr>
<td></td>
<td><strong>Number of Resubmittals</strong></td>
<td></td>
<td>PPC Trend</td>
</tr>
<tr>
<td></td>
<td><strong>Resubmittals per $1 Million</strong></td>
<td></td>
<td>Absenteeism Costs %</td>
</tr>
<tr>
<td></td>
<td><strong>Rework Cost %</strong></td>
<td></td>
<td>Turnover Costs %</td>
</tr>
<tr>
<td></td>
<td><strong>Number of Claims</strong></td>
<td></td>
<td>Overmanning Experienced?</td>
</tr>
<tr>
<td><strong>CHANGES</strong></td>
<td><strong>CO Hours</strong></td>
<td><strong>LABOR</strong></td>
<td>Budgeted/Actual Man-Hours at NTP</td>
</tr>
<tr>
<td></td>
<td><strong>%Changes</strong></td>
<td></td>
<td><strong>Man-Hour Growth (%)</strong></td>
</tr>
<tr>
<td></td>
<td><strong>Overtime Labor for Change</strong></td>
<td></td>
<td>Amount Overtime</td>
</tr>
<tr>
<td></td>
<td><strong>% OT Labor for Change</strong></td>
<td></td>
<td>%OT of Man-Hours</td>
</tr>
<tr>
<td></td>
<td><strong>Shiftwork for Change</strong></td>
<td></td>
<td>Amount Shiftwork</td>
</tr>
<tr>
<td></td>
<td><strong>% Shiftwork for Change</strong></td>
<td></td>
<td>% Shiftwork of Man-Hours</td>
</tr>
<tr>
<td></td>
<td><strong>CO Effect on Schedule</strong></td>
<td></td>
<td>Peak # Craftsmen</td>
</tr>
<tr>
<td></td>
<td><strong>CO Effect on Cost</strong></td>
<td></td>
<td><strong>Peak Craftsmen per Week</strong></td>
</tr>
<tr>
<td></td>
<td><strong>CO Processing Time</strong></td>
<td></td>
<td>Average Manpower</td>
</tr>
<tr>
<td><strong>BUSINESS</strong></td>
<td><strong>Overhead and Profit</strong></td>
<td></td>
<td>Peak/Average Manpower</td>
</tr>
<tr>
<td></td>
<td><strong>Image and Return Business</strong></td>
<td></td>
<td>% Lost Productivity</td>
</tr>
</tbody>
</table>

### 3.4 Coding of Non-Numerical Variables

While much of the independent and control variables collected are numerical and do not require coding (value of incentives, number of representatives on the project leadership team, percent
design complete when MEP contractors brought on board), several are non-numerical and require coding in order to perform analysis. Binary data, such as yes/no questions, require coding. In most cases, a “yes” answer is coded as one and a “no” answers is coded as zero. Examples of binary data includes use of incentives, formal risk review, competition in subcontractor selection, use of leadership/cluster/executive teams, use of prefabrication, and use of BIM. Other data is ordinal and based on a scale such as none, a little, some, or a lot. Table 3-6 below shows the ordinal independent variables that require coding. In many cases, the coding of ordinal data is intuitive as it is in incremental steps (-1, 0, 1 or 0, 1, 2, 3 etc.). However, in other cases (past performance, fiscal transparency, etc.), the coding of ordinal data does not follow incremental steps such as the none, a little, some, or a lot scale. From Table 3-6, you can see that these values are coded as zero, one, three, or nine respectively. The reason for this is to add more weight to the projects that recorded use of a certain independent variable as “a lot”.

Most of the dependent variables or performance metrics are numerical data in terms of dollars, percentage, man-hours, and others. However, there are examples of dependent binary variables (yes coded to one and no coded to zero) and ordinal variables. The binary performance variables include the use of subcontractors and whether the MEP subcontractor experienced overmanning. Shown in Table 3-7 is the ordinal performance metric coding.
Table 3-6: Ordinal Independent Variable Coding

<table>
<thead>
<tr>
<th>Scale</th>
<th>Survey Value</th>
<th>Coded Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fiscal Transparency Experience (PDS, Size, BIM, etc.)</td>
<td>None</td>
<td>0</td>
</tr>
<tr>
<td>Tools and Techniques (Lean Tools, BIM, etc.)</td>
<td>A Little</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Some</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>A lot</td>
<td>9</td>
</tr>
<tr>
<td>Complexity</td>
<td>Low</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>Average</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>High</td>
<td>2</td>
</tr>
<tr>
<td>Quality</td>
<td>Economy</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Standard</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>High</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>Premium</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>High Eff. Premium</td>
<td>5</td>
</tr>
<tr>
<td>Current Team Experience</td>
<td>Poor</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Fair</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>Good</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>Very Good</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>Excellent</td>
<td>5</td>
</tr>
<tr>
<td>Leadership Meeting Frequency (Preplanning, Construction, Commissioning)</td>
<td>Monthly</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Every Other Week</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>Weekly</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>Daily</td>
<td>4</td>
</tr>
<tr>
<td>Cluster Team Meeting Frequency (Preplanning, Construction, Commissioning)</td>
<td>Quarterly</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Monthly</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>Weekly</td>
<td>3</td>
</tr>
<tr>
<td>Executive Team Meeting Frequency (Preplanning, Construction, Commissioning)</td>
<td>Never</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>At Completion</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Throughout Project</td>
<td>3</td>
</tr>
<tr>
<td>Lessons Learned</td>
<td>Voting</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Anything Else</td>
<td>0</td>
</tr>
<tr>
<td>Conflict Authority</td>
<td>Absolutely</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>Somewhat</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>No</td>
<td>0</td>
</tr>
<tr>
<td>Other Project Leadership Questions</td>
<td>Very</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>Somewhat</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>Little</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>None</td>
<td>0</td>
</tr>
<tr>
<td>Timing and Collaboration</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Scale</td>
<td>Survey Value</td>
<td>Coded Value</td>
</tr>
<tr>
<td>-------------------------------------------</td>
<td>--------------</td>
<td>-------------</td>
</tr>
<tr>
<td>How Change Orders Affected Schedule</td>
<td>Extension</td>
<td>-1</td>
</tr>
<tr>
<td></td>
<td>Did Not Affect</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>Compression</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Increased</td>
<td>-1</td>
</tr>
<tr>
<td></td>
<td>Did Not Affect</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>Decreased</td>
<td>1</td>
</tr>
<tr>
<td>How Change Orders Affected Cost</td>
<td>Increased</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Did Not Affect</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>Decreased</td>
<td>1</td>
</tr>
<tr>
<td>Change Order Processing Time (days)</td>
<td>1-7</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>8-14</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>15-21</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>22-28</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>29-35</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>35-42</td>
<td>6</td>
</tr>
<tr>
<td></td>
<td>&gt;42</td>
<td>7</td>
</tr>
<tr>
<td>RFI Processing Time (days)</td>
<td>1-7</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>8-14</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>15-21</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>22-28</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>29-35</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>&gt;35</td>
<td>6</td>
</tr>
<tr>
<td>RFI Work-Around</td>
<td>No</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>A Few Times</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Many</td>
<td>3</td>
</tr>
<tr>
<td>PPC Trend</td>
<td>Increased</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Stable</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>Decreased</td>
<td>-1</td>
</tr>
<tr>
<td>Absenteeism</td>
<td>0-5%</td>
<td>1</td>
</tr>
<tr>
<td>Turnover</td>
<td>6-10%</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>11-20%</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>&gt;20%</td>
<td>4</td>
</tr>
<tr>
<td>Value Associated with Punchlist Items</td>
<td>0-0.25%</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>0.25-0.5%</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>0.5-1%</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>1-2%</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>&gt;2%</td>
<td>4</td>
</tr>
<tr>
<td>Warranty Costs</td>
<td>0% (0%)</td>
<td>0</td>
</tr>
<tr>
<td>Latent Defect Costs (Percentage Rework)</td>
<td>0-0.5% (0-1%)</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>0.6-1% (1-2%)</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>1-2% (2-3%)</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>2-3% (3-4%)</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>&gt;3% (&gt;4%)</td>
<td>5</td>
</tr>
<tr>
<td>Project Overhead and Profit</td>
<td>Negative</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>&lt;5%</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>5-10%</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>11-15%</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>&gt;15%</td>
<td>4</td>
</tr>
<tr>
<td>Company Image and Return Business</td>
<td>Very Negative</td>
<td>-2</td>
</tr>
<tr>
<td></td>
<td>Negative</td>
<td>-1</td>
</tr>
<tr>
<td></td>
<td>Neutral</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>Positive</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Very Positive</td>
<td>2</td>
</tr>
</tbody>
</table>
3.5 **Combined Independent Variables**

In order to make analysis simpler, many of the independent variables are combined into an overall score with other similar independent variables. The overall score calculated is the analysis level of the variable while the values used to calculate these scores are the survey level variables. In some cases, there are intermediate level variables. For example, the Management Structure Score (analysis level) is determined by summing scores for conflict authority, core team score (sum of parties represented, meeting frequency, authority, joint goals, decisions, periodic reviews, and opinion valued), cluster team score (sum of meeting frequency multiplied by amount of time utilized on project), and the executive team score (sum of the meeting frequency). Similarly, a Fiscal Transparency Score is calculated by summing fiscal transparency regarding change orders, fiscal transparency regarding bidding and procurement, fiscal transparency regarding contingency usage, and fiscal transparency regarding project costs. *Figures 3-1 and 3-2 visually portray the Management Structure Score and the Fiscal Transparency Score.*

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**Survey Level**

- Conflict Authority

**Intermediate Level**

- Parties Represented, Meetings, Authority, etc.

**Analysis Level**

- Core Team Score
- Cluster Team Score
- Executive Team Score

**Management Structure Score**

*Figure 3-1: Management Structure Score*
The Stakeholder Past Experience Score is calculated by summing the experience with project type score, the experience with project size score, the experience with project delivery system score, the experience with BIM score, and the previous experience with other stakeholders score (average of all past experience with stakeholders). The experience with project type score, experience with project size score, experience with project delivery system score, and experience with BIM score are all averages of the experience of the general contractor, owner, subcontractors, and designers. Similarly, the Stakeholders Current Experience Score is calculated by summing the current experience with architect and owner and the current experience with the construction team. Figures 3-3 and 3-4 graphically display how the Stakeholder Past Experience Score and the Stakeholder Current Experience Score are determined.
Selection Scores for each project are computed by summing the method of selection (zero for open bidding, one for prequalified or negotiated, and three for voting) with the binary variable of competition in selection. Involvement Scores for subcontractors on each project are computed by summing subcontractor familiarity, owner participation, design support, general contractor design involvement, subcontractor design involvement, use of co-location, risk review process (binary), and participation of subcontractors in risk review (binary).

Various tools and techniques also have computed scores. The Pull Planning Score is a product of the pull planning frequency and pull planning effectiveness. The Last Planner Score is a
summation of the frequency of Last Planner, the frequency of weekly commitments, and the frequency of PPC tracking. The Just-in-Time (JIT) Delivery Score is computed through the product of JIT frequency and JIT definition. Finally, the Lean Score combines all of the other lean tools (5S, Set Based Design, Value Stream Mapping, and Target Value Design), with the Last Planner Score, the JIT Score, and the Pull Planning Score. To keep equal weights, the Last Planner Score and the Pull Planning Score are divided by three and the JIT Score is divided by nine. Figure 3-5 displays various components of the Lean Score. The BIM score is calculated through the product of the BIM functions score (average of BIM use for visualization, space validation, site logistics, etc.), and the BIM effectiveness score (past experience with BIM multiplied by the average of the binary variables BIM protocol, right of reliance, and joint servers). Figure 3-6 visually portrays how the BIM score is calculated.

Figure 3-5: Tools and Techniques Scores
Getting MEP contractors to respond to the data collection tool was a difficult task. As mentioned earlier, IPD is still developing as a project delivery system and its use is still very rare. Finding projects that utilized IPD was the first difficulty. A second challenge was finding projects that used pure IPD or had the MEP contractors as part of the multiparty agreement. In many projects, the multiparty contract included the general contractor, owner, and architect but did not include the subcontractors. For these reasons, the definition of IPD-ish from El Asmar (2012) was modified slightly for this study to the following:

1. MEP contractors who were part of projects labeled as IPD but did not sign a multiparty contract or a joining agreement.
2. MEP contractors who stated their project was construction management at risk or design-build but the project was IPD from the general contractor perspective based on El Asmar (2012).
3. MEP contractors who stated their project was construction management at risk or design-build but the project was advertised as being IPD.
Finally, another challenge was getting the MEP contractors from IPD projects to share their data. Many of these subcontractors viewed their ability to use IPD as an industry advantage and were unwilling to share data. Many of these initially unwilling contractors were persuaded to share their data after an explanation of the benefits that this research will provide the MEP contracting industries. Overall, 32 MEP contractors responded to the data collection tool with 58% being mechanical and the remaining 42% being electrical. It should be noted that for one respondent, the company actually performed both mechanical and electrical work. The 32 responses came from 22 different companies with a response rate of 37%. Figure 3-7 below is a visual representation of the data according to the type of construction. Additionally, Figure 3-8 shows a map that displays the location of U.S. responders. Additionally, projects were also located in Canada.

Figure 3-7: Distribution of Response by Industry
Figures 3-9 through 3-11 show the project delivery system selected for all projects, mechanical projects, and electrical projects respectively. In the mechanical dataset, there is a higher percentage of IPD responses than in the electrical dataset. One important note is that the mechanical dataset does not include a design-bid-build project.
Figure 3-9: Distribution of Project Delivery System for All Data

Figure 3-10: Distribution of Project Delivery System for Mechanical Data
Many of the projects that reported they used IPD, both in the mechanical and electrical datasets, are in reality IPD-ish as they did not use a multiparty contract. Likewise, some of the projects that reported design-build or construction management at risk were actually IPD-ish as they used many IPD principles without a multiparty contract. *Figures 3-12 through 3-14* show the distribution of IPD, IPD-ish, and non-IPD for all projects, mechanical projects, and electrical projects respectively. From these graphs, it is clear that the mechanical dataset has a nearly even distribution between non-IPD, IPD-ish, and IPD. However, the electrical dataset has much more non-IPD projects than IPD or IPD-ish.
Figure 3-12: Entire Dataset Breakdown for Non-IPD, IPD-ish, and IPD

Figure 3-13: Mechanical Breakdown for Non-IPD, IPD-ish, and IPD
Most of the projects studied were institutional type projects (hospitals and schools), however, three mechanical and three electrical projects were commercial (retail and office buildings) and one mechanical and one electrical project was industrial. Figures 3-15 through 3-17 show the cost distribution for each project for the entire dataset, the mechanical dataset, and the electrical dataset respectively. All three of these distribution show that most of the projects have a MEP scope of work ranging between $1 million and $20 million.
Figure 3-15: Cost Distribution for Entire Dataset

Figure 3-16: Cost Distribution for Mechanical Dataset
Figures 3-18 through 3-20 show the gross square footage for each project for the entire dataset, the mechanical dataset, and the electrical dataset respectively. These histograms show an even distribution for all types of construction. Only one project was greater than 500,000 square feet.
Figures 3-21 through 3-23 display the distribution for the total man-hours for the MEP scope of work for the entire dataset, the mechanical dataset, and the electrical dataset respectively. Most of the projects were above 50,000 man-hours.
Figure 3-21: Man-Hour Distribution for MEP Scope for Entire Dataset

Figure 3-22: Man-Hour Distribution for Mechanical Scope
Figures 3-24 through 3-26 show pie chart distributions for type of construction in terms of new, addition, or renovation for the entire dataset, the mechanical dataset, and the electrical dataset respectively. From the charts, most of the projects consisted of brand new construction. Additionally, the distributions are very similar between mechanical and electrical contractors.
Figures 3-27 through 3-29 show the distribution of procurement type for subcontractors for the entire dataset, the mechanical dataset, and the electrical dataset respectively. For mechanical contractors, more than half used a negotiated contract while for electrical contractors roughly one half used a negotiated contract.
Figure 3-27: Procurement Type for Entire Dataset

Figure 3-28: Procurement Type for Mechanical Dataset
In the previously cited El Asmar (2012), the data showed that 68% of general contractors used negotiated contracts while only 24% of subcontractors used negotiated contracts. In his report, El Asmar suggested that many of the principles of IPD, such as a negotiated contract, have not yet trickled down to the subcontractors. The data from this report confirms this suggestion as it appears that MEP contractors could still utilize more from IPD principles. However, as El Asmar stated, it might just be a matter of time until all project stakeholders, including subcontractors, adapt to the IPD environment.

Additionally, the total percentage of lump sum contracts for the entire dataset is 25%. However, there is an obvious difference in the use of lump sum contracts between mechanical and electrical contractors surveyed. While mechanical contractors studied used a lump sum contract on 16% of the projects, electrical contractors used a lump sum contract on 36% of the projects. However, no mechanical and electrical contractors on the IPD projects studied used lump sum compensation.
After examining the figures in this section, it appears that the mechanical and electrical datasets are similar since they have the same characteristics. For this reason, the two datasets are assumed to be the same population and can be studied with a MEP combined dataset.

This chapter explained the variables used in the study and gave a description of the dataset. The next few chapters will discuss the analysis of the data including a univariate analysis, the development of the *Project Quarterback Rating* for MEP contractors, and a regression analysis to determine which inputs from the 3Ts have the greatest effect on construction project performance.
Chapter 4  

Evaluating Performance of IPD for MEP Contractors

Chapter 3 introduced performance metrics in the categories of safety, cost, schedule, communication, quality, business, labor productivity, and changes. This chapter will compare IPD to non-IPD projects in respect to the metrics in the categories listed. In this univariate analysis, project delivery system will be the only independent variable. Statistical methods will determine if IPD significantly affects the performance metrics. Additionally, strip charts will provide visual representations of the effects of IPD. After analysis, this chapter will explain and discuss the results.

4.1 Statistical Methods

The univariate analysis consists mainly of two statistical tests: the t-test and the Mann-Whitney-Wilcoxon (MWW) test. The t-test determines if the means between two groups are significantly different. However, use of the t-test requires that the data be normally distributed. The MWW test, on the other hand, is a non-parametric test that does not require the data to be normally distributed. The MWW test has slightly less power than the t-test if the data is normally distributed but much more power than the t-test if the data is not normally distributed (Loh 2013). For this reason, the MWW test is more conservative.

Since testing for normality for every metric is cumbersome, all performance metrics were first tested using the two-sided MWW tests. Output for these tests consisted of p-values. In all tests, the null hypothesis was that IPD had no effect on the performance metric being tested for MEP contractors while the alternative hypothesis was that IPD affected the metric in question. These hypotheses were stated in Table 1-1 of the introduction. Performance metrics were divided into three different levels of significance: evidence against the null hypothesis at the 0.01 level of significance,
evidence against the null hypothesis at the 0.05 level of significance, and evidence against the null hypothesis at the 0.1 level of significance. Any metric with a p-value greater than 0.1 had no evidence against the null hypothesis. Displayed alongside of the MWW p-values were t-test p-values. Q-Q plots were created to determine the normality of the data for the metrics that would change significance level with the t-test. For example, if a certain metric was significant at the 0.1 level with the MWW test but significant at the 0.05 level with the t-test, the normality of the data for that metric was tested using the Q-Q plot. If the data was normally distributed for the particular metric, then the p-value from the t-test was used.

As mentioned in Chapter 3, the mechanical and electrical dataset follow similar distributions for square footage, total man-hours, and type of construction showing that the two datasets are the same population. This meant that these two datasets could be combined for analysis purposes. Having both datasets in the same population created a larger sample size of thirty-two projects as compared with a sample size of nineteen for the mechanical dataset and a sample size of fourteen for the electrical dataset.

In addition to the MWW tests and t-tests, strip charts were used to visually portray the effects of IPD for MEP contractors. The strip charts plotted each data point for the specific metric for IPD, IPD-ish, and non-IPD projects and displayed the medians with an “X” and mean values with an “O”. Strip charts were important for giving insight into the distribution of the data. Boxplots were not used in this report since there were few data points in each category, allowing the strip charts to portray more information than boxplots.

While IPD-ish projects were shown on the strip charts, they were not used in the initial MWW tests or t-tests. However, for metrics where IPD was significantly different from non-IPD, the MWW test was also used to test for differences between IPD-ish and non-IPD. IPD-ish included mostly projects in which the participant said the project was IPD but did not use a multiparty contract. Additionally, for cases in which the participant said the project was construction management at risk
or design-build but the project was advertised as IPD on the general contractor level, these projects were grouped as IPD-ish.

The second portion of the univariate analysis examined the comparison between IPD and non-IPD split up into design-bid-build, construction management at risk, and design-build. This portion of the analysis utilized the Kruskal-Wallis test, a nonparametric test used to compare more than two groups. The null hypotheses for these tests were that the four groups (design-bid-build, construction management at risk, design-build, and IPD) had equal medians while the alternative hypotheses were that at least one of the groups had a different median. This portion of the analysis also included strip charts for the data found significant at the 0.1 level. IPD-ish projects were included in both the strip charts and the Kruskal-Wallis test. For cases where a respondent listed a project as construction management at risk or design-build but the project was IPD-ish, the project was assigned to the delivery system according to the response. For projects where the respondent said the project was IPD but no multiparty contract was used, these projects were considered under IPD for this portion of the analysis.

### 4.2 Univariate Results: IPD vs. Non-IPD

This section will compare IPD to non-IPD for each performance metric individually. The subsections of this chapter are organized by the category of performance metric.

#### 4.2.1 Safety Performance Metrics

The safety metrics gathered from the data collection tool are the number of OSHA recordable incidents, the number of lost-time incidents, and the number of fatalities. Fortunately, there were zero fatalities on the projects in this study. From the data gathered, safety performance metrics were normalized into the OSHA recordable incident rate, the lost-time incident rate, the OSHA recordable incidents per million dollars, and the lost-time incidents per million dollars. Rates were calculated
using the Bureau of Labor Statistics formula by multiplying the number of incidents by 200,000 and then dividing by the total man-hours (BLS 2012). The 200,000 represents the equivalent of 100 employees working 40 hours per week, 50 weeks per year.

Figure 4-1 below shows strip charts for all four safety metrics. While the medians for non-IPD, IPD-ish, and IPD (represented by the “X”) are zero for all four safety metrics, fewer IPD projects have a high number of OSHA recordable or lost-time incidents as indicated by the means (represented by the “O”). The strip charts show that non-IPD and IPD-ish projects may have more recordable and lost-time incidents but statistical tests must be performed to determine significance. Through the two-sided MWW test, the p-value for the OSHA recordable incident rate is 0.303, which is above the threshold of 0.1 and is therefore not significant. Similarly, the p-value for the OSHA recordable incidents per million dollars is 0.253 and is not enough to prove significance. The MWW test for lost-time incident rate and lost-time incidents per million dollars show no evidence against the null hypothesis with p-values of 0.125 for both.

From the analysis, there is no conclusive evidence that IPD affects safety metrics for MEP contractors. The previous study that examined the effects of IPD on general contractors also shows no evidence that IPD outperforms non-IPD in regards to the OSHA recordable incident rate, the lost-time incident rate, or the OSHA recordable incidents per million dollars (El Asmar 2012). However, the previous study does show evidence that IPD outperforms non-IPD in regards to the lost-time incidents per million dollars for general contractors. Both studies appear to agree that IPD generally does not affect safety performance metrics. This conclusion is expected because current construction practices place a high priority on safety regardless of project delivery system.
4.2.2 Cost Performance Metrics

The analysis for cost includes the following performance metrics: the unit cost in dollars per square foot, the construction cost growth (percentage difference between final actual cost and contract value including changes), the budget factor (percentage difference between the initial or estimated cost and the contract value including changes), and the total cost growth (percentage difference between the final actual cost and the initial or estimated cost). Of course, costs gathered from the data collection tool were adjusted for time and location using the ENR Construction Cost Index,
which includes indices for twenty cities across the U.S. and two cities in Canada. For projects where the actual city was not included in the ENR Construction Cost Index, the index used was from the closest city.

*Figure 4-2* below shows strip charts for construction cost growth, budget factor, total cost growth, and unit cost. The upper left strip chart shows the construction cost growth. In this case, it appears that IPD may have a slight affect in lowering the construction cost growth but it still must be tested for significance. The upper right strip chart shows the budget factor, and it appears that IPD may increase this metric. The lower left strip chart shows the total cost growth. It appears that IPD may have a slight effect in decreasing the total cost growth. Finally, the plot in the lower right shows the unit cost. From this plot, it appears that IPD-ish and IPD may increase the unit cost when compared with non-IPD for MEP contractors. One reason may be is the increased complexity that is typical on IPD projects. Additionally, the median and mean unit cost for the IPD-ish group is larger because of a very large and complex industrial project included in this group.

The two-sided MWW test for cost growth has an alternative hypothesis that IPD affects the construction cost growth for MEP contractors. However, this test does not show conclusive evidence that IPD significantly affects the construction cost growth for MEP contractors with a p-value of 0.367. Additionally, the two-sided MWW tests for budget factor and total cost growth do not show conclusive evidence that IPD significantly affects these metrics for MEP contractors with p-values equal to 0.687 and 0.832 respectively. Finally, the two-sided MWW test for unit cost shows no conclusive evidence that IPD affects this metric for MEP contractors with a p-value of 0.186. The null hypotheses for the cost metrics cannot be rejected.

This analysis cannot show conclusive evidence that IPD affects any of the four cost metrics for MEP contractors. The results from this study on MEP contractors agrees with the results from the previous study analyzing general contractors that also does not show conclusive evidence that IPD affects cost metrics (El Asmar 2012). This conclusion also agrees with other IPD research with
similar results for cost metrics (Cho & Ballard 2011). These results are expected as cost savings are typically invested back into the project to improve quality or increase scope.

4.2.3 Schedule Performance Metrics

The analysis for schedule performance involves several performance metrics including the construction speed in square feet per day, the schedule growth (percentage difference between actual and estimated duration), and the schedule intensity, which is a metric measuring the average dollar
value of construction installed per day. These three metrics were computed through the surveyed metrics of estimated weeks for completion and actual weeks for completion.

*Figure 4-3* below shows strip charts for construction speed, schedule growth, and schedule intensity. The strip chart on the upper left shows the data for construction speed for non-IPD, IPD-ish, and IPD projects. It appears that IPD reduces the construction speed, probably because of the focus on overall productivity instead of individual productivity. The upper right strip chart shows schedule growth. This strip chart appears to show that IPD significantly reduces the schedule growth for MEP contractors. Finally, the lower strip chart shows that IPD likely has no effect on the schedule intensity for MEP contractors.

The two-sided MWW test for construction speed reports a p-value of 0.379, which is not enough to provide conclusive evidence against the null hypothesis. Additionally, the two-sided MWW test for schedule intensity reports a p-value of 0.972, which also is not enough to provide conclusive evidence that IPD affects this metric for MEP contractors. However, the two-sided MWW test for schedule growth reports a p-value of 0.0208, with an alternative hypothesis that IPD affects this metric. Therefore, this study shows evidence that IPD affects the schedule growth for MEP contractors at the 0.05 level of significance. From the strip chart, the effect of IPD is an improvement from non-IPD as it reduces the schedule growth and can produce, in many cases, negative schedule growth. On average, MEP contractors on IPD projects from the dataset have a schedule growth of -5% indicating that the actual duration is less than estimated. On the other hand, MEP contractors on non-IPD projects from the dataset average a schedule growth of 11% indicating that the actual duration is more than estimated. Additionally, the MWW test was used to compare IPD-ish to non-IPD for the schedule growth of MEP contractors. However, the two-sided test shows no conclusive evidence of a significant difference in schedule growth between non-IPD and IPD-ish with a p-value of 0.174.
This study can conclude that there is significant evidence that IPD reduces the schedule growth for MEP contractors. However, this study shows no conclusive evidence that IPD has any effect on the construction speed or the schedule intensity for MEP contractors. The results for construction speed and schedule intensity are very similar to the results from the previous study of the effects of IPD on general contractors, which also shows no conclusive evidence that IPD affects construction speed or schedule intensity (El Asmar 2012). However, the previous study concludes that IPD does not affect the schedule growth, a fact that is not supported by this study. A reason why
IPD may reduce schedule growth for subcontractors but not for general contractors is the increased involvement of the subcontractors in the design phase. In many non-IPD projects, such as design-build projects, the general contractor already has input in the design phase but subcontractors generally do not. In most cases, IPD takes the collaboration a step further by not only involving the general contractor in design, but the major subcontractors as well.

4.2.4 Communication Metrics

The focus of the communication metrics in this study is on RFIs (Requests for Information), rework, and resubmittals. RFIs are typically submitted by contractors to designers when design intent is not clear. Resubmittals, for example, can refer to any design submittals or shop drawings submitted by contractors. The metrics used for analysis include the RFI processing time measured in weeks, RFIs per million dollars, resubmittals per million dollars, and rework cost as a percentage of total cost. Rework cost is measured on a six-point scale with 0% coded as zero, 0-1% coded as one, 1-2% coded as two, 2-3% coded as three, 3-4% coded as four, and >4% coded as five. While the number of RFIs and resubmittals may not directly increase cost, they indirectly affect cost by halting workflow on a project.

Figure 4-4 shows strip charts for the communication metrics. The upper left plot shows the comparison of RFIs per million dollars for MEP contractors on IPD projects and those on non-IPD projects. While the medians are similar between IPD and non-IPD for this metric, it is clear that the non-IPD group has a much wider range, which is the reason this group has a larger mean. The upper right plot shows the RFI processing time for MEP contractors on IPD, IPD-ish, and non-IPD projects. This plot shows that MEP contractors on IPD projects tend to have RFIs processed quicker than those on non-IPD or IPD-ish projects. The lower left plot shows the resubmittals per million dollars for the dataset. It appears that the median and mean values of this metric are lower for IPD projects when compared to non-IPD projects. Additionally, the range of this metric is much larger for MEP
contractors on non-IPD projects. Finally, the lower right plot shows the rework cost for MEP contractors on IPD, IPD-ish, and non-IPD projects. This plot shows that the medians are the same for IPD and non-IPD but the mean is slightly lower for MEP contractors on IPD projects.

![Chart showing communication metrics](image)

**Figure 4-4: Strip Charts for Communication Metrics**

The two-sided MWW test for RFIs per million dollars shows no conclusive evidence that IPD affects this metric for MEP contractors with a p-value of 0.241. Additionally, the two-sided MWW test for RFI processing time shows no conclusive evidence that IPD affects this metric for MEP contractors with a p-value of 0.136. However, the two-sided MWW tests for resubmittals per million
dollars and rework cost do show evidence that IPD affects these metrics with p-values of 0.0168 and 0.0819 respectively. The null hypotheses can be rejected for these two metrics. From the projects studied, MEP contractors on IPD projects have an average of 0.32 resubmittals per million dollars while MEP contractors on non-IPD projects have an average of 1.58 resubmittals per million dollars. Additionally, MEP contractors on IPD projects from the dataset average a rework cost of 0-1% of total cost while MEP contractors on non-IPD projects from the dataset average a rework cost of 2-3% of total cost. In addition to the comparison of IPD to non-IPD the resubmittals per million dollars and the rework cost were tested for a difference between IPD-ish and non-IPD for MEP contractors. However, these two-sided MWW tests show no conclusive evidence of a significant difference between IPD-ish and non-IPD for these metrics with p-values of 0.264 and 0.374 respectively.

Overall, IPD has a significant effect on MEP contractors regarding communication metrics. This study shows that IPD can reduce the number of resubmittals on a project at the 0.05 level of significance as well as the rework cost at the more lenient 0.1 level of significance for MEP contractors. These effects on MEP contractors are very similar to that of general contractors. The previous study on the effects of IPD on general contractors also shows that IPD reduces the number of design resubmittal and the number of RFIs as well as the RFI processing time (El Asmar 2012). It makes sense that IPD should reduce the number of design resubmittals and other communication metrics as the subcontractors can provide their input during the design phase of a project.

### 4.2.5 Quality Performance Metrics

The quality metrics for this study includes both qualitative and quantitative metrics. The metrics analyzed include the quality of the mechanical or electrical system measured on a five-point scale (economy coded as one, standard coded as two, high coded as three, premium coded as four, and high efficiency premium coded as five), the deficiency issues per million dollars, the percent cost of punchlist items measured on a five-point scale (0-0.25% coded as zero, 0.25-0.5% coded as one,
0.5-1% coded as two, 1-2% coded as three, and >2% coded as four), and the number of punchlist items per million dollars. The quality performance metrics also include the cost of warranties and latent defects as a percentage of total cost on a five-point scale similar to the scale of the cost of punchlist items. Deficiencies refer to code and inspection issues that occur and require repair during the construction phase prior to substantial completion. Since deficiency issues occur during construction, they can have a serious effect on project workflow, much like RFIs and resubmittals. Warranty issues, on the other hand, occur after substantial completion. Latent defects refer to defects that are not obvious and are discovered more than one year after substantial completion. Punchlist items are typically minor issues that must be resolved after occupancy such as incorrect panelboard labels for electrical contractors or bent diffusers for mechanical contractors.

Figure 4-5 shows strip charts for the six quality performance metrics. The upper left strip chart shows the distribution for the systems quality data by non-IPD, IPD-ish, and IPD. Since all three types have system quality medians at four (premium), it appears that IPD does not have an effect on system quality. Additionally, the means for this metric are quite similar for MEP contractors on IPD and non-IPD projects. The upper right strip chart appears to show that IPD may reduce the number of deficiencies per million dollars on construction projects. The middle left plot shows the distribution of punchlist items per million dollars for MEP contractors on IPD, IPD-ish, and non-IPD projects. This plot once again appears to show that IPD reduces this metric for MEP contractors. The middle right plot shows punchlist cost as a percentage of total cost. It appears form this plot that there is likely no difference in this metric between IPD and non-IPD for MEP contractors. Finally, the last two plots show the warranty and latent defect costs may not be affected by IPD since the medians for non-IPD, IPD-ish, and IPD are all the same for both metrics. Additionally, the means for these two metrics are very similar between all three groups.
Figure 4-5: Strip Charts for Quality Metrics
The two-sided MWW test shows no conclusive evidence that IPD affects system quality for MEP contractors with a p-value of 0.855. Additionally, the two-sided MWW tests for warranty cost and latent defect cost show no conclusive evidence that IPD affects MEP contractors regarding these metrics with p-values of one and 0.911 respectively. Additionally, the two-sided MWW tests for punchlist items per million dollars and punchlist cost show no conclusive evidence of a difference between IPD and non-IPD for MEP contractors with p-values of 0.113 and 0.226 respectively. However, the two-sided MWW test for deficiencies per million dollars does show evidence at the 0.01 level of significance that IPD affects this metric for MEP contractors with a p-value of 0.00196. From the strip chart, the study shows this effect is an improvement since IPD reduces the deficiency issues per million dollars for MEP contractors. The null hypothesis for deficiencies per million dollars can be rejected. On average, IPD projects from the dataset have 0.27 deficiency issues per million dollars while non-IPD projects have 4.53 deficiency issues per million dollars. Additionally, the null hypothesis that IPD-ish and non-IPD projects have the same values of deficiencies per million dollars for MEP contractors was tested using a two-sided MWW test. This test shows conclusive evidence at the more lenient 0.1 level of significance that IPD-ish can reduce the deficiencies per million dollars for mechanical and electrical contractors with a p-value of 0.0977.

This study shows that IPD has a somewhat significant effect on quality metrics with one of the six metrics, deficiencies per million dollars, significant at the 0.01 level of significance. The study also shows that IPD-ish reduces this metric for MEP contractors at the 0.1 level of significance. This reduction in deficiencies is important since, as mentioned earlier, deficiencies can halt the workflow of a project, creating a cumulative impact on overall construction project performance. While these results show that IPD outperforms non-IPD regarding some quality metrics, they differ from the previous study on general contractors. The previous study shows that IPD increases the quality of project systems, while reducing the deficiencies per million dollars, punchlist cost, punchlist items per million dollars, and warranty costs (El Asmar 2012). Essentially, the previous
study shows that IPD affects the quality of projects for general contractors more than it does for MEP contractors from this study. One reason may be, as mentioned in Chapter 3, is that many of the principles of IPD have yet to trickle down from the general contractor level to the subcontractor level. Once this occurs, subcontractors may see greater benefits from IPD regarding quality metrics.

4.2.6 Business Performance Metrics

Obtaining data for business metrics was difficult as many participants viewed their profit data as confidential information. In an effort to encourage participants to answer questions on their profit for the project, profit and overhead were grouped into one metric. This metric is measured on a four-point scale with negative overhead and profit coded as zero, between zero and five percent overhead and profit coded as one, between five and ten percent overhead and profit coded as two, and between eleven and fifteen percent overhead and profit coded as three. The only other business metric analyzed in this study is the image and potential for return business resulting from their work on the project. This qualitative metric is measured on a five-point scale with very negative impact coded as minus two, negative impact coded as minus one, neutral impact coded as zero, positive impact coded as one, and very positive impact coded as two.

Figure 4-6 below shows strip charts for the business performance metrics. The plot on the left shows the distributions for overhead and profit. It appears from this graph that IPD may lower the overhead and profit but tests must be performed to determine significance. The plot on the right shows the distribution for the image metric. The plot shows that IPD likely has no effect on the image metric, as the medians are the same for non-IPD, IPD-ish, and IPD projects and the means are very similar.

The two-sided MWW test for overhead and profit shows no conclusive evidence against the null hypothesis hypothesis with a p-value of 0.258. As expected, the two-sided MWW test for image
and potential for return business also shows no conclusive evidence that IPD has an effect on this metric with a p-value of 0.724. The null hypothesis for both business metrics can be rejected.

This study shows no conclusive evidence that IPD affects the overhead and profit or the image and potential for return business for MEP contractors. The previous study on general contractors shows that IPD increases the overhead and profit (El Asmar 2012). The reason that IPD may affect a general contractors overhead and profit while not affecting subcontractors’ overhead and profit is the same as discussed for the quality metrics. It is likely that many of the IPD principles have not trickled down from the general contractor level to the subcontractor level. Even though there is no evidence that IPD affects overhead and profit for MEP contractors, the strip chart is a bit worrisome as it shows a lower median value of this metric for MEP contractors on IPD projects. A possible explanation for why MEP contractors on non-IPD projects have a higher median value of overhead and profit is that IPD may significantly reduce overhead costs for MEP contractors while not changing profit. This would result in a decrease of the overhead and profit metric. If this is the case, then MEP contractors should not be hesitant to join IPD projects. However, future research must show if this is actually the case.
4.2.7 Labor Performance Metrics

Labor metrics are extremely important for MEP contractors since labor is such a high risk. In many cases, small downturns in labor productivity can wipeout an MEP contractor’s profit. The factors used to study labor performance metrics include the percent plan complete (PPC) trend coded as minus one for decreasing, zero for stable, and one for increasing. PPC is a measure of the amount of reliable promises kept by members of the project team. Additionally, labor performance metrics include the absenteeism and turnover costs as a percentage of total costs measured on a four-point scale with 0-5% coded as one, 6-10% coded as two, 11-20% coded as three, and >20% coded as four. Overmanning is a binary labor performance metric coded as one if overmanning is experienced and zero if overmanning is not experienced. The peak manpower divided by the average manpower is also studied with an optimum value of 1.6 (Hanna 2010b). The percent loss of productivity is a metric that measures the lost productivity due to changes in percent. A positive value for this metric indicates a loss in productivity while a negative value indicates a gain in productivity. Also analyzed are the percentage growth of direct man-hours from estimated man-hours to actual man-hours, the amount of overtime hours in respect to total projects hours, and the amount of shiftwork hours in respect to total project hours.

*Figure 4-7* shows strip charts for the PPC trend, the absenteeism cost, the turnover cost, overmanning, man-hour growth, and the amount of overtime hours. From the strip charts, it appears that IPD has no effect on absenteeism cost, turnover cost, and overmanning since all of the medians are the same between non-IPD, IPD-ish, and IPD and the means are similar. It appears from the figure that IPD may outperform non-IPD regarding the trend of completed promises throughout the project as well as reduce the man-hour growth and amount of overtime hours. However, the two-sided MWW tests for these six metrics show no conclusive evidence against the null hypothesis with p-values of 0.221 and greater. The null hypothesis cannot be rejected for the labor performance metrics in *Figure 4-7*. 
Figure 4-7: Strip Charts for Labor Metrics
Figure 4-8 shows the remaining labor performance metrics including the amount of shiftwork hours with respect to total hours, the peak man-hours divided by average man-hours, and the loss of productivity due to changes. The strip chart for peak man-hours divided by average man-hours appears to show that IPD reduces this metric for MEP contractors. The strip chart for the amount of shiftwork hours appears to show that IPD does not affect this metric since all of the medians are the same and the means are very similar. Finally, the strip chart for loss of productivity appears to show that IPD tends to produce lower values of lost productivity. However, once again, the two-sided MWW tests show no conclusive evidence that IPD has an effect on these labor performance metrics with p-values ranging from 0.591 to 0.899. The null hypotheses for labor performance metrics in Figure 4-8 cannot be rejected.

This study shows no conclusive evidence that IPD has an effect on the labor performance metrics studied for MEP contractors. These results agree with the previous study of the effects of IPD on general contractors, which only shows conclusive evidence that IPD outperforms non-IPD for the PPC trend for productivity metrics (El Asmar 2012). One reason that IPD may have little effect on subcontractors and general contractors regarding labor performance metrics is because the laborers (those actually performing the work) have not yet bought into the IPD concept. As mentioned in the literature review, IPD is hindered by the cognitive impairments of those who have worked in construction for many years and have not yet bought into the IPD concept.
4.2.8 Change Performance Metrics

The last category is the change performance. The metrics studied for this category include the percent change (change order hours with respect to total labor hours), the amount of overtime labor hours due to changes, and the amount of shiftwork labor hours due to changes. The change order effect on schedule and the change order effect on cost, both measured on a three-point scale, are also analyzed. For change order effect on cost, an answer of increased is coded as negative one, an answer of no effect is coded as zero, and an answer of decreased is coded as positive one. For the
change order effect on schedule, an answer of extension is coded as negative one, an answer of no effect is coded as zero, and an answer of compression is coded as positive one. Finally, the change order processing time measured in weeks is another change performance metric.

Figure 4-9 shows strip charts for the six change performance metrics. The upper left plot shows the distribution for overtime hours due to changes with respect to total hours. It appears that IPD does not affect this metric. Similarly, the plot on the upper right shows that IPD has little effect on the distribution for shiftwork hours due to change with respect to total hours. The middle plots appear to show that IPD has little effect on the change order effect on cost and schedule. The lower left plot shows the percent change and appears to show that IPD reduces this metric for MEP contractors. Finally, the lower right plot shows the change order processing time measured in weeks. This plot appears to show that IPD results in faster change order processing time for MEP contractors.

The two-sided MWW tests for overtime due to change, shiftwork due to change, change order effect on schedule, and percent change show no evidence of a significant difference between IPD and non-IPD for MEP contractors with p-values ranging between 0.211 and 0.491. However, the two-sided MWW test does show evidence that IPD affects the change order effect on cost at the more lenient 0.1 level of significance with a p-value of 0.0859. This effect is positive as IPD has more values of zero (no effect on cost) than the non-IPD group, which has mostly values of minus one (increases cost). Additionally, the two-sided MWW test for change order processing time shows evidence that IPD affects this metric for MEP contractors at the 0.05 level of significance with a p-value of 0.0182. The median values from the strip chart clearly show that IPD reduces this metric for MEP contractors. From the MEP contractors studied, those on IPD projects average a change order processing time of 2.58 weeks while those on non-IPD projects average a change order processing time of 4.69 weeks. This reduction in change order processing time is important because the sooner a change order is resolved, the sooner workflow can resume.
Figure 4-9: Strip Charts for Change Metrics
In addition to the tests performed above, two-sided MWW tests were used to compare IPD-ish to non-IPD for MEP contractors for the change order effect on cost metric and the change order processing time metric. The two-sided MWW test for change order effect on cost shows no conclusive evidence that IPD-ish affects this metric when compared with non-IPD for MEP contractors with a p-value of 0.278. However, a two-sided MWW test comparing IPD-ish to non-IPD for the change order processing time shows that IPD-ish does affect this metric for MEP contractors with a p-value of 0.0374. The tests show conclusive evidence that IPD and IPD-ish reduce the change order processing time for MEP contractors.

This study shows that overall, IPD does affect change performance metrics for MEP contractors by improving the change order effect on cost and reducing the change order processing time. Additionally, the study shows that IPD-ish reduces the change order processing time as well. This is most likely because the subcontractors are in discussion with the owners and designers from the beginning of the project allowing for improved communication. This improved communication helps to quicken the change order processing time. This current study on the effects of IPD on MEP contractors confirms the results from the previous study of IPD for general contractors. The previous study also shows that change order processing time is significantly improved by IPD (El Asmar 2012).

4.3 Final Univariate Results: IPD vs. Non-IPD

This section will summarize the results of the previous section as well as compare the presented MWW test results with t-test results. Table 4-1 displays the results for all performance metrics. Shown in the first column is the performance metric. The second and third columns show the mean and median values, respectively, for IPD and non-IPD projects. The fourth column shows the p-value from the t-test while the fifth column shows the p-value from the MWW test. The performance metrics are not displayed by category; instead, they are displayed by increasing p-values.
from the MWW tests. Again, the smaller the p-value, the greater the significance is regarding the difference between IPD and non-IPD projects.

Table 4-1: Univariate Results for IPD vs. Non-IPD

<table>
<thead>
<tr>
<th>Performance Metric</th>
<th>Mean Values (IPD)</th>
<th>Median Values (IPD)</th>
<th>t-test p-values</th>
<th>MWW test p-values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Deficiencies per $Mil</td>
<td>(0.27) (4.53)</td>
<td>(0.00) (2.16)</td>
<td>0.0276</td>
<td>0.00196</td>
</tr>
<tr>
<td>Resubmittals per $Mil</td>
<td>(0.32) (1.58)</td>
<td>(0.00) (0.67)</td>
<td>0.127</td>
<td>0.0168</td>
</tr>
<tr>
<td>CO Processing Time (weeks)</td>
<td>(2.58) (4.69)</td>
<td>(1.5) (5.0)</td>
<td>0.0243</td>
<td>0.0182</td>
</tr>
<tr>
<td>Schedule Growth</td>
<td>(-5%) (11%)</td>
<td>(-3%) (10%)</td>
<td>0.0120</td>
<td>0.0208</td>
</tr>
<tr>
<td>Deficiencies per $Mil</td>
<td>(0.27) (4.53)</td>
<td>(0.00) (2.16)</td>
<td>0.0276</td>
<td>0.00196</td>
</tr>
<tr>
<td>Above are MWW results statistically significant at the 0.01 level</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Resubmittals per $Mil</td>
<td>(0.32) (1.58)</td>
<td>(0.00) (0.67)</td>
<td>0.127</td>
<td>0.0168</td>
</tr>
<tr>
<td>CO Processing Time (weeks)</td>
<td>(2.58) (4.69)</td>
<td>(1.5) (5.0)</td>
<td>0.0243</td>
<td>0.0182</td>
</tr>
<tr>
<td>Schedule Growth</td>
<td>(-5%) (11%)</td>
<td>(-3%) (10%)</td>
<td>0.0120</td>
<td>0.0208</td>
</tr>
<tr>
<td>Above are MWW results statistically significant at the 0.05 level</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rework Cost</td>
<td>(1.00) (1.58)</td>
<td>(1.00) (1.00)</td>
<td>0.244</td>
<td>0.0819</td>
</tr>
<tr>
<td>CO Effect on Cost</td>
<td>(-0.58) (-0.85)</td>
<td>(-1.00) (-1.00)</td>
<td>0.232</td>
<td>0.0859</td>
</tr>
<tr>
<td>Above are MWW results statistically significant at the 0.1 level</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Punchlist Items per $Mil</td>
<td>(1.90) (16.02)</td>
<td>(0.00) (5.03)</td>
<td>0.0680</td>
<td>0.113</td>
</tr>
<tr>
<td>Lost-Time Incident Rate</td>
<td>(0.00) (1.01)</td>
<td>(0.00) (0.00)</td>
<td>0.214</td>
<td>0.125</td>
</tr>
<tr>
<td>Lost-Time Incidents per $Mil</td>
<td>(0.00) (0.05)</td>
<td>(0.00) (0.00)</td>
<td>0.237</td>
<td>0.125</td>
</tr>
<tr>
<td>RFI Processing Time (weeks)</td>
<td>(1.55) (2.09)</td>
<td>(1.00) (2.00)</td>
<td>0.188</td>
<td>0.136</td>
</tr>
<tr>
<td>Unit Cost ($/SF)</td>
<td>(77.21) (61.64)</td>
<td>(60.24) (37.02)</td>
<td>0.576</td>
<td>0.186</td>
</tr>
<tr>
<td>Percent Change</td>
<td>(9%) (12%)</td>
<td>(6%) (11%)</td>
<td>0.544</td>
<td>0.211</td>
</tr>
<tr>
<td>PPC Trend</td>
<td>(0.36) (0.08)</td>
<td>(0.00) (0.00)</td>
<td>0.202</td>
<td>0.221</td>
</tr>
<tr>
<td>Punchlist Cost</td>
<td>(1.27) (1.75)</td>
<td>(1.00) (1.00)</td>
<td>0.203</td>
<td>0.226</td>
</tr>
<tr>
<td>RFI's per $Mil</td>
<td>(6.96) (63.65)</td>
<td>(5.91) (16.34)</td>
<td>0.0517</td>
<td>0.241</td>
</tr>
<tr>
<td>Rec. Incidents per $Mil</td>
<td>(0.03) (0.09)</td>
<td>(0.00) (0.00)</td>
<td>0.454</td>
<td>0.253</td>
</tr>
<tr>
<td>Overhead and Profit</td>
<td>(2.00) (2.50)</td>
<td>(2.00) (2.50)</td>
<td>0.185</td>
<td>0.258</td>
</tr>
<tr>
<td>Recordable Incident Rate</td>
<td>(0.89) (2.19)</td>
<td>(0.00) (0.00)</td>
<td>0.345</td>
<td>0.303</td>
</tr>
<tr>
<td>Turnover Costs</td>
<td>(1.09) (1.00)</td>
<td>(1.00) (1.00)</td>
<td>0.341</td>
<td>0.316</td>
</tr>
<tr>
<td>Shiftwork Due to Change</td>
<td>(9%) (0%)</td>
<td>(0%) (0%)</td>
<td>0.341</td>
<td>0.316</td>
</tr>
<tr>
<td>Overmanning</td>
<td>(0.08) (0.23)</td>
<td>(0.00) (0.00)</td>
<td>0.329</td>
<td>0.346</td>
</tr>
<tr>
<td>Construction Cost Growth</td>
<td>(-5%) (1%)</td>
<td>(-7%) (1%)</td>
<td>0.324</td>
<td>0.367</td>
</tr>
<tr>
<td>Construction Speed (SF/day)</td>
<td>(277) (417)</td>
<td>(211) (331)</td>
<td>0.208</td>
<td>0.379</td>
</tr>
<tr>
<td>Man-Hour Growth</td>
<td>(14%) (18%)</td>
<td>(3%) (10%)</td>
<td>0.748</td>
<td>0.427</td>
</tr>
<tr>
<td>CO Effect on Schedule</td>
<td>(0.25) (0.00)</td>
<td>(0.00) (0.00)</td>
<td>0.351</td>
<td>0.429</td>
</tr>
<tr>
<td>Amount Overtime Hours</td>
<td>(1%) (2%)</td>
<td>(1%) (1%)</td>
<td>0.345</td>
<td>0.471</td>
</tr>
<tr>
<td>Overtime Due to Change</td>
<td>(15%) (26%)</td>
<td>(0%) (0%)</td>
<td>0.497</td>
<td>0.491</td>
</tr>
<tr>
<td>Loss of Productivity</td>
<td>(-3%) (0%)</td>
<td>(-3%) (2%)</td>
<td>0.510</td>
<td>0.591</td>
</tr>
<tr>
<td>Peak / Average Man-Hour</td>
<td>(2.22) (2.4)</td>
<td>(2.13) (2.30)</td>
<td>0.501</td>
<td>0.659</td>
</tr>
<tr>
<td>Budget Factor</td>
<td>(6%) (2%)</td>
<td>(6%) (1%)</td>
<td>0.579</td>
<td>0.687</td>
</tr>
<tr>
<td>Image and Return Business</td>
<td>(1.83) (1.77)</td>
<td>(2.00) (2.00)</td>
<td>0.702</td>
<td>0.724</td>
</tr>
<tr>
<td>Total Cost Growth</td>
<td>(1%) (2%)</td>
<td>(-4%) (1%)</td>
<td>0.833</td>
<td>0.832</td>
</tr>
<tr>
<td>Systems Quality</td>
<td>(3.50) (3.62)</td>
<td>(4.00) (4.00)</td>
<td>0.702</td>
<td>0.855</td>
</tr>
<tr>
<td>Shiftwork Hours</td>
<td>(0%) (1%)</td>
<td>(0%) (0%)</td>
<td>0.572</td>
<td>0.889</td>
</tr>
<tr>
<td>Latent Defect Costs</td>
<td>(0.64) (0.64)</td>
<td>(1.00) (1.00)</td>
<td>1.000</td>
<td>0.911</td>
</tr>
<tr>
<td>Schedule Intensity</td>
<td>(16,135) (20,752)</td>
<td>(12,769) (16,551)</td>
<td>0.483</td>
<td>0.972</td>
</tr>
<tr>
<td>Warranty Costs</td>
<td>(1.18) (1.25)</td>
<td>(1.00) (1.00)</td>
<td>0.851</td>
<td>1.000</td>
</tr>
</tbody>
</table>
This table shows that the MWW results provide significant evidence that IPD reduces the deficiencies per million dollars for MEP contractors at the 0.01 level of significance. Additionally, the MWW results show significant evidence that IPD reduces the resubmittals per million dollars, reduces the change order processing time, and reduces the schedule growth for MEP contractors at the 0.05 level of significance. Finally, the MWW results also provide evidence that IPD reduces the cost due to rework and improves the change order effect on cost for MEP contractors at the 0.1 level of significance.

For a few metrics, the p-values from the t-test change significance level from the MWW test p-values. These metrics are the deficiencies per million dollars, the resubmittals per million dollars, the rework cost, the change order effect on cost, the punchlist items per million dollars, and the RFIs per million dollars. These values are bold in Table 4-1. For example, the significance level for deficiencies per million dollars changes from the 0.01 level of significance with the MWW test to a 0.05 level of significance with the t-test. As mentioned earlier, the t-test is more powerful than the MWW test if the data is normally distributed. The standard method for determining if data is normally distributed is to use Q-Q plots, which plot the observations on the y-axis and theoretical normal values of the data on the x-axis. If the points on a Q-Q plot follow a straight line, the data is normally distributed.

The metrics listed above were tested for normality. However, after examining the Q-Q plots that can be found in Appendix D, none of the data for the previously listed metrics were normally distributed. Therefore, the t-test p-values cannot substitute the MWW p-values for any metrics. Table 4-2 below shows the final univariate results. The first column shows the performance metrics while the second column shows the median values for IPD and non-IPD. The third column displays a 95% confidence interval for the difference in medians (the non-IPD median minus the IPD median). The fourth column displays the p-value and the fifth column displays the IPD effect (improvement or not improvement).
Table 4-2: Final Significant Univariate Results for IPD vs. Non-IPD

<table>
<thead>
<tr>
<th>Performance Metric</th>
<th>Median Values (IPD)</th>
<th>95% CI for ΔMedian (AMedian = Non-IPD – IPD)</th>
<th>P-Value</th>
<th>IPD Effect</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Deficiencies per $1Mil</td>
<td>(0.00)</td>
<td>(0.0545, 4.696)</td>
<td>0.00196</td>
<td>Improvement</td>
</tr>
<tr>
<td>2 Resubmittals Per $Mil</td>
<td>(0.00)</td>
<td>(1.958e-05, 0.962)</td>
<td>0.0168</td>
<td>Improvement</td>
</tr>
<tr>
<td>3 CO Processing Time</td>
<td>(1.5)</td>
<td>(5.706e-05, 4.000)</td>
<td>0.0182</td>
<td>Improvement</td>
</tr>
<tr>
<td>4 Schedule Growth</td>
<td>(-3%)</td>
<td>(1.92%, 0.25.0%)</td>
<td>0.0208</td>
<td>Improvement</td>
</tr>
<tr>
<td>5 Rework Cost</td>
<td>(1.00)</td>
<td>(-4.090e-05, 1.000)</td>
<td>0.0819</td>
<td>Improvement</td>
</tr>
<tr>
<td>6 CO Effect on Cost</td>
<td>(-1.00)</td>
<td>(-1.000, 3.280e-05)</td>
<td>0.0859</td>
<td>Improvement</td>
</tr>
</tbody>
</table>

Overall, six performance metrics show significant differences between IPD and non-IPD at the 0.1 level, four show significant differences at the 0.05 level, and one shows a significant difference at the very stringent 0.01 level. From these results, it appears that IPD has the largest impact on communication metrics for MEP contractors, as the study shows evidence that IPD outperforms non-IPD for two of the metrics in this category (resubmittals per million dollars and rework cost). The change performance metric of change order processing time is also very similar to communication metrics. Additionally, the study shows evidence that IPD outperforms non-IPD in regards to the deficiencies per million dollars (quality), the schedule growth (schedule), and the change order effect on cost (change).

4.4 Univariate Analysis: IPD vs. Design-Bid-Build, Construction Management at Risk, Design-Build

In the previous section, IPD was compared with non-IPD projects consisting of design-bid-build, construction management at risk, and design-build projects. This section, instead of comparing IPD with the non-IPD delivery systems grouped together, compares IPD to each of these project delivery systems separately using the Kruskal-Wallis test, a non-parametric test similar to an F-test. Just as the MWW test does not require the data to be normally distributed, neither does the Kruskal-
Wallis test require normality. In this section, the null hypothesis is that the median for the four
groups (design-bid-build, construction management at risk, design-build, and IPD) are equal while the
alternative hypothesis is that at least one group has a different median. IPD-ish projects were divided
into the construction management at risk, design-build, or IPD groups. For the metrics that show
evidence against the null hypothesis, pairwise t-tests were performed to identify which groups were
different. While the pairwise t-tests assume normality, the assumption is robust so the pairwise t-tests
can still give valuable insight even when data is not normally distributed.

Some of the performance metrics that are significantly different when comparing IPD to non-
IPD delivery systems together are not significantly different when compared separately. This is
because dividing the non-IPD delivery systems reduces the sample sizes, which in turn increases
variances and makes it less likely to determine significance. However, many of the performance
metrics that are not significantly different when comparing IPD to non-IPD delivery systems grouped
together are significantly different when compared separately. As will be shown later in strip charts,
this is because design-bid-build performs significantly worse than construction management at risk
and design-build for many performance metrics. Essentially, the construction management at risk and
design-build results cancelled out the poor performance of design-bid-build in many cases, making
the previous analysis comparing IPD to non-IPD not significantly different.

Table 4-3 displays the significant results of the Kruskal-Wallis test in order of increasing p-
value. Some metrics included in this table are also significant when comparing IPD to non-IPD as a
group including deficiencies per million dollars, resubmittals per million dollars, and schedule
growth. Values that were previously significant but not included in this table include the change
order processing time, rework cost, and change order effect on cost.
Table 4-3: Significant Univariate Results for IPD vs. DBB, CMR, DB

<table>
<thead>
<tr>
<th>Performance Metric</th>
<th>P-Value</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Image and Potential for Return Business</td>
<td>0.00239</td>
<td>DBB performs worst; CMR, DB, IPD same</td>
</tr>
<tr>
<td>RFIs per $Mil</td>
<td>0.00486</td>
<td>DBB performs worst; CMR, DB, IPD same</td>
</tr>
<tr>
<td>Resubmittals per $Mil</td>
<td>0.00581</td>
<td>DBB performs worst; CMR, DB, IPD same</td>
</tr>
<tr>
<td>Punchlist Items per $Mil</td>
<td>0.00714</td>
<td>DBB performs worst; CMR, DB, IPD same</td>
</tr>
</tbody>
</table>

Above are results statistically significant at the 0.01 level

<table>
<thead>
<tr>
<th>Performance Metric</th>
<th>P-Value</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lost-Time Incident Rate</td>
<td>0.0160</td>
<td>CMR worse than IPD; all others the same</td>
</tr>
<tr>
<td>Lost-Time Incidents per $Mil</td>
<td>0.0160</td>
<td>CMR worse than IPD; all others the same</td>
</tr>
<tr>
<td>Amount Overtime Due to Change</td>
<td>0.0297</td>
<td>DBB has most OT due to CO; others same</td>
</tr>
<tr>
<td>Construction Speed</td>
<td>0.0322</td>
<td>CMR performs fastest; DBB, DB, IPD same</td>
</tr>
<tr>
<td>OSHA Recordable Incident Rate</td>
<td>0.0342</td>
<td>CMR worse than IPD; all others the same</td>
</tr>
<tr>
<td>Deficiency Issues per $Mil</td>
<td>0.0384</td>
<td>No significance with pairwise t-tests</td>
</tr>
<tr>
<td>OSHA Recordable Incidents per $Mil</td>
<td>0.0465</td>
<td>CMR worse than IPD; all others the same</td>
</tr>
<tr>
<td>Schedule Growth</td>
<td>0.0481</td>
<td>No significance with pairwise t-tests</td>
</tr>
</tbody>
</table>

Above are results statistically significant at the 0.05 level

<table>
<thead>
<tr>
<th>Performance Metric</th>
<th>P-Value</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Percent Change</td>
<td>0.0829</td>
<td>No significance with pairwise t-tests</td>
</tr>
</tbody>
</table>

Above are results statistically significant at the 0.1 level

Figure 4-10 below shows strip charts comparing IPD, design-bid-build, construction management at risk, and design-build for the image and potential for return business, RFIs per million dollars, resubmittals per million dollars, punchlist items per million dollars, lost-time incident rate, and the amount overtime due to change. The strip chart for image clearly shows that design-bid-build performs worse than the three other delivery methods regarding this metric. While the median values for construction management at risk, design-build, and IPD are at “very good”, design-bid-build has a median of “good” for the image metric. Pairwise t-tests confirm this with p-values of 0.00089, 0.00045, and 0.00056 comparing design-bid-build to construction management at risk, design-build, and IPD, respectively. The strip chart for RFIs per million dollars clearly shows that the more integrated delivery systems of construction management at risk, design-build, and IPD have smaller values of this metric when compared with design-bid-build. Pairwise t-tests confirm this with p-values below 0.0001 when comparing design-bid-build to construction management at risk, design-build, and IPD. The pairwise t-tests show no difference between construction management at risk, design-build, and IPD for RFIs per million dollars. The strip chart for resubmittals per million dollars...
for MEP contractors shows a similar distribution with construction management at risk, design-build, and IPD being similar but design-bid-build having much higher values for this metric. Pairwise t-tests confirm this with p-values below 0.0001 when comparing design-bid-build to construction management at risk, design-build, and IPD. Once again, the pairwise t-tests show no difference between construction management at risk, design-build, and IPD for the resubmittals per million dollars for MEP contractors. As mentioned earlier, increased RFIs and resubmittals have a serious impact on project workflow. Similar to the results for RFIs and resubmittals, the strip charts and pairwise t-tests for punchlist items per million dollars for MEP contractors show that design-bid-build performs worse than construction management at risk, design-build, and IPD with p-values under 0.0001. Since the data for lost-time incident rate and lost-time incidents per million dollars are essentially the same, only the strip chart for lost-time incident rate is shown in the figure below. This plot shows that MEP contractors on construction management at risk projects tend to have more incidents than MEP contractors on the other delivery systems. The pairwise t-tests show that MEP contractors on construction management at risk projects have a higher lost-time incident rate than MEP contractors on IPD projects with a p-value of 0.094. All other comparisons show no significant difference. Finally, the last plot in Figure 4-10 shows strip charts comparing the amount of overtime due to changes for MEP contractors on design-bid-build, construction management at risk, design-build, and IPD projects. This plot shows that MEP contractors on design-bid-build projects tend to have a higher portion of overtime hours caused by change orders while the other three delivery systems have similar results. The pairwise t-tests confirm this with p-values of 0.0221, 0.0078, and 0.0144 comparing design-bid-build to construction management at risk, design-build, and IPD, respectively. The pairwise t-tests show that there is no difference for this metric for MEP contractors between construction management at risk, design-build, and IPD.
Figure 4-10: Strip Charts Comparing Performance Metrics for Different Project Delivery Systems
Figure 4-11 shows the remaining five significant metrics of construction speed, OSHA recordable incident rate, deficiency issues per million dollars, schedule growth, and percent change. The strip chart for construction speed appears to show that MEP contractors on construction management at risk projects complete work faster. The pairwise t-tests confirm this with p-values of 0.075, 0.075, and 0.036 when comparing the construction speed of MEP contractors on construction management at risk projects to the construction speed of those on design-bid-build, design-build, and IPD projects respectively. The pairwise t-tests show no difference between the construction speed of MEP contractors on design-bid-build, design-build, and IPD projects. Similar to the strip chart for lost-time incident rate, the strip chart for OSHA recordable incident rate shows more incidents on construction management at risk projects. The pairwise t-tests confirm this with MEP contractors on IPD projects having lower OSHA recordable incident rates than those on construction management at risk projects. All other comparisons show no significant differences. The strip chart for deficiencies per million dollars shows construction management at risk, design-build, and IPD have lower values of this metric than design-bid-build for MEP contractors. However, the pairwise t-tests cannot confirm this with all p-values greater than 0.1, most likely because the normality assumption is more than slightly violated for this metric. Similarly, the strip charts for schedule growth and for percent change appear to show that MEP contractors on IPD projects have lower values for these two metrics while MEP contractors on design-bid-build projects have higher values for these two metrics. Once again, the pairwise t-tests cannot confirm these, most likely because the normality assumption is more than slightly violated for this metric.
Figure 4-11: Strip Charts Comparing Performance Metrics for Different Project Delivery Systems (continued)
This section further investigated the effects of project delivery selection concerning many performance metrics. Similar to the previous section comparing IPD to non-IPD delivery systems lumped together, change, communication, quality, and schedule metrics are all affected by the project delivery selection. Additionally, some safety and business metrics are significantly affected by delivery system selection with this analysis. Furthermore, many of the results from this section show that the more integrated a project delivery system is, the better the performance. In most of the metrics, design-bid-build (the least integrated delivery system) performs worse than the three more integrated delivery systems.

4.5 Conclusions of the Univariate Analysis

This chapter first compared IPD to non-IPD delivery systems grouped together to determine if IPD significantly affects construction project performance metrics for MEP contractors under the categories of safety, cost, schedule, communication, quality, business, labor, and changes. This analysis demonstrated that IPD outperforms non-IPD for MEP contractors in terms of deficiencies per million dollars the most, as this metric is significant at the very stringent 0.01 level. Expanding the significance level to 0.05, IPD significantly outperforms non-IPD in regards to resubmittals per million dollars, change order processing time, and schedule growth for MEP contractors. Finally, at the least stringent level of 0.1, IPD significantly outperforms non-IPD in regards to the rework cost and the change order effect on cost for MEP contractors. Additionally, IPD-ish outperforms non-IPD for the deficiency issues per million dollars and the change order processing time for MEP contractors.

This chapter also compared IPD to the three main project delivery systems: design-bid-build, construction management at risk, and design-build. From strip charts and p-values, this analysis shows that the more integrative delivery systems tend to perform better than the less integrative delivery systems especially for communication and quality metrics.
The univariate analysis shows that IPD does not offer significant improvement for MEP contractors in terms of safety, cost, business, and labor productivity. While the study does show that IPD outperforms non-IPD for some schedule, change, and quality metrics over non-IPD projects, perhaps the greatest benefit of IPD for mechanical contractors falls under the communication category. The study shows that IPD outperforms non-IPD for two of the four communication metrics (resubmittals per million dollars and rework cost) for MEP contractors. With all the key participants including designers, owners, and contractors involved in the project from the beginning, it makes sense that IPD improves communication metrics.

While the univariate analysis does show that IPD outperforms non-IPD for six different performance metrics for MEP contractors, it is less than the prior study on general contractors that shows IPD outperforms non-IPD for seventeen different metrics, most of them at the 0.05 level (El Asmar 2012). The greatest deviance from the two studies is from the quality performance area. Once again, this is likely because many of the principles of IPD have not been used as extensively on the subcontractor level as it has on the general contractor level. For instance, many of the MEP contractors were surveyed for data on the same projects as surveyed in the previous study on general contractors. In many of the sampled projects, projects that are clearly IPD for the general contractors are only IPD-ish for the subcontractors since they are not involved in the multiparty agreement. Additionally, the previous study on general contractors used several one-sided tests resulting in lower p-values. This study chose to be more conservative by conducting only two-sided tests.

For some metrics with no conclusive evidence of a significant difference, IPD shows trends of improvement when compared with non-IPD. At a p-value of 0.113, this study nearly shows that IPD reduces the punchlist items per million dollars for MEP contractors. Similarly, with p-values of 0.125, this study almost shows conclusive evidence that IPD reduces the lost-time incident rate and the lost-time incidents per million dollars. The RFI processing time metric has a p-value of 0.136, almost enough evidence to show conclusively that IPD reduces this metric for MEP contractors. It is
very possible that future studies will find that IPD significantly improves these metrics for MEP contractors.

In addition to showing how IPD outperforms non-IPD for select performance metrics for MEP contractors, this study also provides benchmarking. MEP contractors can use the data from this study while working on IPD projects. For example, this study showed that MEP contractors on IPD projects average a schedule growth of -5%. This value can be used to determine how well subcontractors are implementing IPD principles.

While this chapter analyzed the difference between IPD and non-IPD projects for individual metrics, Chapter 5 will combine these metrics into one score. This score will be easy to use for MEP contractors in the industry. Additionally, this score will be used for this study to again compare IPD to non-IPD projects.
Chapter 5  The Project Quarterback Rating (PQR)

The Project Quarterback Rating (PQR) is a comprehensive measure of construction project performance that considers several individual performance metrics. Chapter 5 discusses the development and validation of the PQR for MEP contractors before comparing this PQR for different project delivery systems. While Chapter 4 compared IPD to non-IPD projects for several individual performance metrics, Chapter 5 will use the developed PQR to compare IPD to non-IPD with one comprehensive metric.

5.1 PQR Motivation

The motivation for developing a PQR for MEP contractors comes from the previous study on the effects of IPD that presents a PQR formula for general contractors (El Asmar 2012). In this study, the author discusses the difficulty of defining success in the construction industry including the difficulty of which metrics to consider and how to define success if a construction project performs extremely well under some metrics but very poorly for others. A single, comprehensive metric can solve both of these difficulties.

The motivation for a PQR that combines several performance metrics into one score originally came from the quarterback rating used by the National Football League (NFL). The NFL’s quarterback rating is used to compare all quarterbacks with one metric by combining individual performance metrics such as completion percentage, passing yards, touchdown passes, and interceptions (NFL 2013). In a similar fashion, the PQR for general contractor project performance combines several individual performance metrics under the categories of customer satisfaction, safety, schedule, budget, quality, profit, and communication. Examples for individual metrics used in the PQR for general contractor project performance include the recordable incident rate and the lost-time incident rate for safety performance as well as unit cost and construction cost growth for budget
performance. The PQR for general contractors is modeled as a linear function for ease of use, using techniques such as weighted averages and normalization. The uses for the PQR extend beyond analysis purposes of academia. General contractors can also use the PQR formula in El Asmar’s paper as a tool for measuring success of their company’s projects.

This current study will follow a similar methodology to develop a PQR model for MEP contractors. This model will be used later as an additional method for comparing IPD projects to non-IPD projects for MEP contractors. Additionally, MEP contractors can use the PQR developed in this study as a baseline for their company’s projects.

5.2 Mathematical Formulation and Technique

The PQR used in this study combines performance metrics under seven categories including customer satisfaction, safety, profit, budget, quality, schedule, and change management. These categories were determined from page fifteen of the data collection tool found in Appendix C where respondents identified criteria that their companies use to measure success.

The developed model computes for each project \( j \) a corresponding \( PQR_j \) that is based on the seven evaluation criteria with weights based on the responses of participants. The basic formula for the PQR is

\[
PQR_j = \sum_{i=1}^{I} w_i z_{ij}
\]

where:

- \( j \) denotes project number \( j \), \( 1 \leq j \leq J \), \( J = 32 \)
- \( w_i \) is the weight of performance area \( i \), \( 1 \leq i \leq I \), \( I = 7 \)
- \( z_{ij} \) is the normalized score for project \( j \) under performance area \( i \)
- \( s_{ij} \) is the composite score for project \( j \) under performance area \( i \)

Essentially, \( PQR_j \) is a weighted average of scores for different performance areas \( i \). The variable \( s_{ij} \) combines many different individual metrics under a performance area. For example, the performance area of customer satisfaction combines the individual performance metrics of potential for return business and whether or not claims occurred on the project. The variable \( X_{ijk} \) denotes the
original scores of the individual performance metrics where $K$ represents the number of metrics combined in performance area $i$ and $1 \leq k \leq K$. In the example for the performance area of customer satisfaction, the potential for return business and the binary claims metric are the only two individual performance metrics. Therefore, $K$ is equal to two for this performance area.

Figure 5-1 on the next page shows the structure of the PQR formula. As it happens, the MEP contractors surveyed used the same seven categories to determine success as general contractors (El Asmar 2012), although with different values for the weights. For this reason, the PQR structure for the MEP contractors in this study is the same as the PQR structure for general contractors with some minor adjustments. The figure shows three levels of PQR. The top level is $PQR_j$, which is the overall score computed for each project. The second level is $s_{ij}$, which is the score for the performance areas identified earlier, computed for each project. Finally, the third level is $X_{ijk}$, which represents the individual performance metrics under each performance area $s_{ij}$ for each project. Originally, fatalities were included under the safety performance area. Thankfully, no fatalities occurred on the project studied so this metric was removed from the formula.

One problem with computing one score from several different individual metrics is that it is not logical to add together metrics with different units. For example, the score for the budget performance area is computed through the individual metrics of unit cost measured in dollars per square foot and construction cost growth measured in percent. It is not logical to add these two metrics together since they have different units. The solution to this problem is standardization.
Figure 5-1: PQR Structure
Standardization in this methodology involves subtracting the mean score from all projects \((\mu_{ik})\) from individual project scores \((X_{ijk})\) and then dividing by the standard deviation \((\sigma_{ik})\), a process otherwise known as normalization. Since the standard deviation is in the same units as \(X_{ijk}\) and the mean, this normalized score is unit less. As a result, the normalized scores for unit cost and construction cost growth can be summed together. Positive values for normalized scores indicate above average performance while negative values indicate below average performance. The normalized value is equal to the number of standard deviations the measurement is away from the mean.

The first step in developing the PQR formula was calculating the mean and standard deviation for each individual performance metric \(X_{ijk}\) (values such as cost growth and unit cost). The mean \((\mu_{ik})\) and the standard deviation \((\sigma_{ik})\) were calculated for each individual metric through the following:

\[
\mu_{ik} = \frac{1}{J} \sum_{j=1}^{J} X_{ijk} \quad \text{and} \quad \sigma_{ik} = \sqrt{\frac{1}{J-1} \sum_{j=1}^{J} (X_{ijk} - \mu_{ik})^2}
\]

With the mean and standard deviation computed, the normalized value for the individual performance metric was computed for each project using the formula \(z_{ijk} = (X_{ijk} - \mu_{ik})/\sigma_{ik}\). With each individual performance metric normalized, the scores for each performance area for every project were computed through:

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

In this equation, \(w_{ik}\) is the weight of each individual performance metric. The weights used on this level are consistent with the prior IPD literature that used interviews with industry experts to develop the weights (El Asmar 2012). Of course, companies can use their own weights to reflect their organizational values and goals. However, just as with all weighted averages, the weights under
$s_{ij}$ must equal one. Following computation, all of the scores for $s_{ij}$ required a second level of normalization through dividing by the standard deviation. This step is shown in the equation below:

$$z_{ij} = \frac{s_{ij}}{\sigma_i}$$

The standard deviation for each performance area was calculated using the formulas

$$\sigma_i = \frac{1}{J-1} \sum_{j=1}^{J} (s_{ij} - \mu_i)^2 \quad \text{and} \quad \mu_i = \frac{1}{J} \sum_{j=1}^{J} s_{ij}.$$  Note that the quantity $u_i$ is equal to zero due to the prior normalization, which is why the normalization of $z_{ij}$ does not subtract a mean in the numerator. Similar to the $z_{ijk}$ scores, this normalization allowed a positive $z_{ij}$ to be interpreted as above average for performance area $i$ and a negative $z_{ij}$ to be interpreted as below average for performance area $i$.

This normalization step also made each score from the seven performance areas comparable with the same mean and standard deviation of zero and one respectively. This allowed proper application of the weights, $w_i$, formed for the overall PQR equation. Finally, $PQR_j$ was computed through the formula:

$$PQR_j = \sum_{i=1}^{I} w_i z_{ij}$$

The values for $PQR_j$ required normalization once more through dividing by the standard deviation. This last normalization allowed the values for $PQR_j$ to be interpreted in the same way as $z_{ijk}$ and $z_{ij}$, with positive values indicating above average overall performance and negative values indicating below average overall performance for project $j$. Additionally, this last normalization allowed the $PQR_j$ to be interpreted as how many standard deviations the project was from average performance.

As will be shown in the next section, this normalization technique is not required every time a user wishes to determine overall construction project performance. Instead, these normalizations were built into the PQR model, based off the data gathered in this study. Through the assumption that the data gathered is a representative sample of MEP contractors, the means and standard deviations
used in the PQR formula do not have to be changed. However, if a MEP construction company desires to create their own PQR formula based off projects in their company database, they can follow the same procedure outlined in the next section.

This section introduced the methodology and techniques for determining the PQR formula. The next section will discuss step-by-step the development of the PQR for MEP contractors.

5.3 The PQR Formula

The first step in developing the PQR formula was to identify the weights for each performance area. The weights are essentially the level of importance for each performance area and, as mentioned earlier, were determined through the responses of participants. On page fifteen of the data collection tool found in Appendix C, respondents were asked to list five ways in which their company measured success on their projects. The responses were grouped into performance area categories and the frequencies were totaled. Figure 5-2 shows how the respondents answered. Just as in the general contractor study, customer satisfaction had the highest response rate with 25 responses accounting for 26%. Profit had the second highest response rate, safety the third highest, budget the fourth highest, quality the fifth highest, schedule the sixth highest, and change management the lowest response rate. The percentages from Figure 5-2 were used to identify the weights ($w_i$ from the previous section) shown in Equation 1. MEP contractors in the industry can adjust these weights for their own use based on how their company quantifies success. The denominator of this formula represents the standard deviation of all project scores and acts as a normalizer for the PQR equation. As mentioned earlier, each performance area (satisfaction, safety, profit, etc.) had to be normalized first. The next several subsections will discuss the formulas developed for each performance area.
\[ PQR = 0.26 \times \text{Satisfaction} + 0.18 \times \text{Profit} + 0.16 \times \text{Safety} + 0.14 \times \text{Budget} + 0.11 \times \text{Quality} + 0.09 \times \text{Schedule} + 0.06 \times \text{Change} \]

\[ (Eq. 1) \]

Figure 5-2: Weighting for PQR Formula
5.3.1 **PQR Part 1/7: Customer Satisfaction**

The highest ranked and most important performance area is customer satisfaction. If a customer is not satisfied with the work of a mechanical or electrical contractor, he or she is likely to bar general contractors from using the underperforming subcontractor on future projects. Although this is clearly the most important performance area, it is very difficult to measure. This study uses two performance metrics for customer satisfaction: the potential for return business and whether or not the project had any claims.

Since the potential for return business clearly shows that a customer is satisfied with the work of a mechanical or electrical contractor, this metric has a higher weight of 0.75. Just as in the univariate analysis, this metric is measured on a five-point scale with a very negative impact coded as minus two, a negative impact coded as minus one, a neutral impact coded as zero, a positive impact coded as one, and a very positive impact coded as two. Whether or not the project had any claims is a binary performance metric with projects that had no claims coded as one and projects that had claims coded as zero. Since this is the only other metric under the performance area of customer satisfaction, the weight for the binary claims metric is 0.25. Since higher values of both of these metrics indicate better performance, the coefficients for both metrics are positive. When using the formula for customer satisfaction, one must use the same coding for the potential for return business and claims metrics as described above in order for the final scores to be interpretable.

The mean for potential for return business is 1.81 with a standard deviation of 0.40. Additionally, the mean for the claims variable is 0.94 with a standard deviation of 0.25. After normalizing the two metrics to obtain z-scores, the weighted average is computed for all projects giving a standard deviation of 0.76. The equation below displays the formula for customer satisfaction.

\[ \text{Customer Satisfaction} = 0.75 \times \text{Potential for Return Business} + 0.25 \times \text{Claims} \]
The equation above will compute the customer satisfaction variable necessary in order to calculate the PQR for MEP contractors. Relating back to the normalization technique outlined in the previous section, the customer satisfaction score from above is one of the seven $z_j$ that form the overall PQR equation while the potential for return business and the claims metrics are the $X_{ijk}$ that form the customer satisfaction score. Additionally, the 1.81 refers to the $\mu_{ik}$ for the return business metric and the 0.40 refers to the $\sigma_{ik}$. The 0.75 and the 0.25 refer to the individual performance metric weights of $w_{ik}$. Finally, the 0.76 refers to the standard deviation of the entire customer satisfaction performance area, or $\sigma_j$. The next section will discuss the formula for the profit performance area.

### 5.3.3 PQR Part 2/7: Profit

The second most important performance area for quantifying success for MEP contractors is the profit they receive. This differs from the ranking in the study on general contractors, which states that general contractors rank profit as the sixth most important performance area (El Asmar 2012). As mentioned in the univariate analysis, profit is a very difficult metric to obtain data for in a study. Many MEP contractors view this information as confidential. The way around this is adding overhead to the profit metric. This overhead and profit metric is the only metric that defines the profit performance area.

Just as in the univariate analysis, the overhead and profit metric is measured on a four-point scale with negative overhead and profit coded as zero, less than five percent overhead and profit coded as one, between five and ten percent overhead and profit coded as two, and between eleven and fifteen percent overhead and profit coded as three. Since this is the only metric under the profit performance area, there is no weight for this metric. Just as with the customer satisfaction metrics that are measured on scales, MEP contractors using this formula for their own purposes must use the
coded values described above for the overhead and profit metric in order to make the output interpretable.

The mean value for overhead and profit from the data is 2.24, or roughly five to ten percent of total cost, with a standard deviation of 0.93. Since overhead and profit is the only metric for this performance area, there is no need to normalize twice.

\[
\text{Profit} = \frac{\text{OH}&P - 2.24}{0.93}
\]

The above equation can be used to calculate the profit portion of the PQR formula for MEP contractors. The next section will discuss the formula for the safety performance area.

5.3.2 PQR Part 3/7: Safety

The third highest ranked performance area is safety. Safety performance is important to MEP contractors not only to avoid citations and financial implications, but also to make sure their employees get home safely each day. Safety performance is much easier to quantify since MEP contractors, like any responsible contractor, keep complete and accurate safety records. The two metrics used to define this metric are the lost-time incidents and the OSHA recordable incidents. Both metrics are standardized by millions of dollars.

Lost-time incidents tend to be more serious than OSHA recordable incidents since lost-time incidents mean that employees miss work while with OSHA recordable incidents, they do not necessarily miss work. For that reason, this study gives the lost-time incident metric a weight of 0.75. Since lost-time incidents per million dollars and OSHA recordable incidents per million dollars are the only two metrics for the safety performance area, the OSHA recordable incidents metric has a weight of 0.25. Unlike the customer satisfaction and profit performance areas, higher values of the safety performance metrics indicate worse performance. Therefore, the coefficients for lost-time incidents per million dollars and OSHA recordable incidents per million dollars are negative. This
makes the previous interpretation of positive values for above average performance and negative values for below average performance possible. In addition, since the safety performance metrics are continuous and not on a scale like the customer satisfaction and profit performance metrics, these metrics have no restrictions on the range of data.

The average for lost-time incidents per million dollars is 0.027 with a standard deviation of 0.096. The range of lost-time incidents per million dollars is between zero and 0.50. Additionally, the average for OSHA recordable incidents per million dollars is 0.067 with a standard deviation of 0.13. The range of OSHA recordable incidents per million dollars is also between zero and 0.50. After normalizing the two metrics to obtain z-scores, the weighted average is computed for all projects giving a standard deviation of 0.90 as displayed in the denominator of the equation below.

\[
\text{Safety} = -0.25 \times \frac{\text{Recordables} - 0.067}{0.13} - 0.75 \times \frac{\text{LTI} - 0.027}{0.096}
\]

The above equation can be used to compute the safety component of the PQR for MEP contractors. The next section will discuss the formula for the budget performance area.

### 5.3.4 PQR Part 4/7: Budget

The budget performance area is ranked fourth highest by MEP contractors for measuring construction project success. Just as with the safety metrics, the budget metrics are readily available for MEP contractors. The budget performance area consists of two performance metrics: unit cost of construction and the construction cost growth.

Since both budget performance metrics are equally important, they both are assigned a weight of 0.5. Just as in the univariate analysis, the unit cost is measured in dollars per square foot and the construction cost growth is measured in percentage difference between the final actual cost and the contract value plus changes. Since neither of these metrics are quantified using scales, there is no
limit to the range of values that can be used in the equation. For both metrics, an increase results in worse construction project performance. Therefore, both metrics have negative coefficients for their respective weights.

The average unit cost for the MEP contractors studied is $85.26 per square foot with a standard deviation of $80.35 per square foot. The range for this metric is between $12.67 per square foot and $341.25 per square foot. The average for cost growth is 0.017 with a standard deviation of 0.18. The range of construction cost growth extends between -0.28 and 0.52. After normalizing the two metrics to obtain z-scores, the weighted average is computed for all projects giving a standard deviation of 0.72 as displayed in the denominator of the equation below.

\[
\text{Budget} = -0.5 \times \frac{\text{UnitCost} - 85.26}{80.35} - 0.5 \times \frac{\text{CostGrowth} - 0.017}{0.18}
\]

The above formula can be used to compute the budget performance portion of the PQR formula for MEP contractors. The next section will discuss the quality performance area.

5.3.5 **PQR Part 5/7: Quality**

The quality performance area ranks fifth out of seven performance areas for MEP contractors for determining success on a construction project. Quality is a difficult performance area to measure and therefore consists of several qualitative and quantitative metrics. The first metric is the qualitative metric of systems quality. This is measured on a five-point scale with economy coded as one, standard coded as two, high coded as three, premium coded as four, and high efficiency premium coded as five. This metric is considered the most important quality metric and therefore has a weight of 0.6. The coefficient for this weight is positive, as an increase in systems quality will lead to better construction project performance. The next two quality metrics are deficiency issues per million dollars and punchlist items per million dollars. These metrics are viewed as equally important and
have weights of 0.1. The coefficients for these two metrics are negative since a higher value of this metric indicates worse performance. The last two quality metrics are the warranty and latent defect cost as a percentage of total cost measured on a five-point scale with 0% coded as zero, 0-0.5% coded as one, 0.6-1% coded as two, 1-2% coded as three, 2-3% coded as four, and >3% coded as five. These metrics are viewed as equally important and have weights of 0.1. Again, the coefficients for the weights of these two metrics are negative as an increase in these two metrics indicates worse performance. The systems quality, warranty costs, and latent defect costs are all measured on scales and therefore, must use the same coding method as described above in order to obtain interpretable results.

The average value for systems quality is 3.63 with a standard deviation of 0.71. The average value for deficiency issues per million dollars is 2.39. The standard deviation for deficiency issues per million dollars is 5.01. The range of deficiency issues per million dollars extends from zero to 22.86. The average punchlist items per million dollars is 8.54 with a standard deviation of 17.09 and a range between zero and 68.80. Finally, the average value for warranty cost and latent defect cost are 1.13 and 0.69 respectively with standard deviations of 0.78 and 0.60 respectively. After normalizing the five metrics to obtain z-scores, the weighted average is computed for all projects giving a standard deviation of 0.57 as is displayed in the denominator of the equation below.

\[
\text{Quality} = \frac{0.6 \times \frac{\text{Syst.} - 3.63}{0.71} - 0.1 \times \frac{\text{Defic.} - 2.39}{5.01} - 0.1 \times \frac{\text{Punch} - 8.54}{17.09} - 0.1 \times \frac{\text{Warran.} - 1.13}{0.78} - 0.1 \times \frac{\text{Latent} - 0.69}{0.60}}{0.57}
\]

The above equation can be used to compute the quality performance component of the PQR formula for MEP contractors. The next section will discuss the formula for the schedule performance area.
5.3.6 PQR Part 6/7: Schedule

The schedule performance area is ranked sixth out of seven by MEP contractors for determining construction project success. Schedule metrics, much like the safety and budget metrics, are easy to obtain because they are important for MEP contractors to record. The individual performance metrics under the schedule performance area include the construction speed, the schedule growth, and the schedule intensity.

All schedule metrics are continuous data meaning that there is no specific range for these values that must be used in order to obtain interpretable results. Construction speed is measured in square feet per day while the schedule intensity is a measurement of the average dollar value of construction installed per day. These metrics improve construction project performance when they increase meaning that the coefficients for construction speed and schedule intensity should be positive. Schedule growth is measured in percent difference between actual weeks for project completion and estimated weeks for project completion. Since this metric will worsen construction project performance when increased, the coefficient for schedule growth is negative. All performance metrics are considered equally important and therefore, all have weights of 0.33.

The average value for construction speed is 350.7 SF/day with a standard deviation of 255.3 SF/day. The range of this metrics extends from 54.95 SF/day to 1307 SF/day. The average schedule intensity is $24,375/day with a standard deviation of $22,690/day and a range between $2,925/day and $96,567/day. Finally, the average value for schedule growth is 0.024 with a standard deviation of 0.14. The range for this metric extends between -0.21 and 0.44. After normalizing the three metrics to obtain z-scores, the weighted average is computed for all projects giving a standard deviation of 0.67 as is displayed in the denominator of the equation below.

\[
\text{Schedule} = 0.33 \times \frac{C.S - 350.7}{255.3} + 0.33 \times \frac{\text{Intense} - 24,375}{22,690} - 0.33 \times \frac{\text{Growth} - 0.024}{0.14} \div 0.67
\]
The above formula can be used to calculate the schedule performance component of the PQR formula for MEP contractors. The next section will discuss the formula for change management performance.

5.3.7 PQR Part 7/7: Change Management

Ranked last out of seven performance areas by MEP contractors, this section discusses the change management performance area. Similar to the quality performance area, change management metrics are difficult to determine and therefore require several qualitative and quantitative metrics. Some communication metrics are included here such as RFIs per million dollars and resubmittals per million dollars. These metrics are viewed as equally important and therefore have the same weight of 0.1. As both of these metrics increase, performance worsens meaning that the coefficients for both of these metrics need to be negative. RFI processing time, another communication metric, measured in weeks is viewed as very important and thus has a weight of 0.25. The coefficient for this metric is negative, as an increase of the RFI processing time will negatively affect a project. Rework cost as a percentage of total cost is a communication metric measured on a five-point scale with 0% coded as zero, 0-1% coded as one, 1-2% coded as two, 2-3% coded as three, 3-4% coded as four, and >4% coded as five. This metric has a weight of 0.1 with a negative coefficient, as an increase in the rework cost will negatively affect a project. Finally, the last communication metric under the change management performance area is the percent plan complete (PPC) trend measured on a three-point scale with decreased coded as minus one, stable coded as zero, and increased coded as one. The weight for this metric is 0.1. The coefficient for PPC trend is positive as a higher value for this metric results in improved construction project performance. For the rework cost and PPC trend metrics, it is important to use the coding method described above in order to obtain interpretable results. Change metrics included under this category are the percent change and the change order processing time. Again, both of these metrics require negative coefficients. The percent change has a weight of
0.1 while the change order processing time is considered more important and therefore has a weight 0.25. The percent change is measured as the percentage of change order hours with respect to total project hours while the change order processing time is measured in weeks.

The average RFI time for the entire dataset is 1.90 weeks with a standard deviation of 0.94. The average change order processing time is 3.41 with a standard deviation of 2.38 weeks. The average for the PPC trend is 0.21 with a standard deviation of 0.50. The average RFIs per million dollars is 34.69 with a standard deviation of 68.84. The average resubmittals per million dollars is 0.94 with a standard deviation of 1.86. The average value of rework for is 1.37 with a standard deviation of 1.07. Finally, the average percent change is 0.091 with a standard deviation of 0.084. After normalizing the seven metrics to obtain z-scores, the weighted average is computed for all projects giving a standard deviation of 0.59 as displayed in the denominator of the equation below.

\[
C = -0.25 \times \frac{RFITime - 1.90}{0.94} - 0.25 \times \frac{ChangeTime - 3.41}{2.38} + 0.1 \times \frac{PPC - 0.21}{0.50} + 0.1 \times \frac{RFI - 34.69}{68.84} + 0.1 \times \frac{Resub. - 0.94}{1.86} + 0.1 \times \frac{Rework - 1.37}{1.07} + 0.1 \times \frac{Change - 0.091}{0.084} \frac{1}{0.59}
\]

The above formula can be used to calculate the change management portion of the PQR formula for MEP contractors. The change management performance component of the PQR formula for MEP contractors concludes the model development.

Table 5-1 below serves as a summary for the developed PQR equation. MEP contractors can determine the overall performance of their projects by using this table as a guide. The first step is to insert individual metrics into the twenty-two equations found in column four. The descriptions of each performance metric in column three are meant to guide users in this stage. The second step is to sum the individual performance metrics to obtain seven performance area sums for customer satisfaction, profit, safety, budget, quality, schedule, and change management. The third step is to divide the sum of each performance area by its respective standard deviation found in column two to
find the seven performance area scores. The final step is to sum each performance area score and divide by 0.47.

**Table 5-1: PQR Equation Summary**

<table>
<thead>
<tr>
<th>Performance Area (Weight)</th>
<th>St. Dev. of Performance Area</th>
<th>Individual Performance Metrics</th>
<th>Individual Metric Description</th>
<th>Individual Metric Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Customer Satisfaction (0.26)</td>
<td>0.76</td>
<td>ReturnBus (very negative = -2; negative = -1; neutral = 0; positive = 1; very positive = 2)</td>
<td>$0.75 \times \text{ReturnBus} - 1.81$</td>
<td>$0.40$</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Claims (1 for no claims, 0 for claims)</td>
<td>$0.25 \times \text{Claims} - 0.94$</td>
<td>$0.25$</td>
</tr>
<tr>
<td>Profit (0.18)</td>
<td>-</td>
<td>OH&amp;P (negative = 0; &lt;5% = 1; 5-10% = 2; 10-15% = 3)</td>
<td>$0.75 \times 2.24$</td>
<td>$0.93$</td>
</tr>
<tr>
<td>Safety (0.16)</td>
<td>0.88</td>
<td>Recordables (OSHA Recordable Incidents per $Mil)</td>
<td>$-0.25 \times \text{Recordables} - 0.067$</td>
<td>$0.13$</td>
</tr>
<tr>
<td></td>
<td></td>
<td>LTI (Lost-Time Incidents per $Mil)</td>
<td>$-0.75 \times \text{LTI} - 0.027$</td>
<td>$0.096$</td>
</tr>
<tr>
<td>Budget (0.14)</td>
<td>0.74</td>
<td>UnitCost (Unit Cost in $/SF)</td>
<td>$-0.5 \times \text{UnitCost} - 8.526$</td>
<td>$80.35$</td>
</tr>
<tr>
<td></td>
<td></td>
<td>CostGrowth (Difference estimated and actual)</td>
<td>$-0.5 \times \text{CostGrowth} - 0.017$</td>
<td>$0.18$</td>
</tr>
<tr>
<td>Quality (0.11)</td>
<td>0.58</td>
<td>Syst. (System Quality: Economy = 1; Standard = 2; High = 3; Premium = 4)</td>
<td>$0.6 \times \text{Syst} - 3.63$</td>
<td>$0.71$</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Defic. (Deficiency Issues per $Mil)</td>
<td>$-0.1 \times \text{Defic} - 2.39$</td>
<td>$5.01$</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Punch. (Punchlist Items per $Mil)</td>
<td>$-0.1 \times \text{Punch} - 8.54$</td>
<td>$17.09$</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Warranty Cost (0%=0; 0-0.5%=1; 0.6-1%=2; 1-2%=3; 2-3%=4; &gt;3%=5)</td>
<td>$-0.1 \times \text{Warranty} - 1.13$</td>
<td>$0.78$</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Latent Defect Cost (same as Warranty Cost)</td>
<td>$-0.1 \times \text{Latent} - 0.69$</td>
<td>$0.60$</td>
</tr>
<tr>
<td>Schedule (0.09)</td>
<td>0.69</td>
<td>C.S. (Construction Speed in SF/day)</td>
<td>$0.33 \times \text{C.S.} - 350.7$</td>
<td>$255.3$</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Intense (Schedule Intensity in $/day)</td>
<td>$0.33 \times \text{Intense} - 24.375$</td>
<td>$22.690$</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Growth (Difference estimated and actual dur.)</td>
<td>$-0.33 \times \text{Growth} - 0.024$</td>
<td>$0.14$</td>
</tr>
<tr>
<td>Change Management. (0.06)</td>
<td>0.59</td>
<td>PPC (PPC Trend: Decreasing = -1; Neutral = 1; Increasing = 1)</td>
<td>$0.1 \times \text{PPC} - 0.21$</td>
<td>$0.50$</td>
</tr>
<tr>
<td></td>
<td></td>
<td>RFI (RFIs per $Mil)</td>
<td>$0.1 \times \text{RFI} - 34.69$</td>
<td>$68.84$</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Resub. (Resubmittals per $Mil)</td>
<td>$0.1 \times \text{Resub} - 0.94$</td>
<td>$1.86$</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Rework (0%=0; 0-1%=1; 1-2%=2; 2-3%=3; 3-4%=4; &gt;4%=5)</td>
<td>$0.1 \times \text{Rework} - 1.37$</td>
<td>$1.07$</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Change (Percent Change)</td>
<td>$0.1 \times \text{Change} - 0.091$</td>
<td>$0.084$</td>
</tr>
<tr>
<td></td>
<td></td>
<td>ChangeTime (CO Processing Time in Weeks)</td>
<td>$0.25 \times \text{ChangeTime} - 3.41$</td>
<td>$2.38$</td>
</tr>
</tbody>
</table>

*Calculate a score for each individual metric by substituting metric into equation in column 4, using the description in column 3 as a guide

**Sum the individual metric scores under each performance area and divide by the value in column 2 to obtain performance area scores

***Sum the performance area scores and divide by 0.47
As was mentioned before, this study assumes the data gathered is a representative sample of the MEP construction industries meaning that the sample means and standard deviations used in the developed PQR formulas are good estimates of the population means and standard deviations. Of course, a different set of data will obtain different values but they should not deviate greatly from the sample means and standard deviations from this study. For this reason, MEP contractors wishing to use the PQR developed in this study do not have to change any of the formulas. However, a company may value certain performance areas and performance metrics differently from what the respondents of this study answered. For this reason, a mechanical or electrical construction company can change the weights, both for the individual metrics and the performance areas, to better reflect their company’s goals and values. Additionally, a mechanical or electrical construction company can use their own company data to develop their own PQR formula using the techniques described above.

The data gathered for this study contain an even distribution of MEP contractors across an even distribution of IPD and non-IPD projects. However, most of the data comes from institutional type projects with very few commercial or industrial type projects. For that reason, MEP construction companies wishing to use this formula on projects that are not institutional type projects need to be wary that results may not be as accurate with these types of projects.

5.4 PQR Validation

In the previous UW-Madison study by El Asmar (2012), the author utilized both factor analysis and multidimensional scaling to validate the PQR formula. This study used the previously developed and validated formula to validate the PQR model in this study. If the PQR model developed in this study followed the same trend, it was considered valid.

First, using the formulas described in the preceding section, the PQR was computed for all projects from which data was collected. Second, the PQR was calculated for all projects using the PQR model developed in El Asmar (2012). The PQR from each project, calculated using both PQR
formulas, are shown in Table 5-2 below. The same results are plotted in Figure 5-3. Both PQR formulas follow the same trend for the projects sampled, thus validating the PQR model developed in this study.

Table 5-2: PQR Comparison with El Asmar (2012)

<table>
<thead>
<tr>
<th>Current PQR</th>
<th>El Asmar PQR</th>
<th>Current PQR</th>
<th>El Asmar PQR</th>
<th>Current PQR</th>
<th>El Asmar PQR</th>
</tr>
</thead>
<tbody>
<tr>
<td>-2.773</td>
<td>-4.361</td>
<td>-0.075</td>
<td>0.418</td>
<td>0.652</td>
<td>0.632</td>
</tr>
<tr>
<td>-2.490</td>
<td>-1.382</td>
<td>0.001</td>
<td>0.353</td>
<td>0.663</td>
<td>0.394</td>
</tr>
<tr>
<td>-1.643</td>
<td>-0.274</td>
<td>0.020</td>
<td>0.436</td>
<td>0.776</td>
<td>0.880</td>
</tr>
<tr>
<td>-1.275</td>
<td>0.082</td>
<td>0.104</td>
<td>0.280</td>
<td>0.786</td>
<td>0.691</td>
</tr>
<tr>
<td>-0.714</td>
<td>-0.984</td>
<td>0.128</td>
<td>0.386</td>
<td>0.879</td>
<td>0.847</td>
</tr>
<tr>
<td>-0.559</td>
<td>0.615</td>
<td>0.174</td>
<td>0.458</td>
<td>0.944</td>
<td>0.971</td>
</tr>
<tr>
<td>-0.543</td>
<td>0.232</td>
<td>0.188</td>
<td>0.395</td>
<td>1.137</td>
<td>0.997</td>
</tr>
<tr>
<td>-0.491</td>
<td>0.344</td>
<td>0.216</td>
<td>0.575</td>
<td>1.201</td>
<td>1.081</td>
</tr>
<tr>
<td>-0.461</td>
<td>0.374</td>
<td>0.236</td>
<td>0.584</td>
<td>1.298</td>
<td>1.292</td>
</tr>
<tr>
<td>-0.449</td>
<td>0.043</td>
<td>0.447</td>
<td>0.709</td>
<td>1.413</td>
<td>0.900</td>
</tr>
<tr>
<td>-0.360</td>
<td>0.076</td>
<td>0.570</td>
<td>0.461</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 5-3: Comparison of PQR with El Asmar (2012)
Another method of validation is to examine the best performing projects and the worst performing projects to determine why these projects were rated in such a way. The worst performing project had a PQR of -2.771 and was a construction management at risk project. This project performed below average for six of the seven performance areas with customer satisfaction being the only performance area above average. The worst performance area for this project was safety with a normalized score of -4.999, nearly five standard deviations below average. The second worst performing project had a PQR of -2.490. This project was a design-bid-build project that performed below average in all seven performance areas. In fact, for customer satisfaction, profit, quality, and schedule, this project performed more than one standard deviation below the average. Customer satisfaction and profit were the two performance areas rated highest in importance for the MEP contractors surveyed, further hurting this project’s overall performance.

The best performing project studied had a PQR of 1.411. This project was also a construction management at risk project that performed above average in four of the seven performance areas with safety, budget, and change management being the below average performance areas. The best performance area for this project was schedule performance with a normalized score of 3.150. The best performing IPD project was fourth highest overall with a PQR of 1.136. This project performed above average in all seven performance areas with the best performance area being change management. This makes sense as the univariate analysis shows that IPD projects perform significantly better concerning change management metrics.

5.5 Comparing Performance of IPD to Non-IPD Using PQR

Chapter 4 examined the effects of IPD on MEP contractors for several individual performance metrics. The problem with this procedure is that a project may perform well under certain metrics but poorly under other metrics, making it difficult to determine the overall success of
the project. This section used the developed PQR model to compare IPD to non-IPD projects but with a comprehensive metric that gives an overall performance score for MEP contractors.

Scores for each project in the database were computed using the developed PQR formula. *Figure 5-4* below shows a strip chart comparing the PQR of MEP contractors for non-IPD, IPD-ish, and IPD projects. From the plot, the median and mean PQR for MEP contractors on IPD projects seems very similar to the median and median PQR for MEP contractors on non-IPD projects. However, statistical tests need to be performed to determine if there is a significant difference. An interesting note is that the non-IPD group has the best performing project and the worst performing project showing a large variability. The MEP contractors on IPD-ish and IPD projects have performance that is more consistent.

*Figure 5-4: PQR Comparison for Non-IPD, IPD-ish, and IPD Projects*
Just as in the univariate analysis, the MWW test was to compare the PQRs for MEP contractors on IPD projects to those on non-IPD projects. Like earlier, the MWW test was two-sided with an alternative hypothesis that IPD affected the PQR for MEP contractors. However, the result from the MWW test has a p-value of 0.728. Since this p-value is not significant at the 0.1 level of significance, the MWW test presents no conclusive evidence against the null hypothesis that IPD has no effect on the PQR for MEP contractors. However, it appears that the variance is much larger for the non-IPD group. Using Levene’s test, there is evidence at the 0.1 level of significance that the non-IPD group has a larger variance with a p-value of 0.0911. This indicates that MEP contractors on IPD projects have more consistent above average performance than the non-IPD group. Even though there is not a significant difference in PQR, MEP contractors on IPD projects gathered in this study have an average PQR of 0.180 while those on non-IPD projects have an average PQR of -0.203.

Next, the analysis was repeated except non-IPD projects were divided into design-bid-build, construction management at risk, and design-build to see if increased collaboration improves the PQR for MEP contractors. Just like in the univariate analysis, the IPD-ish projects were split into the construction management at risk, design-build, and IPD groups based on the contract type for the general contractor. *Figure 5-5* below shows the variation of PQR for design-bid-build, construction management at risk, design-build, and IPD projects side-by-side. From the plot, it is clear that construction management at risk, design-build, and IPD all have similar median and mean values for PQR. The data for construction management at risk clearly has the largest variance as this delivery method includes the project with the highest PQR but also the project with the lowest PQR. This large variance results in an average PQR of -0.113 for MEP contractors on construction management at risk projects. Design-build has a higher average PQR than construction management at risk at 0.414. IPD performs very closely with design-build regarding PQR. However, with some of the IPD projects having a lower PQR than design-build projects, the average PQR for MEP contractors on IPD projects is 0.180. This is not enough to prove that design-build significantly outperform IPD for
PQR. The main takeaway from Figure 5-5 is how poorly design-bid-build appears to perform in comparison with the three more collaborative delivery systems. None of the MEP contractors on design-bid-build projects has a positive PQR leading to an average PQR of -1.559.

The Kruskal-Wallis test was used to statistically determine if the PQRs for MEP contractors differ depending on the project delivery system selected. The Kruskal-Wallis test is a nonparametric test that, similar to the MWW test, does not require that the data be normally distributed. The null hypothesis was that all four delivery systems (design-bid-build, construction management at risk, design-build, and IPD) had the same PQR while the alternative hypothesis was that at least one of the groups was different. This test has a p-value of 0.0876, showing evidence against the null hypothesis.
at the 0.1 level of significance. *Figure 5-6* shows Q-Q plots for the PQR data on design-bid-build, construction management at risk, design-build, and IPD projects. The Q-Q plots for the separate delivery systems appear to resemble a straight line meaning the data is normally distributed and the F-test may be used.

*Figure 5-6: Q-Q Plots for DBB, CMR, DB, and IPD*
The F-test comparing the PQRs for the separate project delivery systems had the same null and alternative hypotheses as the earlier Kruskal-Wallis test in this section. This test generates a p-value of 0.0199. Therefore, there is evidence against the null hypothesis at the 0.05 level of significance. It is clear from the strip chart that the MEP contractors on design-bid-build projects have significantly lower PQRs than those on any other project delivery method. Table 5-3 below shows results from the pairwise t-tests that evaluate whether there is a difference between each project delivery system. The null hypothesis was that the two delivery systems being tested are the same, while the alternative hypothesis was that the two groups are different, meaning this was a two-sided t-test. The results in the table show no conclusive evidence that construction management at risk, design-build, and IPD have different PQRs with p-values of 0.838. However, the results do show evidence of a significant difference in PQR between design-build and design-bid-build as well as IPD and design-bid-build with p-values of 0.023 for both tests. While slightly less significant, the pairwise t-test comparing design-bid-build to construction management at risk also results in a significant difference at the 0.1 level with a p-value of 0.090. Therefore, the study concludes that MEP contractors on design-bid-build projects have worse overall performance than MEP contractors on more integrative projects such as construction management at risk, design-build, and IPD. However, this study cannot show any conclusive evidence that IPD has overall performance that is different from construction management at risk and design-build for MEP contractors.

<table>
<thead>
<tr>
<th></th>
<th>DBB</th>
<th>CMR</th>
<th>DB</th>
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</thead>
<tbody>
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<td>-</td>
<td>-</td>
</tr>
<tr>
<td>DB</td>
<td>0.023</td>
<td>0.838</td>
<td>-</td>
</tr>
<tr>
<td>IPD</td>
<td>0.023</td>
<td>0.838</td>
<td>0.838</td>
</tr>
</tbody>
</table>

This chapter developed, validated, and used PQR to show that MEP contractors on more integrated delivery systems, such as design-build and IPD, outperform design-bid-build projects for overall performance. However, this study could not show that IPD improves the PQR for MEP
contractors over construction management at risk or design-build. This study shows that IPD does not outperform non-IPD in regards to the PQR for MEP contractors as much as it does for general contractors. As has been repeated several times, this is likely because the full collaborative efforts of IPD have yet to reach the subcontractors in the same way as general contractors. Additionally, from Figure 5-4, IPD-ish has little effect on the PQR for MEP contractors. Part of the reason that IPD did not perform better than other project delivery systems in this study is because the MEP contractors surveyed valued quality and change management metrics as fifth and seventh most important respectively. These are the categories for which the univariate analysis shows that IPD performs the best. The next chapter will examine the effects of the other independent variables including the project management structure and fiscal transparency on the PQR for MEP contractors. This section will utilize regression analysis to show which independent variables affect PQR the most.
Chapter 6  Investigating Individual Delivery Characteristics

Chapter 4 analyzed the effects of IPD with the project delivery system being the only independent variable. After creating the PQR for MEP contractors, Chapter 5 followed the same method by identifying the effects of IPD on the PQR with project delivery system again being the only independent variable. This chapter will analyze the effects of other independent variables on the PQR for MEP contractors. As defined in Chapter 3, these independent variables fall under the 3Ts: tone, terms, and tools. This analysis will utilize both regression and MWW tests to determine the effects of these delivery characteristics on PQR and to determine whether IPD projects implement the tested delivery characteristics more than non-IPD projects.

6.1 Statistical Methods

The statistical methods for this chapter consist of regression analysis and MWW tests to determine if certain delivery characteristics (independent variables) have an effect on PQR (dependent variable). For the continuous variables (not binary) that make up this chapter, regression analysis was used. The output of the regression analysis consisted of four components: a scatterplot, a slope coefficient, a confidence interval for the slope coefficient, and an R-squared value. The purpose of the scatterplot was to discern if there were any significant relationship between PQR and the delivery characteristic being tested. The slope coefficient indicated whether the relationship between the PQR and the delivery characteristic tested was a direct relationship (positive slope coefficient) or an indirect relationship (negative slope coefficient). The purpose of the 95% confidence interval was to determine if the relationship between PQR and the delivery characteristic tested was significant. The meaning of the 95% confidence interval was to say there was 95% confidence that the true slope coefficient fell within this range. If the confidence interval did not include zero, the study concluded with 95% confidence that there was a significant relationship
between the PQR and the delivery characteristic. Finally, the purpose of the R-squared value was to state how much of the variance was explained by the variation of the independent variable. Values closer to one indicated strong relationships while values closer to zero indicated weak relationships. Most of the independent variables tested in this analysis showed R-squared values less than 0.4, indicating weak predictability of the regression equations. For this reason, the regression analyses in this section should not be used to predict PQR from certain delivery characteristics. The regression analysis should only be used to discern if significant relationships exist. The output for the regression analysis can be found in Appendix D. As with any regression analysis, residual analyses were performed to determine if the data followed the linear regression assumptions of linearity, constant variance, independence, and normality. These residual analyses can also be found in Appendix D.

This chapter also includes analyses for a few binary variables, or variables with yes or no answers. This portion of the analysis utilized two-sided MWW tests to show if the delivery characteristics affected PQR. These binary variables included the lump sum compensation type variable and the use of incentives variable. Just like with the univariate analysis, the null hypothesis was that the delivery characteristic had no effect on the PQR while the alternative hypothesis was that the delivery characteristic did have an effect on the PQR. If the p-value was significant, the study accepted the alternative hypothesis and rejected the null hypothesis concluding that there was evidence of a relationship between the binary variable and the PQR.

After determining if there was a relationship between PQR and the delivery characteristic being tested, this chapter used strip charts and two-sided MWW tests to determine if MEP contractors on IPD projects implemented the tested delivery characteristic more than the MEP contractors on non-IPD projects. Just as in the univariate analysis, the null hypothesis was that MEP contractors on IPD projects did not implement the delivery characteristic differently than MEP contractors on non-IPD projects. This portion of the test utilized the same three levels of significance as in the univariate analysis. If the p-value was less than 0.1, the study concluded that there was evidence that MEP
contractors on IPD projects implemented the delivery characteristic differently than those on non-IPD projects. This method was only used for the continuous variables. For the binary variables, percentages for the implementation rates of the delivery characteristic on IPD projects were compared to the implementation rates on non-IPD projects.

Just as in the univariate analysis, the mechanical and electrical datasets were combined for analysis since they were from the same population. This allowed for larger sample sizes, which decreased the variance.

6.2 Individual Delivery Characteristics Analysis

This section will analyze the individual delivery characteristics and their effect on PQR. Additionally, this section will determine if MEP contractors on IPD projects implement these delivery characteristics more often than those on non-IPD projects. This section is organized by the 3Ts: tone, terms, and tools.

6.2.1 Tone

The individual metrics under tone include the past team experience score, the current team experience score, the involvement score, the percent design complete when subcontractors are first involved, the core team leadership score, and the project management structure score. The first characteristic analyzed under tone is the past team experience score. The data collection tool found in Appendix C asks respondents to rate the past team experience of all project stakeholders (owner, designer, general contractor, subcontractors) regarding the project type, project size, project delivery system, BIM use, and the experience with other project stakeholders. An answer of none is coded as zero, an answer of little is coded as one, an answer of some is coded as three, and an answer of a lot is coded as nine. A score is computed individually for past team experience with type, size, project
delivery system, BIM, and other stakeholders by taking averages. Then, the past team experience score is just the sum of these five averages.

Figure 6-1 below shows a scatterplot with PQR on the y-axis and the past team experience score on the x-axis. The scatterplot appears to show an indirect relationship between PQR and past team experience and the regression analysis confirms this with a slope coefficient of -0.0440. Essentially, the slope coefficient is saying that for every unit increase in the past team experience score, the PQR will drop on average 0.0440. This is counterintuitive, as one would think that with more prior experience with projects of the same type, size, and project delivery system, performance would improve. However, the 95% confidence interval is from -0.094 to 0.007. Since this interval contains zero, the study cannot show conclusive evidence that a significant relationship exists between PQR and the past team experience score. The R-squared is only 0.0941 indicating a weak relationship for predictability. Additionally, it appears that the two points in the lower right corner of the plot and the one point in the upper left corner of the plot may have high influence on the regression lines. If these points were to be subtracted from the dataset, it appears that the overall pattern for PQR and past team experience score would be a direct relationship. However, Cook’s Distance values for all points are below one, therefore, none of the points have high influence. There is no justification for removing these points from the model. Still, these few points may have been by chance and led to the slope coefficient being unexplainably negative.

Next, the past team experience score for MEP contractors on IPD projects is compared with the past team experience score of those on non-IPD projects. From the strip chart shown in Figure 6-2, the median value for past team experience on IPD projects is higher but the mean is lower. Not surprisingly, due to this discrepancy, the two-sided MWW test shows no conclusive evidence that MEP contractors on IPD projects have different past team experience scores with a p-value of 0.624.
Figure 6-1: PQR vs. Past Team Experience Score

Figure 6-2: Strip Chart for Past Team Experience Score
The next delivery characteristic that this section will analyze is the current team experience score. The data collection tool asks respondents to rate their experience with the architect and owner as well as their experience with other contractors. A response of poor is coded as one, a response of fair is coded as two, a response of good is coded as three, a response of very good is coded as four, and a response of excellent is coded as five. The current team experience score is just the sum of these two responses.

As expected, the scatterplot in Figure 6-3 appears to show a direct relationship between PQR and the current team experience score. The regression analysis supports this with a slope coefficient of 0.251. This result is much more intuitive as one would expect that a more collaborative and friendly environment between project participants would improve overall construction project performance. However, the confidence interval is between -0.06 and 0.56. Since the confidence interval contains zero, there is no conclusive evidence that the current team experience has an effect on PQR. Furthermore, the R-squared value of 0.0814 indicates another weak equation for predictability.

The next step is to determine if MEP contractors on IPD projects have higher current team experience scores than those on non-IPD projects. The strip chart in Figure 6-4 shows that MEP contractors on IPD projects appear to have higher current team experience scores than those on non-IPD projects. However, the two-sided MWW test shows no conclusive evidence of a difference between IPD and non-IPD for current team experience with a p-value of 0.534.
Figure 6-3: PQR vs. Current Team Experience Score

Figure 6-4: Strip Chart for Current Team Experience Score
Next, the involvement score for the entire dataset is analyzed. On page twelve of the data collection tool found in Appendix C, the respondents are asked about their familiarity with the owner’s objectives, the degree of owner participation, the degree of design support, the degree of general contractor involvement in design, the degree of subcontractor involvement in design, and the use of co-location or the “Big Room” concept. All of these are scored on a scale from zero to nine, similar to that of the past team experience score. The involvement score is computed by summing the variables listed above and the binary variable of subcontractor involvement in risk review.

Shown in Figure 6-5 is a scatterplot with PQR on the y-axis and involvement score on the x-axis. This scatterplot shows a direct relationship between PQR and involvement score and the regression analysis supports this with a slope coefficient of 0.192. Additionally, there is evidence that this relationship is significant as the 95% confidence interval does not contain zero, ranging between 0.054 and 0.329. Essentially, the regression analysis says that for every unit increase in the involvement score, the PQR increases by 0.192 for MEP contractors. Since the PQR is on a standard normal distribution (mean of zero and standard deviation of one), the magnitude of the slope can be represented in terms of standard deviation. MEP contractors with the highest recorded involvement score in the dataset (twenty) have an overall performance 1.72 standard deviations above the MEP contractors with the lowest recorded involvement score in the dataset (eleven). This was calculated through the product of the slope coefficient (0.192) and the range of involvement scores in the dataset (nine). Like most of the regression analysis in this study, this relationship has a low R-squared value of 0.213.

The strip chart in Figure 6-6 below shows that the involvement score for MEP contractors on IPD projects is not very different from the involvement score for MEP contractors on non-IPD projects. The two-sided MWW test confirms this with a p-value of 0.507 indicating no conclusive evidence against the null hypothesis.
Figure 6-5: PQR vs. Involvement Score

Figure 6-6: Strip Chart for Involvement Score
The percent design complete before subcontractors are involved is taken directly from the data collection tool with no coding or computation necessary. The belief is that the earlier subcontractors are involved in the design, the greater the construction project performance, as the subcontractors are allowed to bring forth their experience and voice their opinion.

Shown in Figure 6-7 is a scatterplot for PQR versus the percent design complete when MEP contractors are first involved. This plot appears to show an indirect relationship between these two variables for these trade contractors. This is intuitive, as one would expect performance to improve the earlier the MEP contractors are involved since this reduces the fragmentation between design and construction phases. The regression analysis reports a slope coefficient of -1.110. Essentially, this means that an MEP contractor involved at 0% design complete should expect to, on average, have a PQR 1.110 standard deviations higher than MEP contractors involved at 100% design complete. There is no conclusive evidence that this relationship is significant using the 95% confidence interval. However, the 90% confidence interval does show a significant relationship ranging between -2.08 and -0.14. The R-squared is only 0.115, indicating weak predictability.

Figure 6-8 shows strip charts displaying distributions of design involvement for MEP contractors on non-IPD, IPD-ish, and IPD projects. The strip chart appears to show that MEP contractors on IPD and IPD-ish projects are involved earlier than MEP contractors on non-IPD projects. The p-value for the two-sided MWW test for percent design complete shows evidence against the null hypothesis at the 0.05 level with a p-value of 0.0235. From the strip chart and the p-value, this study shows conclusive evidence that MEP contractors on IPD projects are involved earlier in the design phase than MEP contractors on non-IPD projects.
Figure 6-7: PQR vs. Percent Design Complete When Trade Contractors Involved

Figure 6-8: Strip Chart for Design Complete When Trade Contractors Involved
The next characteristic to analyze under tone is the core team leadership. The core team score is calculated through a summation of the core team meeting frequency, the project authority, jointly developed goals, collaborative decision making, and lessons learned. The coded values for the components of the core team score can be found in Chapter 3.

Figure 6-9 shows a scatterplot of the PQR versus the core team score for MEP contractors. The plot appears to show a slight direct relationship with a slope coefficient of 0.00511. However, there is no evidence that this slope coefficient results in a significant relationship between PQR and core team score for MEP contractors as the 95% confidence interval contains zero, ranging between -0.022 and 0.032. Additionally, the R-squared value is very low at 0.00493.

![Core Team Leadership](image)

Next, the study will determine if there is a significant difference in the core team leadership for MEP contractors on IPD projects and the core team leadership for MEP contractors on non-IPD projects. Figure 6-10 below shows that MEP contractors on IPD projects tend to have lower core
team leadership scores than those on non-IPD projects. However, the two-sided MWW test shows no conclusive evidence of a difference in core team leadership score between IPD and non-IPD with a p-value of 0.430.

Finally, the last delivery characteristic analyzed under tone is the management structure. This characteristic combines the core team leadership score analyzed above with the cluster team score and the executive team score. The cluster team score and the executive team score are both calculated similarly to the core team score.

*Figure 6-11* below shows a scatterplot of the PQR versus the management structure score for MEP contractors. The scatterplot shows a direct relationship and the regression output displays a slope coefficient of 0.00594. However, the 95% confidence interval contains zero, ranging between -0.016 and 0.028. This means there is no conclusive evidence of a significant relationship between PQR and management structure. Additionally, the R-squared is very low at 0.0103.
Figure 6-11: PQR vs. Management Structure

Figure 6-12 below shows that the management structure score is very similar between non-IPD, IPD-ish, and IPD for MEP contractors. The two-sided MWW test confirms this with a p-value of 0.594 showing that there is no difference in management structure between MEP contractors on IPD projects and those on non-IPD projects.
Figure 6-12: Strip Chart for Management Structure

This study finds that, under the tone delivery characteristics, the uncharacteristic stakeholder involvement and the percent design complete when key trade contractors are involved all have an impact on overall construction project performance for MEP contractors. Only the percent design complete when key trade contractors are involved is found to be different between MEP contractors on IPD projects and those on non-IPD projects. For the most part, this study on MEP contractors agrees with the previous study, which finds that increased current team experience as well as increased involvement and early involvement improve the performance for general contractors (El Asmar 2012). However, the previous study also shows that increased past team experience improves overall construction project performance for general contractors. Overall, tone has a significant impact on the PQR for MEP contractors.
6.2.2 Terms

The delivery characteristics under terms include the continuous variable of fiscal transparency as well as the binary variables of lump sum compensation type and the use of incentives. In addition to the characteristics listed above, the project delivery system is another example of a term delivery characteristic. The project delivery system characteristic has already been tested in the univariate analysis as well as the PQR analysis.

The fiscal transparency score rates the fiscal transparency regarding change orders, bidding and procurement, contingency usage, and all project costs. On page thirteen of the data collection tool found in Appendix C, respondents rate the fiscal transparency with respect to the four areas mentioned above as none, a little, some, or a lot. Just as with the past team experience score and involvement scores, an answer of none is coded as zero, an answer of a little is coded as one, an answer of some is coded as three, and an answer of a lot is coded as nine. The fiscal transparency score for a particular project is computed as the average of the fiscal transparency regarding change orders, bidding and procurement, contingency usage, and all project costs.

Figure 6-13 shows a scatterplot with PQR on the y-axis and fiscal transparency score on the x-axis. The scatterplot and the regression analysis both show a slight direct relationship with a slope coefficient of 0.0158. However, the study shows no conclusive evidence that this relationship is significant as the 95% confidence interval contains zero, ranging between -0.089 and 0.121. Additionally, the R-squared value shows a weak relationship with a value of 0.00312.
Additionally, Figure 6-14 is a strip chart showing the distribution of fiscal transparency scores for MEP contractors on non-IPD, IPD-ish, and IPD projects. This figure shows that the median and mean values of fiscal transparency for MEP contractors on IPD projects are higher than the median and mean values of fiscal transparency for those on non-IPD projects. The two-sided MWW test supports the alternative hypothesis with a p-value of 0.0712 showing evidence against the null hypothesis at the 0.1 level of significance. Again, it is clear from the plot that MEP contractors on IPD projects have higher fiscal transparency scores than MEP contractors on non-IPD projects.
The next delivery characteristic under terms is the binary independent variable of incentive use. Since this is a binary variable, regression cannot be used effectively so an MWW test is used for analysis. Figure 6-15 below shows a strip chart displaying the distribution of PQR for MEP contractors who used an incentives clause and the PQR of those who did not use an incentives clause. The strip chart shows that the median and mean values of PQR are very similar for MEP contractors using incentives and MEP contractors not using incentives. The alternative hypothesis that incentives clauses change the PQR is not supported by the two-sided MWW test with a p-value of 0.617. The study shows no conclusive evidence that the PQR is different for MEP contractors using an incentives clause. Overall, MEP contractors on IPD projects use an incentives clause 83% of the time while those on non-IPD projects use an incentives clause only 8% of the time.
The last variable to analyze under terms is the binary independent variable of lump sum compensation. Since this is a binary variable, the study cannot utilize regression effectively and will rely instead on MWW tests. Shown below in Figure 6-16 is a strip chart displaying the distribution of PQR for MEP contractors with lump sum compensation and MEP contractors without lump sum compensation. The distribution shows that MEP contractors using lump sum compensation have slightly lower median PQRs than those not using lump sum compensation. However, the two-sided MWW test shows no conclusive evidence against the null hypothesis with a p-value of 0.113. Overall, the dataset shows that MEP contractors on IPD projects use lump sum compensation on zero projects while MEP contractors on non-IPD projects use lump sum compensation on 50% of projects.
Figure 6-16: Strip Chart for Lump Sum Compensation (Binary Independent Variable)

This study shows no conclusive evidence that the terms affect the PQR for MEP contractors. However, MEP contractors on IPD projects have much higher fiscal transparency scores than MEP contractors on non-IPD projects. Additionally, the implementation rates of the binary variables appear to show differences between IPD and non-IPD for MEP contractors. This study partially agrees with the previous study on general contractors as the previous study shows that the lump sum compensation variable is the only term delivery characteristic to affect overall construction project performance (El Asmar 2012). Essentially, both the previous study on general contractors and this study on MEP contractors agree that the term delivery characteristics, other than the project delivery system, have little effect on overall performance.

6.2.3 Tools

The only two delivery characteristics included under tools are the lean principles score and the BIM use score. Both of these independent variables are continuous so regression analysis can be
used. The first delivery characteristic that this section will discuss is the lean principles score. This score is the summation of the pull planning score, the Last Planner score, the just-in-time delivery score, the 5S score, the target value design score, the set-based design score, and the value stream mapping score. The pull planning score is the product of the pull planning frequency (never coded as zero, monthly coded as one, weekly coded as two, and daily coded as three) and the pull planning effectiveness (not used coded as zero, little effectiveness coded as one, some effectiveness coded as two, and very effectively coded as three). The Last Planner score is the summation of the Last Planner use, the weekly commitments use, and the percent plan complete tracking use with answers of none coded as zero, answers of a little coded as one, answers of some coded as three, and answers of a lot coded as nine. The just-in-time delivery score is computed through the product of just-in-time delivery use (none coded as zero, a little coded as one, some coded as three, and a lot coded as nine) and the just-in-time delivery definition (site warehouse coded as one, minor storage coded as three, and material directly off truck coded as nine). The remaining metrics that make up the lean principles score are just rated on their use with none coded as zero, a little coded as one, some coded as three, and a lot coded as nine. To give all of the inputs to the lean principles score the same weight, the pull planning score and the Last Planner score must be divided by three and the just-in-time delivery score must be divided by nine.

The scatterplot in Figure 6-17 shows a direct relationship with PQR and the lean principles score. The regression analysis confirms this with a slope coefficient of 0.0242. Additionally, there is evidence of a significant relationship since the 95% confidence interval does not contain zero, ranging between 0.002 and 0.046. Essentially, this means that for every unit increase in the lean principles score, the PQR is expected to increase by 0.0242. In terms of standard deviation, MEP contractors with the highest recorded value of lean principle score (sixty-three) have a PQR 1.525 standard deviations higher than those with the lowest recorded value of lean principles score (zero). Like most of the regression analyses in this chapter, the R-squared value indicates a weak relationship at 0.143.
Figure 6-17: PQR vs. Lean Principles

Figure 6-18 below shows strip charts for the lean principles score for MEP contractors on non-IPD, IPD-ish, and IPD projects. The strip charts show that the MEP contractors on IPD projects have higher median and mean values of lean principles score compared to those on non-IPD projects. The two-sided MWW test supports the alternative hypothesis with a p-value of 0.0913. However, the t-test shows no conclusive evidence against the null hypothesis with a p-value of 0.145. The data must be tested for normality. Figure 6-19 below shows Q-Q plots for the lean principles score. Since the data for both plots appears to follow a straight line, the data is normally distributed and the t-test is more appropriate. Therefore, with a p-value of 0.145, the study shows no conclusive evidence that lean principles are used differently between IPD and non-IPD for MEP contractors. This is in agreement with Cho and Ballard (2011), which shows that IPD projects do not implement lean principles such as Last Planner more than non-IPD projects.
The only other delivery characteristic under tools is the BIM score. The BIM score is computed through the product of the BIM functions score and the BIM effectiveness score. The BIM functions score is computed as an average of the different BIM uses (visualization, space validation,
etc.) with none coded as zero, a little coded as one, some coded as three, and a lot coded as nine. The BIM effectiveness score is computed as the sum of the BIM past experience (used earlier in the past experience score) and the binary variables of the use of BIM protocol, allowance for right of reliance, and the use of joint servers.

The scatterplot in Figure 6-20 shows a slight direct relationship between PQR and the BIM score. The regression analysis confirms this with a slope coefficient of 0.00851 but there is no conclusive evidence that this relationship is significant since the 95% confidence interval contains zero, ranging between -0.020 and 0.037. Additionally, the R-squared value indicates a weak relationship with a value of 0.0125.

![BIM Use](image)

**Figure 6-20: PQR vs. BIM Use**

Additionally, Figure 6-21 shows a strip chart depicting the BIM score for MEP contractors on non-IPD, IPD-ish, and IPD projects. It appears from the strip chart that MEP contractors on IPD projects actually have lower median and mean values of BIM score than those on non-IPD projects.
However, the two-sided MWW test does not support the alternative hypothesis with a p-value of 0.294. The study shows no conclusive evidence of a difference in BIM use between IPD and non-IPD for MEP contractors.

Overall, tools have a small impact on the PQR for MEP contractors as only the lean principles score leads to improved construction project performance. However, the BIM score shows no significant relationship with PQR for MEP contractors. This is somewhat in agreement with the previous study that shows both the lean principles score and the BIM score significantly improve construction project performance for general contractors (El Asmar 2012). The reason for the difference in BIM may be that many subcontractors are still not using BIM to the same extent that general contractors are. BIM software for MEP designers and contractors, such as Revit MEP, still has room for improvement before it can be widely used.
6.3 Individual Delivery Characteristics Conclusion

This chapter examined the effects of the individual delivery characteristics under the 3Ts (tone, terms, and tools), on PQR for MEP contractors. Table 6-1 displays a summary of the analysis. The first column displays the category of delivery characteristic as defined by the 3Ts. The second column displays the delivery characteristic. The third column displays whether or not there is a significant relationship between PQR for MEP contractors and the delivery characteristic from column two. This column states whether there is no relationship, an indirect relationship, or a direct relationship. Finally, column four displays whether or not there is a difference in implementation between MEP contractors on IPD projects and those on non-IPD projects. For the continuous independent variables, this column states if there is no difference between IPD and non-IPD, more with IPD, or less with IPD. For the binary variables, this column restates the implementation rate in terms of percentages of MEP contractors on IPD projects and those on non-IPD projects.

<table>
<thead>
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<tr>
<td></td>
<td>Current Team Experience</td>
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<td>No</td>
</tr>
<tr>
<td></td>
<td>Involvement</td>
<td>Direct</td>
<td>No</td>
</tr>
<tr>
<td></td>
<td>% Design Complete</td>
<td>Indirect</td>
<td>Earlier with IPD</td>
</tr>
<tr>
<td></td>
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<td>No</td>
</tr>
<tr>
<td></td>
<td>Management Structure</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>TERMS</td>
<td>Fiscal Transparency</td>
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<tr>
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<td>Lean Principles</td>
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<tr>
<td></td>
<td>Use of BIM</td>
<td>No</td>
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</tr>
</tbody>
</table>

From this table, one can see that of the 3Ts, the delivery characteristics under tone have the greatest impact on overall construction project performance for MEP contractors. Three of the six
delivery characteristics under tone have a significant relationship with the PQR. Under tone, this study shows that an increase in the involvement score increases the PQR for MEP contractors. Additionally, the study shows that earlier involvement in the design phase improves PQR for MEP contractors. Not including the project delivery system characteristic analyzed in Chapter 4 and Chapter 5, the terms have no impact on MEP contractors as none of the other term delivery characteristics show a significant relationship with PQR. However, the term characteristics show the largest difference between IPD and non-IPD for MEP contractors. The tool delivery characteristics have a slight impact on MEP contractors since the lean principles score has a significant relationship with PQR.

This current study on the effects of delivery characteristics on the performance of MEP contractors is mostly in agreement with the previous study on general contractors. Both studies show that the delivery characteristics under tone have a larger impact than either of the other 3Ts. However, there are some differences between the two studies. The previous study on general contractors finds that BIM improves performance for general contractor but the current study shows that BIM has no effect on MEP contractors. This is most likely because BIM is not as widely used by subcontractors as it is by general contractors.

Perhaps the greatest contribution from this chapter is that it shows the delivery characteristics that can best improve construction project performance without using a multiparty contract. In many situations, IPD is not an option either because the owner is unwilling to take on extra risk or because statutes do not permit the use of IPD on certain projects. Of the three characteristics that are shown to improve overall performance (increased involvement and collaboration, earlier involvement of key subcontractors in design, and greater use of lean construction principles), only the early involvement of key subcontractors is different between MEP contractors on IPD projects and those on non-IPD projects. This means that the characteristics of increased involvement and collaboration as well as greater use of lean construction principles are independent of IPD and a multiparty contract.
Therefore, when a project is constrained from using IPD, the stakeholders can still focus on these two characteristics to improve overall performance.
Chapter 7  Conclusion

7.1 Summary of Research Methods

This thesis studied the effects of IPD on MEP contractors using several statistical methods. The univariate analysis was used to determine the effect that IPD has on individual performance metrics for MEP contractors. This included thirty-eight performance metrics under several categories including safety, cost, schedule, communication, quality, business, labor, and changes. The univariate analysis involved statistical tests such as the Mann-Whitney-Wilcoxon (MWW) test, the t-test, and the Kruskal-Wallis test. Next, a comprehensive metric called the Project Quarterback Rating (PQR) was developed for use by MEP contractors to determine the overall success on their projects. For this study, the same methods used in the univariate analysis were again used to test whether IPD affects the overall performance of MEP contractors. Finally, several project delivery characteristics were analyzed using regression and MWW tests to determine the effect that these characteristics have on the PQR for MEP contractors. Additionally, the MWW test was performed to determine if MEP contractors on IPD projects implement these delivery characteristics differently than MEP contractors on non-IPD projects.

The next section will discuss the key results and contributions of this research to the construction industry. Additionally, the following sections will discuss the research limitations, barriers to IPD implementation, future research, and final remarks.

7.2 Summary of Results and Contributions

The objectives mentioned at the beginning of this document were met and provide several contributions to the MEP construction industries. These include:
1. **IPD Performance:** This study shows evidence that IPD outperforms non-IPD in several performance categories for MEP contractors. These include quality, communication, schedule, and change metrics. Perhaps the greatest benefit of IPD for MEP contractors is the impact on communication metrics. The study shows conclusive evidence that IPD outperforms non-IPD for the resubmittals per million dollars and the rework cost under the communication category. Additionally, the change performance metric of change order processing time is very similar to communication metrics. In addition to the three metrics listed above, this study shows conclusive evidence that IPD outperforms non-IPD for deficiencies per million dollars under the quality performance area, the schedule growth under the schedule performance area, and the change order effect on cost under the change performance area for MEP contractors. These results align with previous UW-Madison research on the effects of IPD on general contractors. This prior study also shows that IPD affects quality and communication metrics most significantly for general contractors (El Asmar 2012). However, this prior study also shows IPD outperforms non-IPD for seventeen different metrics, covering all performance categories except cost. One reason that IPD may have a greater effect on general contractors than on MEP contractors is that IPD has not yet reached its full potential for subcontractors. In many instances, projects that are clearly IPD on the general contractor level, are only IPD-ish on the subcontractor level as these key subcontractors are not included in the multiparty agreement. Another reason that the previous study concludes that IPD offers improved performance for a wider range of metrics is because this prior study utilizes mostly one-sided tests. In the current study, two-sided tests are utilized to remove any bias towards IPD and to stay conservative. Overall, this study shows that IPD offers improved performance for six performance metrics under the areas of schedule, communication, quality, and changes.

2. **PQR Development:** This study develops a single comprehensive performance metric called the PQR for MEP contractors that considers twenty-two individual performance metrics under the
seven performance areas of customer satisfaction, profit, safety, budget, quality, schedule, and change management. With this metric, the study again compares IPD to non-IPD for MEP contractors. As a result of this comparison, the study finds no difference in PQR between IPD and non-IPD for MEP contractors. However, when comparing IPD to design-bid-build, construction management at risk, and design-build, this study finds that design-bid-build leads to significantly worse overall construction project performance than the three more integrative delivery methods. However, the study finds no evidence of a difference in overall performance between IPD, design-build, and construction management at risk for MEP contractors. This current study on MEP contractors deviates slightly from the previous study on general contractors, which finds that general contractors on IPD projects have higher PQRs than general contractors on non-IPD projects. Again, this may be because subcontractors are not fully involved in the IPD process as mentioned earlier. Another explanation is that, from the univariate analysis, IPD affects quality and change management metrics the most for MEP contractors. However, these two performance areas are rated fifth and seventh in importance by MEP contractors surveyed. This leads to smaller weight coefficients of these performance areas for the PQR equation.

3. **Delivery Characteristics**: In addition to the project delivery system, this study identifies other delivery characteristics that lead to improved construction project performance for MEP contractors. These delivery characteristics fall under one of the 3Ts: tone, terms, and tools. The study shows that the delivery characteristics under tone have the greatest effect on overall construction project performance. For MEP contractors, improvements in overall performance are related to more collaborative involvement of project stakeholders and the percent design complete when key trade contractors are first involved. Additionally, increased past team experience is shown to decrease overall construction project performance, a result that is not intuitive. Other than the project delivery system selected, this study shows that the delivery
characteristics under terms have no effect in improving the overall construction project performance for MEP contractors. Finally, under tools, the study shows that the use of lean construction principles leads to improved overall performance for MEP contractors. Perhaps the most important contribution of this study comes from comparing the implementation of these three delivery characteristics (collaboration through increased involvement, percent design complete when key trade contractors involved, and use of lean construction principles) between IPD and non-IPD for MEP contractors. This comparison shows that increased collaboration and use of lean construction principles are not implemented any differently on IPD projects. Essentially, these two characteristics are independent of IPD. This is key as many situations restrict the use of pure IPD with a multiparty contract. If this is the case, the MEP contractors, along with other key project stakeholders, should focus on improved collaboration through increased involvement and the use of lean construction principles.

4. **Recommendations to MEP Contractors:** Since IPD and other integrative delivery systems improve several individual performance metrics as well as overall construction project performance, it is recommended that MEP contractors pursue IPD and other integrated opportunities. Perhaps most importantly, MEP contractors should pursue projects where they are involved in the design as early as possible. This study recommends to all project stakeholders, including general contractors, owners, and designers, to be involved in all phases of the project. In situations where pure IPD through a multiparty contract is not permissible, MEP contractors should focus on improved collaboration and use of lean construction principles. Finally, this study recommends that MEP contractors use the developed PQR to measure the overall performance of their projects.
7.3 Research Limitations

The first limitation of this research is that the results only apply to MEP contractors as this is the sampled population. The study cannot say that IPD outperforms non-IPD from the viewpoint of other project stakeholders or other subcontractors including, for example, structural steel subcontractors and glazing subcontractors.

Secondly, the collected data is not a random sample. Since IPD is still a novel concept, there are very few examples of IPD projects. Therefore, a random sample is very unlikely to draw any IPD projects. Instead, publications from Engineering News Record and the American Institute of Architects had to be reviewed to discover IPD projects from which to potentially receive data (ENR 2009, 2010, 2011; AIA, 2007, 2008, 2009, 2010, 2011). Randomness insures that the collected data points are independent. However, there is no reason to believe that any of the collected data points in this study are dependent on each other. Even without the data being randomly collected, this study still gives excellent insight into the effects of IPD on various performance metrics for MEP contractors.

Another limitation to this study is the small sample size. Compared to the prior literature on project delivery systems, this study has a small sample size of only thirty-two projects. Dividing the samples into smaller sub-samples, there are thirteen non-IPD projects, seven IPD-ish projects, and twelve IPD projects. Further dividing the sample into project delivery systems, there are three design-bid-build, eight construction management at risk, six design-build, and fifteen IPD projects. Smaller sample sizes increase the variance leading to a smaller chance of finding data significantly different between IPD and non-IPD. It is possible with a larger sample size, some of the metrics close to being significantly different may become significantly different. Examples of these metrics include punchlist items per million dollars, lost-time incident rate, lost-time incidents per million
dollars, and RFI processing time. All of these nearly significantly different metrics show that IPD tends to improve these metrics over non-IPD for MEP contractors.

The final limitation of this study is that the projects examined are for the most part complex, institutional projects such as healthcare facilities and research laboratories. This makes sense as IPD is most often used for complex projects for which IPD is a great benefit. The same results may not occur for less complex projects.

7.4 Barriers to IPD Implementation

Several issues addressed in the literature review are obstacles to widespread implementation of IPD. These are mainly cultural and legal barriers. As mentioned in the literature review, cultural barriers include professional cognitive impairments and institutional adaptive challenges. Professional cognitive impairments refer to professionals working in the construction industry for many years who are more resistant to change. In some cases, these individuals find it difficult to implement new principles such as those of IPD. Institutional adaptive challenges refer to the challenges facing organizations that are trying to implement integrative approaches to project delivery. These include the training of employees, changing of the organizational structure, and allocating risk.

In addition to cultural barriers, legal barriers refer to insurance issues related to IPD as well as fairness in public projects. In many public sector projects, competitive bidding is required to avoid favoritism. Since potential contractors need to bid at 100% design completion, there is no opportunity to involve general contractors and key subcontractors early in the design phase. However, this challenge is similar to the challenges faced by design-build for use in public sector, which were eventually overcome in most states.
In order for the use of IPD and other integrated approaches to project delivery to become more widespread, their benefits must continue to be identified and the cultural and legal barriers must be addressed.

7.5 Future Research

This current study on the effects of IPD on MEP contractors follows in the footsteps of previous UW-Madison research studying the effects of IPD on general contractors. This study is the first quantitative assessment of IPD performance specifically for MEP contractors. Current studies at UW-Madison include the effects of IPD on owners as well as a follow-up study on the effects of IPD on general contractors. A possible future study could quantify the effect of IPD on architects and other designers.

The current study could also be expanded by future research. By adding more projects to the dataset, the study could draw conclusions more confidently. Additionally, the follow up study on the effects of IPD on MEP contractors could form a more representative sample of the MEP construction industries. A future study could also examine the dollar impact of some of the performance metrics such as safety incidents, deficiencies, resubmittals, and changes. Finally, data can be gathered to measure the waste on projects to examine if IPD significantly reduces the amount of waste on construction projects.

7.6 Final Remarks

This study shows evidence that IPD outperforms non-IPD for several performance metrics. These include improvements in deficiencies per million dollars, resubmittals per million dollars, change order processing time, schedule growth, rework cost, and the change order effect on cost. This study also develops a Project Quarterback Rating (PQR) for use by MEP contractors. While the study cannot show that IPD outperforms construction management at risk and design-build for the
PQR, the study shows that these three integrative approaches perform significantly better than the traditional design-bid-build approach to project delivery for MEP contractors. Finally, this study shows other delivery characteristics that lead to improved construction project performance including improved collaboration through increased involvement, percent design complete when key trade contractors are first involved, and the use of lean construction principles.

This research shows evidence that IPD can provide benefits to subcontractors as well as general contractors. Future studies may show more positive effects of IPD for other project stakeholders as IPD appears to solve many of the issues faced by the construction industry. However, before IPD can be implemented in a widespread manner, several barriers must be addressed including cultural and legal challenges. With the improved performance that IPD offers, integrated projects may be the future of the construction industry.
Appendix A: Bibliography


NASFA, COAA, APPA, AGC, and AIA. (2010). *Integrated Project Delivery For Public and Private Owners*.


Appendix B: Glossary of Terms and Acronyms

The section following contains definitions of several terms used in this document. The sources for these definitions include AIA 2007b, 2011; Ballard 2008; CII 2005, 2007a; El Asmar 2012; Forbes and Ahmed 2011; Kim and Dossick 2011; LCI 2012; Salem et al. 2005.

Glossary

**5S:** an approach to eliminating waste through five steps (sort, set in order, shine, standardize, sustain)

**Building Information Modeling (BIM):** a model-based digital design process of generating and managing project and building data so that the knowledge created throughout the model development is more usable, accessible and transparent

**Cluster Teams:** interdisciplinary teams of subject matter experts, comprised of owners, designers and trade specialists, assembled to handle specific design and production areas

**Co-location (Big Room Concept):** a collaborative method where project participants conduct their day-to-day work in the same physical space; otherwise known as the “Big Room”

**Core Team Leadership:** a group responsible for major project decision-making comprised of representatives from a minimum of the owner, contractor and designer teams

**Early Trade Involvement Packages (ETIPs):** engaging select, major trade contractors at some early (to-be-determined) point in the creative phase. Likely trades include various MEP and enclosure subs
Executive Team: a small group of the most senior stakeholders from the Owner, Architect and Contractor organizations. Executive team meetings are held monthly and are intended as review and affirmation events more so than functional decision-making events

Integrated Form of Agreement (IFOA): the original standard form for an IPA

Integrated Project Agreement (IPA) (Multiparty Agreement): a single written multiparty contract linking all key IPD project participants (owner, designer, constructor, and often key consultants and subcontractors), that specifies their respective roles, rights, obligations, and liabilities

Integrated Project Delivery (IPD): a delivery system distinguished by a multiparty agreement and the very early involvement of the key participants

IPD-ish: a project that uses some IPD principles but not a multiparty contract

Joining Agreement: a written document linking two or more project stakeholders. Format can range from informal Memo of Understanding to a more formal full-blown legal contract

Just in Time Delivery (JIT): delivers the right items at the right time in the right amount

Last Planner System (LPS): a production control tool that smoothes construction project task workflow

Lean: lean manufacturing, or simply lean, is a business philosophy and production practice of maximizing customer value and minimizing waste

Lean Construction: a production management approach to construction projects, aimed at maximizing value and minimizing waste
**Lean Project Delivery System (LPDS):** a project delivery system that incorporates lean thinking for managing project. LPDS has five, interconnected stages: Project Definition, Lean Design, Lean Supply, Lean Assembly and Use

**Percent Plan Complete (PPC):** a measure of workflow reliability, calculated by dividing the number of actual task completions by the number of planned task completions

**Project Delivery System (PDS):** a system that determines the relationships between the different project stakeholders and their timing of engagement to provide a facility

**Pull Planning:** a scheduling tool that works backward from desired condition to current condition, pulling production items into the system only as needed

**Reliable Promising:** a commitment management system that measures Percentages of Promises Completed (PPC). A promise should not be made if there is any doubt that it can be fulfilled

**Set Based Design (SBD):** an approach that defers design decisions to the “last responsible moment” to allow for the evaluation of several alternatives against all design criteria

**Target Value Design (TVD) or Target Costing:** a collaborative process that is iterative in nature, and consists of establishing early financial targets for the project and then designing to a detailed estimate rather than estimating based on a detailed design, in order to drive innovation

**Value Stream Mapping (VSM):** a tool used to visualize material and information flows of project activities in order to minimize waste. VSM helps understand work processes and identify sources of waste by distinguishing between value-added and non-value-added activities
**Acronyms**

<table>
<thead>
<tr>
<th>Acronym</th>
<th>Description</th>
</tr>
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<tbody>
<tr>
<td>AEC</td>
<td>Architecture / Engineering / Construction</td>
</tr>
<tr>
<td>AIA</td>
<td>American Institute of Architects</td>
</tr>
<tr>
<td>CM/GC</td>
<td>Construction Manager or General Contractor</td>
</tr>
<tr>
<td>CMR</td>
<td>Construction Management at Risk</td>
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<tr>
<td>CII</td>
<td>Construction Industry Institute</td>
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<tr>
<td>CO</td>
<td>Change Orders</td>
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<tr>
<td>DB</td>
<td>Design-Build</td>
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<tr>
<td>DBB</td>
<td>Design-Bid-Build</td>
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<tr>
<td>GC</td>
<td>General Contractor</td>
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<tr>
<td>GMP</td>
<td>Guaranteed Maximum Price</td>
</tr>
<tr>
<td>IPD</td>
<td>Integrated Project Delivery</td>
</tr>
<tr>
<td>IPD-ish</td>
<td>IPD project with no multiparty contract</td>
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<tr>
<td>LCI</td>
<td>Lean Construction Institute</td>
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<tr>
<td>LCJ</td>
<td>Lean Construction Journal</td>
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<tr>
<td>LTI</td>
<td>Lost-Time Incident</td>
</tr>
<tr>
<td>MEP</td>
<td>Mechanical, Electrical, Plumbing, and Fire Protection Trades</td>
</tr>
<tr>
<td>MWW</td>
<td>Mann-Whitney-Wilcoxon</td>
</tr>
<tr>
<td>OSHA</td>
<td>Occupational Safety and Health Administration</td>
</tr>
<tr>
<td>OT</td>
<td>Overtime</td>
</tr>
<tr>
<td>Q-Q Plots</td>
<td>Quantile-to-Quantile Plots</td>
</tr>
<tr>
<td>RFI</td>
<td>Request for Information</td>
</tr>
<tr>
<td>RI</td>
<td>(OSHA) Recordable Incidents</td>
</tr>
</tbody>
</table>
Appendix C: Data Collection Tool

SECTION I: PROJECT CHARACTERISTICS & CONTRACT

Person completing this survey:
Name _________________________________________
Address _______________________________________

Telephone __________________________ Fax ___________ Email __________________

Would you prefer correspondence by email or telephone (please circle one)?
What is the best time to reach you? ___________________________________________

What position do you hold with your company?
☐ Owner ☐ Superintendent ☐ President
☐ Project manager ☐ Vice president ☐ Other (specify) ____________________________

Your Company name _____________________________________________
Project name _________________________________________________________
Project location _______________________________________________________
Year your company’s work was completed on the project _________________

For this project, your company acted as a:
☐ Electrical Subcontractor
☐ Mechanical Subcontractor
☐ Subcontractor Design-Build

What was the specific work that was self-performed by your company on this job?

**Mechanical**
☐ HVAC
☐ Plumbing
☐ Fire Protection
☐ Process Piping
☐ Sheet Metal Work
☐ Other: ________________

**Electrical**
☐ Electrical
☐ Communications
☐ Electronic Safety and Security
☐ Integrated CSI
☐ Other: ________________

1. Project type:
☐ Commercial (banks, retail, office buildings, etc.)
☐ Institutional (hospitals, correctional facilities, schools, etc.)
☐ Industrial or Manufacturing
☐ Residential
☐ Heavy Civil/Highway
☐ Other (please specify) ________________________________

2. Planned Building gross square footage
   sqft

Final Building gross square footage

Number of floors
floors

Site size
sqft

3. What type of construction was this project?
   □ New construction __________ %
   □ Addition or expansion __________ %
   □ Renovation __________ %

   \[\text{Sum} = 100\%\]

**Delivery and Contract**

1. What was the Project Delivery System used on this project?
   □ Design Bid Build (DBB) / “hard money” single prime / Plans and Specifications
   □ 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?
     - If no, was there a multiparty contract used at the general contractor level for which you signed a joining agreement effectively making you a part of the shared risk and reward? □ No □ Yes
     - 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 the electrical/mechanical subcontractor.
   □ Lump sum
   □ Cost + fee
   □ %or □ fixed
   □ GMP
   □ Unit price
   □ Time & Mat
   □ Negotiated
   □ Fee
   □ Other: _______
3. What percentage of the electrical/mechanical design time was completed when the GMP was established?
   □ Not GMP    □ ___% of design time

4. How much contingency did the electrical/mechanical subcontract include to account for unknown project risk? ___%  

5. Which of these parties were involved in the design phase?
   □ CM/GC
   □ Electrical Subcontractor
   □ Mechanical Subcontractor
   □ Other 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: ______

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

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

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

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

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

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

7. Rate the existence of regulatory/legal constraints: Many □ Few □ None □
   How problematic were they, on average? Very □ Somewhat □ Not at all □

SECTION II: PROJECT PERFORMANCE

Safety Performance (for mechanical/electrical scope of work)
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 (costs should include labor, materials, equipment, any subcontracted
work, overhead and profit)
1. Please specify the following project costs for the electrical/mechanical scope of work.
   a. Bid / Initial GMP / Target Value $________
   b. Contract Value or Target, including changes/GMP increase $________
   c. Final Actual Costs $________
2. Was there any portion of the electrical/mechanical work that was performed by subcontractors? □ Yes □ No

3. If so, what was the total subcontractor cost? $________

Schedule Performance
Please provide the following schedule information for the electrical/mechanical scope of work:

1. The estimated project duration at contract award ________ calendar weeks
2. The actual project duration at completion ________ calendar weeks

Changes

* Total hours – All field personnel and supervision for the project

1. What were the total owner approved change order man-hours for the mechanical/electrical scope of work?
   - Direct labor hours for changes ______ hr.
   - Total hours for changes ______ hr.

2. What were the total credit change order hours for the electrical/mechanical scope of work, if any (i.e., for deletions)?
   - Direct labor credit hours ______ hr.
   - Total credit hours ______ hr.

3. What was the amount of overtime labor, in man-hours, for change orders for the mechanical/electrical scope of work?
   ______ hr.

4. What was the amount of shift-work, in man-hours, for change orders for the mechanical/electrical scope of work?
   ______ hr.

5. How did the changes impact the mechanical/electrical schedule?
   □ Created an extension of time
   □ Created a compression of time
   □ Did not affect the schedule

6. How did the changes impact the mechanical/electrical project cost?
   □ Decreased the project cost
   □ Increased the project cost
   □ Did not affect the cost
   Was the budget adjusted accordingly? □ Yes □ No

7. 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
- ☐ 8-14 days
- ☐ 15-21 days
- ☐ 22-28 days
- ☐ 29-35 days
- ☐ 36-42 days
- ☐ Greater than 42 days

8. The following are possible reasons for change orders. For each reason that applies to your project, indicate the percent of actual executed man-hours of change orders for the electrical/mechanical scope of work.

<table>
<thead>
<tr>
<th>Reason</th>
<th>Percent of Man-hours of Change orders</th>
</tr>
</thead>
<tbody>
<tr>
<td>Additions</td>
<td>%</td>
</tr>
<tr>
<td>Change in codes/standards/laws</td>
<td>%</td>
</tr>
<tr>
<td>Changes in technology</td>
<td>%</td>
</tr>
<tr>
<td>Deletions</td>
<td>%</td>
</tr>
<tr>
<td>Design changes</td>
<td>%</td>
</tr>
<tr>
<td>Design coordination</td>
<td>%</td>
</tr>
<tr>
<td>Design error/insufficient/incomplete</td>
<td>%</td>
</tr>
<tr>
<td>Manpower problems/availability</td>
<td>%</td>
</tr>
<tr>
<td>Material handling constraints</td>
<td>%</td>
</tr>
<tr>
<td>Over-inspection</td>
<td>%</td>
</tr>
<tr>
<td>Rework</td>
<td>%</td>
</tr>
<tr>
<td>Site layout</td>
<td>%</td>
</tr>
<tr>
<td>Unknown conditions</td>
<td>%</td>
</tr>
<tr>
<td>Value engineering</td>
<td>%</td>
</tr>
<tr>
<td>Weather</td>
<td>%</td>
</tr>
<tr>
<td>Others (specify)</td>
<td>%</td>
</tr>
</tbody>
</table>

(The total percentages should sum to 100%)

Labor Performance / Productivity (Please provide your best guess)

1. What was the absenteeism (the ratio between the number of craftsmen that fail to appear for work to the number of craftsmen employed) for mechanical/electrical craftsmen on this project?

- ☐ 0 - 5%
- ☐ 6 - 10%
- ☐ 11 - 20%
- ☐ > 20%

2. What was the turnover (ratio of the number of craftsmen hired to replace those who have left to the number of craftsmen employed) for the mechanical/electrical craftsmen on this project?

- ☐ 0 - 5%
- ☐ 6 - 10%
- ☐ 11 - 20%
- ☐ > 20%

3. What was the total amount of overtime labor, in man-hours, for the mechanical/electrical scope of work?

_____ hr.
4. What was the total amount of shift-work, in man-hours for the mechanical/electrical scope of work?  
   _______ hr.

5. Was overmanning experienced on this job?  
   □ Yes  □ No

6. What was the peak number of mechanical/electrical craftsmen used for this project?  
   _______ #

7. What were the contract budgeted man-hours at the notice to proceed for the mechanical/electrical scope of work?  
   Direct labor hours  _______ hr.  
   Total contract hours  _______ hr.

8. What were the actual man-hours utilized at completion of the mechanical/electrical portion of the project, including change orders?  
   Direct labor hours  _______ hr.  
   Total contract hours  _______ hr.

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), on average, was:  
   □ 1-7 days  
   □ 8-14 days  
   □ 15-21 days  
   □ 22-28 days  
   □ 29-35 days  
   □ Greater than 35 days

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

Other Performance Metrics (all for electrical/mechanical work)

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)

3. What is the number of punchlist items?  _______ items

4. What is the value associated with punchlist items, in percentage of total construction cost?  
   □ 0-0.25 %  □ 0.25 - 0.5 %  □ 0.5 - 1%  □ 1 - 2%  □ >2%

---

University of Wisconsin-Madison 2011.  
Iwanski, M., and Hanna, A.S.
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 did you file on this project, if any?  ___________ cases

8. What was the total cost of claims?  $___________
   For a project of this type and size, do you consider this value:  □ below average  □ average  □ above average

9. What are the approximate warranty costs (measured one year after occupation date)?  
   □ 0 %   □ 0 – .5%   □ .6 – 1%   □ 1 – 2%   □ 2 – 3%   □ > 3%

10. What are the approximate latent defect costs (measured one year after occupation date)?  
    □ 0 %   □ 0 – .5%   □ .6 – 1%   □ 1 – 2%   □ 2 – 3%   □ > 3%

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

12. 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
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>
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<tr>
<td>Structure</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Interior Finishes</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Exterior Enclosure</td>
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<td></td>
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<tr>
<td>Roofing</td>
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<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>
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<tr>
<td>Site</td>
<td></td>
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<tr>
<td>Process Equipment, if applicable</td>
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<tr>
<td>Conveying Systems, if applicable</td>
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<tr>
<td>Specialties, if applicable</td>
<td></td>
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</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

Page 3
### SECTION IV: PROJECT TEAM AND COLLABORATION

#### Experience

1. Please tell us about your assessment of the prior experience of the stakeholders before the start of this project. Example: was 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>
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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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</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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<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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<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 BIM:</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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<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>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>CM/GC</td>
<td></td>
<td></td>
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<tr>
<td>Owner</td>
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<td></td>
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</tr>
<tr>
<td>A/E</td>
<td></td>
<td></td>
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</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
Mechanical/Electrical Subcontractor Selection
1. Subcontractors selection:
   □ Open Bidding
   □ Prequalified Bidding
   □ Negotiated Contract
   □ Voting of key people
   □ Other: __________
2. 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.
   - Mechanical Subs: _______ Reps.  Total: ______ Representatives
   - Electrical Subs: _______ Reps.
   - Plumbing Subs: _______ Reps.
   - 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
i. Did you feel that your input/opinion was valued by the project leadership team? □ Yes □ No
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 electrical/mechanical subcontractor 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. What was your perception of the architect/engineer support during construction?
   □ Very adequate    □ Some support    □ A little support    □ None

5. What was your perception on the involvement of CM/GC in the design/preplanning stage of the project?
   □ Very involved    □ Some involvement    □ Limited involvement    □ None

6. How involved were you and other key subcontractors in the design/preplanning stage of the project?
   □ Very involved    □ Some involvement    □ Limited involvement    □ None

7. Rate the project parties’ 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. Did the electrical/mechanical contractors use off-site prefabrication?
   - Yes
   - No

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

<table>
<thead>
<tr>
<th>Tool / Technique</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>
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<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>
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<tr>
<td><strong>5S</strong> - 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>
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<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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<tr>
<td><strong>Value Stream Mapping</strong> - 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>Just In Time Delivery (JIT) - bulk materials are delivered just prior to installation</td>
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<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><strong>Open Books</strong> - fiscal transparency between key participants, with respect to:</td>
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<td></td>
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<tr>
<td>- Change orders</td>
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<tr>
<td>- Bidding and procurement</td>
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<tr>
<td>- Contingency usage</td>
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<tr>
<td>- All project costs</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>
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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 comprehensive change order management process? □ Yes □ No

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>
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<tr>
<td>Space Validation</td>
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<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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</tbody>
</table>
SECTION V: CONTRACTOR BACKGROUND & SUCCESS MEASURES

Do you consider this project successful? □ Yes  □ No

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

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.

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University of Wisconsin-Madison 2011.
Iwanski, M., and Hanna, A.S.
Appendix D: R Input and Output

Sample Strip Chart Code

```r
stripchart(LTI.Per.Mil ~ TYPE, vertical=TRUE, ylab="Lost-Time Incidents per $Mil", 
main="Lost-Time Incidents per $Mil", data=ALL, method="jitter", jitter=.2, 
ylab="TYPE", xlab="TYPE", cex=1.5, group.names=c("Non-IPD","IPD-ish","IPD"), col=c("gray47"), pch=c(19,18,17))
medians=tapply(ALL$LTI_Per.Mil, ALL$TYPE,median,na.rm=TRUE)
points(c(1,2,3),medians,pch="X",cex=2)
means=tapply(ALL$LTI_Per.Mil, ALL$TYPE,mean,na.rm=TRUE)
points(c(1,2,3),means,pch="O",cex=2)

stripchart(LTI.Per.Mil ~ PDS, vertical=TRUE, ylab="Lost-Time Incidents Per $Mil", 
main="Lost-Time Incidents Per $Mil", data=ALL, method="jitter", jitter=.2, 
ylab="TYPE", xlab="TYPE", cex=1.5, group.names=c("DBB","CMR","DB","IPD"), col=c("gray47"), pch=c(19,18,15,17))
medians=tapply(ALL$LTI_Per.Mil, ALL$PDS,median,na.rm=TRUE)
points(c(1,2,3,4),medians,pch="X",cex=2)
means=tapply(ALL$LTI_Per.Mil, ALL$PDS,mean,na.rm=TRUE)
points(c(1,2,3,4),means,pch="O",cex=2)

stripchart(PQR ~ TYPE, vertical=TRUE, ylab="PQR", 
main="PQR By Type", data=PQR_BOX_NEW, method="jitter", jitter=.2, 
ylab="TYPE", xlab="TYPE", cex=1.5, group.names=c("Non-IPD","IPD-ish","IPD"), col=c("gray47"), pch=c(19,18,17))
medians=tapply(PQR_BOX_NEW$PQR, PQR_BOX_NEW$TYPE,median,na.rm=TRUE)
points(c(1,2,3),medians,pch="X",cex=1.5)
means=tapply(PQR_BOX_NEW$PQR, PQR_BOX_NEW$TYPE,mean,na.rm=TRUE)
points(c(1,2,3),means,pch="O",cex=1.5)

stripchart(PQR ~ PDS, vertical=TRUE, ylab="PQR", 
main="PQR By PDS", data=PQR_BOX_NEW, method="jitter", jitter=.2, 
ylab="TYPE", xlab="TYPE", cex=1.5, group.names=c("DBB","CMR","DB","IPD"), col=c("gray47"), pch=c(19,18,15,17))
medians=tapply(PQR_BOX_NEW$PQR, PQR_BOX_NEW$PDS,median,na.rm=TRUE)
points(c(1,2,3,4),medians,pch="X",cex=2)
means=tapply(PQR_BOX_NEW$PQR, PQR_BOX_NEW$PDS,mean,na.rm=TRUE)
points(c(1,2,3,4),means,pch="O",cex=2)

stripchart(Exp_Past ~ TYPE, vertical=TRUE, ylab="Past Team Experience", 
main="Past Team Experience", data=ALL_input_box_NEW, method="jitter", jitter=.2, 
ylab="TYPE", xlab="TYPE", cex=1.5, group.names=c("Non-IPD","IPD-ish","IPD"), col=c("gray47"), pch=c(19,18,17))
medians=tapply(ALL_input_box_NEW$Exp_Past, ALL_input_box_NEW$TYPE,median,na.rm=TRUE)
points(c(1,2,3),medians,pch="X",cex=1.5)
means=tapply(ALL_input_box_NEW$Exp_Past, ALL_input_box_NEW$TYPE,mean,na.rm=TRUE)
points(c(1,2,3),means,pch="O",cex=1.5)
```
stripchart(PQR ~ Incentives, vertical=TRUE, ylab="PQR",
  main="Use of Incentives",data=ALL_binary_box_NEW,method="jitter",
  jitter=.2,cex=1.5,group.names=c("No","Yes"),col=c("gray47"),pch=c(19,18))
medians=tapply(ALL_binary_box_NEW$PQR, ALL_input_box_NEW$Incentives,median,na.rm=TRUE)
points(c(1,2),medians,pch="X",cex=1.5)
means=tapply(ALL_binary_box_NEW$PQR, ALL_input_box_NEW$Incentives,mean,na.rm=TRUE)
points(c(1,2),means,pch="O",cex=1.5)
Univariate MWW Output

Sample Code:

```r
> wilcox.test(ALL_sigTYPESRI_Rate, ALL_sigTYPESRI_Rate_IPD,
+ alternative='two.sided', paired=FALSE)
```

Output:

OSHA Recordable Incident Rate:

- data: ALL_sigTYPESRI_Rate and ALL_sigTYPESRI_Rate_IPD
  - W = 77.5, p-value = 0.3026
  - alternative hypothesis: true location shift is not equal to 0

OSHA Recordable Incidents per Million Dollars:

- data: ALL_sigTYPESRI_Per.Mil and ALL_sigTYPESRI_Per.Mil_IPD
  - W = 86, p-value = 0.2534
  - alternative hypothesis: true location shift is not equal to 0

Lost-Time Incident Rate:

- data: ALL_sigTYPESLTI_Rate and ALL_sigTYPESLTI_Rate_IPD
  - W = 80, p-value = 0.1246
  - alternative hypothesis: true location shift is not equal to 0

Lost-Time Incidents per Million Dollars:

- data: ALL_sigTYPESLTI_Per.Mil and ALL_sigTYPESLTI_Per.Mil_IPD
  - W = 80, p-value = 0.1246
  - alternative hypothesis: true location shift is not equal to 0

Construction Cost Growth:

- data: ALL_sigTYPESCost_Growth and ALL_sigTYPESCost_Growth_IPD
  - W = 80, p-value = 0.3673
  - alternative hypothesis: true location shift is not equal to 0

Budget Factor:

- data: ALL_sigTYPESBudget_Factor and ALL_sigTYPESBudget_Factor_IPD
  - W = 58, p-value = 0.6866
  - alternative hypothesis: true location shift is not equal to 0
Total Cost Growth:

data:  ALL_sigTYPE$Total_Growth and ALL_sigTYPE$Total_Growth_IPD  
W = 69, p-value = 0.8315  
alternative hypothesis: true location shift is not equal to 0

Unit Cost:

data:  ALL_sigTYPE$Unit_Cost and ALL_sigTYPE$Unit_Cost_IPD  
W = 43, p-value = 0.1862  
alternative hypothesis: true location shift is not equal to 0

data:  ALL_sigTYPE$Unit_Cost and ALL_sigTYPE$Unit_Cost_IPDish  
W = 17, p-value = 0.02361  
alternative hypothesis: true location shift is not equal to 0

Construction Speed:

data:  ALL_sigTYPE$Const_Speed and ALL_sigTYPE$Const_Speed_IPD  
W = 81, p-value = 0.3793  
alternative hypothesis: true location shift is not equal to 0

Schedule Growth:

data:  ALL_sigTYPE$Sched_Growth and ALL_sigTYPE$Sched_Growth_IPD  
W = 104, p-value = 0.02084  
alternative hypothesis: true location shift is not equal to 0  
95 percent confidence interval:  
0.01920985 0.24998432  
sample estimates:  
difference in location  
0.1303391

data:  ALL_sigTYPE$Sched_Growth and ALL_sigTYPE$Sched_Growth_IPDish  
W = 58.5, p-value = 0.174  
alternative hypothesis: true location shift is not equal to 0

Schedule Intensity:

data:  ALL_sigTYPE$Cost_Intensity and ALL_sigTYPE$Cost_Intensity_IPD  
W = 55, p-value = 0.9723  
alternative hypothesis: true location shift is not equal to 0

RFI Processing Time:

data:  ALL_sigTYPE$RFI_time and ALL_sigTYPE$RFI_time_IPD  
W = 82, p-value = 0.1355  
alternative hypothesis: true location shift is not equal to 0
RFIs per Million Dollars:

data: ALL_sigTYPESRFI_Per.1Mil and ALL_sigTYPESRFI_Per.1Mil_IPD
W = 49, p-value = 0.2407
alternative hypothesis: true location shift is not equal to 0

Resubmittals per Million Dollars:

data: ALL_sigTYPESResub_Per.1Mil and ALL_sigTYPESResub_Per.1Mil_IPD
W = 102.5, p-value = 0.0168
alternative hypothesis: true location shift is not equal to 0
95 percent confidence interval:
1.957741e-05 9.617366e-01
sample estimates:
difference in location
0.5261827

data: ALL_sigTYPESResub_Per.1Mil and ALL_sigTYPESResub_Per.1Mil_IPDish
W = 55.5, p-value = 0.2644
alternative hypothesis: true location shift is not equal to 0

Rework Cost:

data: ALL_sigTYPESRework and ALL_sigTYPESRework_IPD
W = 89.5, p-value = 0.08191
alternative hypothesis: true location shift is not equal to 0
95 percent confidence interval:
-4.08972e-05 1.00001e+00
sample estimates:
difference in location
6.0624e-05

data: ALL_sigTYPESRework and ALL_sigTYPESRework_IPDish
W = 32.5, p-value = 0.3738
alternative hypothesis: true location shift is not equal to 0

Systems Quality:

data: ALL_sigTYPESQual and ALL_sigTYPESQual_IPD
W = 81.5, p-value = 0.8545
alternative hypothesis: true location shift is not equal to 0
Deficiency Issues per Million Dollars:

- data: `ALL_sigTYPESDef_Per.1Mil` and `ALL_sigTYPESDef_Per.1Mil_IPD`
  - W = 114, p-value = 0.001958
  - alternative hypothesis: true location shift is not equal to 0
  - 95 percent confidence interval:
    - 0.0544756 4.6963723
  - sample estimates:
    - difference in location
      - 1.35342

- data: `ALL_sigTYPESDef_Per.1Mil` and `ALL_sigTYPESDef_Per.1Mil_IPdish`
  - W = 54, p-value = 0.09768
  - alternative hypothesis: true location shift is not equal to 0

Warranty Cost:

- data: `ALL_sigTYPESWarranty` and `ALL_sigTYPESWarranty_IPD`
  - W = 59.5, p-value = 1
  - alternative hypothesis: true location shift is not equal to 0

Latent Defect Cost:

- data: `ALL_sigTYPESLatent` and `ALL_sigTYPESLatent_IPD`
  - W = 62.5, p-value = 0.9107
  - alternative hypothesis: true location shift is not equal to 0

Punchlist Items per Million Dollars

- data: `ALL_sigTYPESPunch_Per.1Mil` and `ALL_sigTYPESPunch_Per.1Mil_IPD`
  - W = 56, p-value = 0.1127
  - alternative hypothesis: true location shift is not equal to 0

Punchlist Cost:

- data: `ALL_sigTYPESPunch_Val` and `ALL_sigTYPESPunch_Val_IPD`
  - W = 82.5, p-value = 0.2255
  - alternative hypothesis: true location shift is not equal to 0

Overhead and Profit:

- data: `ALL_sigTYPESOH.P` and `ALL_sigTYPESOH.P_IPD`
  - W = 55, p-value = 0.2581
  - alternative hypothesis: true location shift is not equal to 0
Image and Potential for Return Business:

data: ALL_sigTYPE$Image and ALL_sigTYPE$Image_IPD  
W = 73, p-value = 0.7241  
alternative hypothesis: true location shift is not equal to 0

PPC Trend:

data: ALL_sigTYPE$PPC and ALL_sigTYPE$PPC_IPD  
W = 49.5, p-value = 0.2208  
alternative hypothesis: true location shift is not equal to 0

Absenteeism Cost:

data: ALL_sigTYPE$Absent and ALL_sigTYPE$Absent_IPD  
W = 58.5, p-value = NA  
alternative hypothesis: true location shift is not equal to 0

Turnover Cost:

data: ALL_sigTYPE$Turnover and ALL_sigTYPE$Turnover_IPD  
W = 65, p-value = 0.3156  
alternative hypothesis: true location shift is not equal to 0

Overmanning:

data: ALL_sigTYPE$Overmanning and ALL_sigTYPE$Overmanning_IPD  
W = 89.5, p-value = 0.3464  
alternative hypothesis: true location shift is not equal to 0

Man-Hour Growth:

data: ALL_sigTYPE$MH_growth_D and ALL_sigTYPE$MH_growth_D_IPD  
W = 59, p-value = 0.4269  
alternative hypothesis: true location shift is not equal to 0

Overtime:

data: ALL_sigTYPE$Overtime and ALL_sigTYPE$Overtime_IPD  
W = 51, p-value = 0.4706  
alternative hypothesis: true location shift is not equal to 0

Shiftwork:

data: ALL_sigTYPE$Shiftwork and ALL_sigTYPE$Shiftwork_IPD  
W = 40, p-value = 0.8891  
alternative hypothesis: true location shift is not equal to 0
Peak MH / Average MH:

data: ALL_sigTYPE$Peak.Avg and ALL_sigTYPE$Peak.Avg_IPD
W = 44, p-value = 0.659
alternative hypothesis: true location shift is not equal to 0

Loss of Productivity:

data: ALL_sigTYPE$Lost_Productivity_D and ALL_sigTYPE$Lost_Productivity_D_IPD
W = 51, p-value = 0.5913
alternative hypothesis: true location shift is not equal to 0

Overtime Due to Changes:

data: ALL_sigTYPE$Overtime.Changes and ALL_sigTYPE$Overtime.Changes_IPD
W = 76, p-value = 0.4912
alternative hypothesis: true location shift is not equal to 0

Shiftwork Due to Changes:

data: ALL_sigTYPE$Shiftwork.Changes and ALL_sigTYPE$Shiftwork.Changes_IPD
W = 65, p-value = 0.3156
alternative hypothesis: true location shift is not equal to 0

CO Effect on Schedule:

data: ALL_sigTYPE$CO_eff_sched and ALL_sigTYPE$CO_eff_sched_IPD
W = 64.5, p-value = 0.4291
alternative hypothesis: true location shift is not equal to 0

CO Effect on Cost:

data: ALL_sigTYPE$CO_eff_cost and ALL_sigTYPE$CO_eff_cost_IPD
W = 54, p-value = 0.08587
alternative hypothesis: true location shift is not equal to 0

95 percent confidence interval:
-9.999337e-01  3.280043e-05
sample estimates:
difference in location
-2.924906e-05

data: ALL_sigTYPE$CO_eff_cost and ALL_sigTYPE$CO_eff_cost_IPDish
W = 36.5, p-value = 0.2781
alternative hypothesis: true location shift is not equal to 0

Percent Change:

data: ALL_sigTYPE$X.Change_D and ALL_sigTYPE$X.Change_D_IPD
W = 80, p-value = 0.2109
alternative hypothesis: true location shift is not equal to 0
CO Processing Time:

- data: ALL__sigTYPE$CO_process and ALL__sigTYPE$CO_process_IPD
  - W = 121, p-value = 0.01819
  - alternative hypothesis: true location shift is not equal to 0
  - 95 percent confidence interval:
    - 5.70502e-05 4.000001e+00
  - sample estimates:
    - difference in location
      - 2.000033

- data: ALL__sigTYPE$CO_process and ALL__sigTYPE$CO_process_IPDish
  - W = 71.5, p-value = 0.03743
  - alternative hypothesis: true location shift is not equal to 0
Univariate t-test Output

Sample Code:

```r
> t.test(ALL_sigTYPESRI_Rate, ALL_sigTYPESRI_Rate_IPD,
+ alternative='two.sided', paired=FALSE)
```

Output:

**OSHA Recordable Incident Rate:**

data:  ALL_sigTYPESRI_Rate and ALL_sigTYPESRI_Rate_IPD
t = 0.9653, df = 20.998, p-value = 0.3454
alternative hypothesis: true difference in means is not equal to 0

**OSHA Recordable Incidents per Million Dollars:**

data:  ALL_sigTYPESRI_Per.Mil and ALL_sigTYPESRI_Per.Mil_IPD
t = 0.7627, df = 21.876, p-value = 0.4538
alternative hypothesis: true difference in means is not equal to 0

**Lost-Time Incident Rate:**

data:  ALL_sigTYPESLTI_Rate and ALL_sigTYPESLTI_Rate_IPD
t = 1.3115, df = 12, p-value = 0.2142
alternative hypothesis: true difference in means is not equal to 0

**Lost-Time Incidents per Million Dollars:**

data:  ALL_sigTYPESLTI_Per.Mil and ALL_sigTYPESLTI_Per.Mil_IPD
t = 1.2447, df = 12, p-value = 0.237
alternative hypothesis: true difference in means is not equal to 0

**Construction Cost Growth:**

data:  ALL_sigTYPESCost_Growth and ALL_sigTYPESCost_Growth_IPD
t = 1.0153, df = 17.43, p-value = 0.3239
alternative hypothesis: true difference in means is not equal to 0

**Budget Factor:**

data:  ALL_sigTYPESBudget_Factor and ALL_sigTYPESBudget_Factor_IPD
t = -0.5634, df = 20.466, p-value = 0.5793
alternative hypothesis: true difference in means is not equal to 0
Total Cost Growth:

data:  ALL_sigTYPE$Total_Growth and ALL_sigTYPE$Total_Growth_IPD
t = 0.2135, df = 20.646, p-value = 0.833
alternative hypothesis: true difference in means is not equal to 0

Unit Cost:

data:  ALL_sigTYPE$Unit_Cost and ALL_sigTYPE$Unit_Cost_IPD
t = -0.5681, df = 20.999, p-value = 0.576
alternative hypothesis: true difference in means is not equal to 0

Construction Speed:

data:  ALL_sigTYPE$Const_Speed and ALL_sigTYPE$Const_Speed_IPD
t = 1.3149, df = 15.269, p-value = 0.2079
alternative hypothesis: true difference in means is not equal to 0

Schedule Growth:

data:  ALL_sigTYPE$Sched_Growth and ALL_sigTYPE$Sched_Growth_IPD
t = 2.8721, df = 14.479, p-value = 0.01197
alternative hypothesis: true difference in means is not equal to 0

Schedule Intensity:

data:  ALL_sigTYPE$Cost_Intensity and ALL_sigTYPE$Cost_Intensity_IPD
t = 0.718, df = 16.917, p-value = 0.4826
alternative hypothesis: true difference in means is not equal to 0

RFI Processing Time:

data:  ALL_sigTYPE$RFI_time and ALL_sigTYPE$RFI_time_IPD
t = 1.3622, df = 19.998, p-value = 0.1883
alternative hypothesis: true difference in means is not equal to 0

RFIs per Million Dollars:

data:  ALL_sigTYPE$RFI_Per.1Mil and ALL_sigTYPE$RFI_Per.1Mil_IPD
t = 2.1762, df = 11.263, p-value = 0.05165
alternative hypothesis: true difference in means is not equal to 0

Resubmittals per Million Dollars:

data:  ALL_sigTYPE$Resub_Per.1Mil and ALL_sigTYPE$Resub_Per.1Mil_IPD
t = 1.6226, df = 13.951, p-value = 0.1271
alternative hypothesis: true difference in means is not equal to 0
Rework Cost:

- data: \texttt{ALL\_sigTYPE$Rework}$ and \texttt{ALL\_sigTYPE$Rework\_IPD}$
  - $t = 1.1976$, df = 20.977, p-value = 0.2444
  - alternative hypothesis: true difference in means is not equal to 0

Systems Quality:

- data: \texttt{ALL\_sigTYPE$Qual}$ and \texttt{ALL\_sigTYPE$Qual\_IPD}$
  - $t = 0.3892$, df = 16.982, p-value = 0.702
  - alternative hypothesis: true difference in means is not equal to 0

Deficiency Issues per Million Dollars:

- data: \texttt{ALL\_sigTYPE$Def\_Per.1Mil}$ and \texttt{ALL\_sigTYPE$Def\_Per.1Mil\_IPD}$
  - $t = 2.5207$, df = 11.517, p-value = 0.02759
  - alternative hypothesis: true difference in means is not equal to 0

Warranty Cost:

- data: \texttt{ALL\_sigTYPE$Warranty}$ and \texttt{ALL\_sigTYPE$Warranty\_IPD}$
  - $t = 0.1899$, df = 20.492, p-value = 0.8512
  - alternative hypothesis: true difference in means is not equal to 0

Latent Defect Cost:

- data: \texttt{ALL\_sigTYPE$Latent}$ and \texttt{ALL\_sigTYPE$Latent\_IPD}$
  - $t = 0$, df = 18.526, p-value = 1
  - alternative hypothesis: true difference in means is not equal to 0

Punchlist Items per Million Dollars:

- data: \texttt{ALL\_sigTYPE$Punch\_Per.1Mil}$ and \texttt{ALL\_sigTYPE$Punch\_Per.1Mil\_IPD}$
  - $t = 2.0355$, df = 10.423, p-value = 0.06803
  - alternative hypothesis: true difference in means is not equal to 0

Punchlist Cost:

- data: \texttt{ALL\_sigTYPE$Punch\_Val}$ and \texttt{ALL\_sigTYPE$Punch\_Val\_IPD}$
  - $t = 1.3196$, df = 18.452, p-value = 0.2031
  - alternative hypothesis: true difference in means is not equal to 0
Overhead and Profit:

   data: ALL_sigTYPESOH.P and ALL_sigTYPESOH.P_IPD
t = 1.3817, df = 16.991, p-value = 0.185
   alternative hypothesis: true difference in means is not equal to 0

Image and Potential for Return Business:

   data: ALL_sigTYPESImage and ALL_sigTYPESImage_IPD
t = -0.3871, df = 22.971, p-value = 0.7022
   alternative hypothesis: true difference in means is not equal to 0

PPC Trend:

   data: ALL_sigTYPESPPC and ALL_sigTYPESPPC_IPD
t = -1.3179, df = 20.895, p-value = 0.2018
   alternative hypothesis: true difference in means is not equal to 0

Absenteeism Cost:

   > t.test(ALL_sigTYPESAbsent, ALL_sigTYPESAbsent_IPD,
   +   alternative='two.sided', paired=FALSE)
   
   NA

Turnover Cost:

   data: ALL_sigTYPESTurnover and ALL_sigTYPESTurnover_IPD
t = -1, df = 10, p-value = 0.3409
   alternative hypothesis: true difference in means is not equal to 0

Overmanning:

   data: ALL_sigTYPESOvermanning and ALL_sigTYPESOvermanning_IPD
t = 1, df = 20.889, p-value = 0.3288
   alternative hypothesis: true difference in means is not equal to 0

Man-Hour Growth:

   data: ALL_sigTYPESMH_growth_D and ALL_sigTYPESMH_growth_D_IPD
t = 0.3282, df = 13.311, p-value = 0.7479
   alternative hypothesis: true difference in means is not equal to 0
Overtime:

- **data**: ALL_sigTYPES$Overtime. and ALL_sigTYPES$Overtime._IPD
- **t** = 0.9713, df = 16.765, p-value = 0.3452
- Alternative hypothesis: true difference in means is not equal to 0

Shiftwork:

- **data**: ALL_sigTYPES$Shiftwork. and ALL_sigTYPES$Shiftwork._IPD
- **t** = 0.5791, df = 13.178, p-value = 0.5723
- Alternative hypothesis: true difference in means is not equal to 0

Peak MH / Average MH:

- **data**: ALL_sigTYPES$Peak.Avg and ALL_sigTYPES$Peak.Avg_IPD
- **t** = 0.689, df = 15.143, p-value = 0.5012
- Alternative hypothesis: true difference in means is not equal to 0

Loss of Productivity:

- **data**: ALL_sigTYPES$Lost_Productivity_D and ALL_sigTYPES$Lost_Productivity_D_IPD
- **t** = 0.6746, df = 15.647, p-value = 0.5098
- Alternative hypothesis: true difference in means is not equal to 0

Overtime Due to Changes:

- **data**: ALL_sigTYPES$Overtime.Changes and ALL_sigTYPES$Overtime.Changes_IPD
- **t** = 0.6912, df = 20.258, p-value = 0.4973
- Alternative hypothesis: true difference in means is not equal to 0

Shiftwork Due to Changes:

- **data**: ALL_sigTYPES$Shiftwork.Changes and ALL_sigTYPES$Shiftwork.Changes_IPD
- **t** = -1, df = 10, p-value = 0.3409
- Alternative hypothesis: true difference in means is not equal to 0

CO Effect on Schedule:

- **data**: ALL_sigTYPES$CO_eff_sched and ALL_sigTYPES$CO_eff_sched_IPD
- **t** = -0.9564, df = 19.012, p-value = 0.3509
- Alternative hypothesis: true difference in means is not equal to 0

CO Effect on Cost:

- **data**: ALL_sigTYPES$CO_eff_cost and ALL_sigTYPES$CO_eff_cost_IPD
- **t** = -1.2286, df = 22.998, p-value = 0.2317
- Alternative hypothesis: true difference in means is not equal to 0
Percent Change:

data: ALL_sigTYPE$X.Change_D and ALL_sigTYPE$X.Change_D_IPD
t = 0.6192, df = 17.052, p-value = 0.544
alternative hypothesis: true difference in means is not equal to 0

CO Processing Time:

data: ALL_sigTYPE$CO_process and ALL_sigTYPE$CO_process_IPD
t = 2.4116, df = 22.807, p-value = 0.02434
alternative hypothesis: true difference in means is not equal to 0
Q-Q Plots for Select Univariate Metrics

Example Code

```r
qqPlot(ALL_sigTYPE$Def_Per.1Mil_IPD, main="Deficiencies Per $Mil (IPD)",ylab="sample quantiles",envelope=FALSE,dist="norm")
```
**Univariate Kruskal-Wallis Output**

**Sample Code:**

```r
> kruskal.test(RI_Rate ~ PDS, data=ALL)
```

**Output:**

**OSHA Recordable Incident Rate:**

- data: RI_Rate by PDS
  - Kruskal-Wallis chi-squared = 7.4397, df = 3, p-value = 0.05913

  Pairwise comparisons using t tests with pooled SD
  - data: ALL$RI_Rate and ALL$PDS
  - P1 P2 P3
  - P2 0.263 - -
  - P3 0.641 0.781 -
  - P4 0.781 0.074 0.610

**OSHA Recordable Incidents per Million Dollars:**

- data: RI_Per.Mil by PDS
  - Kruskal-Wallis chi-squared = 7.3313, df = 3, p-value = 0.06205

**Lost-Time Incident Rate:**

- data: LTI_Rate by PDS
  - Kruskal-Wallis chi-squared = 7.5905, df = 3, p-value = 0.05528

  Pairwise comparisons using t tests with pooled SD
  - data: ALL$LTI_Rate and ALL$PDS
  - P1 P2 P3
  - P2 0.950 - -
  - P3 1.000 0.204 -
  - P4 1.000 0.094 1.000

**Lost-Time Incidents per Million Dollar:**

- data: LTI_Per.Mil by PDS
  - Kruskal-Wallis chi-squared = 7.5905, df = 3, p-value = 0.05528
Construction Cost Growth:

data: Cost_Growth by PDS
Kruskal-Wallis chi-squared = 4.6516, df = 3, p-value = 0.1992

Budget Factor:

data: Budget_Factor by PDS
Kruskal-Wallis chi-squared = 3.1018, df = 3, p-value = 0.3762

Total Cost Growth:

data: Total_Growth by PDS
Kruskal-Wallis chi-squared = 0.1018, df = 3, p-value = 0.9916

Unit Cost:

data: Unit_Cost by PDS
Kruskal-Wallis chi-squared = 4.0993, df = 3, p-value = 0.2509

Construction Speed:

data: Const_Speed by PDS
Kruskal-Wallis chi-squared = 9.0128, df = 3, p-value = 0.02912

Pairwise comparisons using t tests with pooled SD

data: ALL$Const_Speed and ALL$PDS

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<td>P4</td>
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<td>0.036</td>
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Schedule Growth:

data: Sched_Growth by PDS
Kruskal-Wallis chi-squared = 6.4893, df = 3, p-value = 0.09009

Pairwise comparisons using t tests with pooled SD

data: ALL$Sched_Growth and ALL$PDS

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<tr>
<td>P2</td>
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<tr>
<td>P3</td>
<td>1.00</td>
<td>1.00</td>
<td></td>
</tr>
<tr>
<td>P4</td>
<td>0.28</td>
<td>0.28</td>
<td>0.28</td>
</tr>
</tbody>
</table>
Schedule Intensity:

data: Cost_Intensity by PDS
Kruskal-Wallis chi-squared = 4.3349, df = 3, p-value = 0.2275

RFI Processing Time:

data: RFI_time by PDS
Kruskal-Wallis chi-squared = 3.8944, df = 3, p-value = 0.2731

RFIs per Million Dollars:

data: RFI_Per.1Mil by PDS
Kruskal-Wallis chi-squared = 11.5434, df = 3, p-value = 0.009123

Pairwise comparisons using t tests with pooled SD

data: ALL$RFI_Per.1Mil and ALL$PDS

<table>
<thead>
<tr>
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<th>P2</th>
<th>P3</th>
</tr>
</thead>
<tbody>
<tr>
<td>P1</td>
<td>3.1e-06</td>
<td>-</td>
</tr>
<tr>
<td>P2</td>
<td>3.0e-07</td>
<td>0.38</td>
</tr>
<tr>
<td>P3</td>
<td>2.3e-07</td>
<td>0.75</td>
</tr>
</tbody>
</table>

Resubmittals per Million Dollars:

data: Resub_Per.1Mil by PDS
Kruskal-Wallis chi-squared = 11.2072, df = 3, p-value = 0.01066

Pairwise comparisons using t tests with pooled SD

data: ALL$Resub_Per.1Mil and ALL$PDS

<table>
<thead>
<tr>
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<th>P3</th>
</tr>
</thead>
<tbody>
<tr>
<td>P1</td>
<td>2.3e-05</td>
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</tr>
<tr>
<td>P3</td>
<td>4.2e-06</td>
<td>1</td>
</tr>
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</table>

Rework Cost:

data: Rework by PDS
Kruskal-Wallis chi-squared = 5.0484, df = 3, p-value = 0.1683

Systems Quality:

data: Qual by PDS
Kruskal-Wallis chi-squared = 0.9675, df = 3, p-value = 0.8091
Deficiency Issues per Million Dollars:

data: Def_Per.1Mil by PDS
Kruskal-Wallis chi-squared = 12.5847, df = 3, p-value = 0.005626

Pairwise comparisons using t tests with pooled SD
data: ALLSDef_Per.1Mil and ALLSPDS

<table>
<thead>
<tr>
<th></th>
<th>P1</th>
<th>P2</th>
<th>P3</th>
</tr>
</thead>
<tbody>
<tr>
<td>P1</td>
<td>0.57</td>
<td>-</td>
<td>-</td>
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<tr>
<td>P2</td>
<td>1.00</td>
<td>0.48</td>
<td>-</td>
</tr>
<tr>
<td>P3</td>
<td>0.37</td>
<td>1.00</td>
<td>0.15</td>
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</table>

Warranty Cost:

data: Warranty by PDS
Kruskal-Wallis chi-squared = 4.4369, df = 3, p-value = 0.218

Latent Defect Cost:

data: Latent by PDS
Kruskal-Wallis chi-squared = 0.0635, df = 3, p-value = 0.9958

Punchlist Items per Million Dollars:

data: Punch_Per.1Mil by PDS
Kruskal-Wallis chi-squared = 11.5344, df = 3, p-value = 0.009161

Pairwise comparisons using t tests with pooled SD
data: ALLSPunch_Per.1Mil and ALLSPDS

<table>
<thead>
<tr>
<th></th>
<th>P1</th>
<th>P2</th>
<th>P3</th>
</tr>
</thead>
<tbody>
<tr>
<td>P1</td>
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<td>-</td>
</tr>
<tr>
<td>P3</td>
<td>5.7e-07</td>
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<td>1</td>
</tr>
</tbody>
</table>

Punchlist Cost:

data: Punch_Val by PDS
Kruskal-Wallis chi-squared = 3.1644, df = 3, p-value = 0.367

Overhead and Profit:

data: OHP by PDS
Kruskal-Wallis chi-squared = 3.6539, df = 3, p-value = 0.3013
Image and Potential for Return Business:

data: Image by PDS
Kruskal-Wallis chi-squared = 14, df = 3, p-value = 0.002905

Pairwise comparisons using t tests with pooled SD

data: ALL$Image and ALL$PDS

<table>
<thead>
<tr>
<th></th>
<th>P1</th>
<th>P2</th>
<th>P3</th>
</tr>
</thead>
<tbody>
<tr>
<td>P2</td>
<td>0.00089</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>P3</td>
<td>0.00045</td>
<td>1.00000</td>
<td>-</td>
</tr>
<tr>
<td>P4</td>
<td>0.00056</td>
<td>1.00000</td>
<td>1.00000</td>
</tr>
</tbody>
</table>

PPC Trend:

data: PPC by PDS
Kruskal-Wallis chi-squared = 2.4923, df = 3, p-value = 0.4767

Absenteeism Cost:

data: Absent by PDS
Kruskal-Wallis chi-squared = NaN, df = 3, p-value = NA

Turnover Cost:

data: Turnover by PDS
Kruskal-Wallis chi-squared = 1.1818, df = 3, p-value = 0.7574

Overmanning:

data: Overmanning by PDS
Kruskal-Wallis chi-squared = 5.5476, df = 3, p-value = 0.1358

Man-Hour Growth:

data: MH_growth_D by PDS
Kruskal-Wallis chi-squared = 3.4655, df = 3, p-value = 0.3253

Overtime:

data: Overtime. by PDS
Kruskal-Wallis chi-squared = 2.5609, df = 3, p-value = 0.4644
Shiftwork:

data:  Shiftwork by PDS
Kruskal-Wallis chi-squared = 2.1036, df = 3, p-value = 0.5512

Peak MH / Average MH:

data: Peak.Avg by PDS
Kruskal-Wallis chi-squared = 1.5581, df = 3, p-value = 0.6689

Loss of Productivity:

data:  Lost_Productivity_D by PDS
Kruskal-Wallis chi-squared = 1.1481, df = 3, p-value = 0.7655

Shiftwork Due to Changes:

data:  Shiftwork.Changes by PDS
Kruskal-Wallis chi-squared = 4.5992, df = 3, p-value = 0.2036

CO Effect on Schedule:

data: CO_eff_sched by PDS
Kruskal-Wallis chi-squared = 1.8831, df = 3, p-value = 0.597

Overtime Due to Changes:

data:  Overtime.Changes by PDS
Kruskal-Wallis chi-squared = 7.5191, df = 3, p-value = 0.05707

CO Effect on Cost:

data:  CO_eff_cost by PDS
Kruskal-Wallis chi-squared = 3.75, df = 3, p-value = 0.2898

Pairwise comparisons using t tests with pooled SD

data: ALL$Overtime.Changes and ALL$PDS

<table>
<thead>
<tr>
<th></th>
<th>P1</th>
<th>P2</th>
<th>P3</th>
</tr>
</thead>
<tbody>
<tr>
<td>P2</td>
<td>0.0221</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>P3</td>
<td>0.0078</td>
<td>1.0000</td>
<td>-</td>
</tr>
<tr>
<td>P4</td>
<td>0.0144</td>
<td>1.0000</td>
<td>1.0000</td>
</tr>
</tbody>
</table>
Percent Change:

data: X.Change_D by PDS
Kruskal-Wallis chi-squared = 5.2528, df = 3, p-value = 0.1542

Pairwise comparisons using t tests with pooled SD

data: ALL$X.Change_D and ALL$PDS

<table>
<thead>
<tr>
<th></th>
<th>P1</th>
<th>P2</th>
<th>P3</th>
</tr>
</thead>
<tbody>
<tr>
<td>P2</td>
<td>0.79</td>
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<td>-</td>
</tr>
<tr>
<td>P3</td>
<td>0.31</td>
<td>1.00</td>
<td>-</td>
</tr>
<tr>
<td>P4</td>
<td>0.31</td>
<td>1.00</td>
<td>1.00</td>
</tr>
</tbody>
</table>

CO Processing Time:

data: CO_process by PDS
Kruskal-Wallis chi-squared = 5.731, df = 3, p-value = 0.1255
**PQR R Output**

**MWW Test**

```r
> wilcox.test(PQR_sig_NEW$ALL_PQR, PQR_sig_NEW$ALL_PQR_IPD,
+ alternative='two.sided', paired=FALSE)

Wilcoxon rank sum test

data:  PQR_sig_NEW$ALL_PQR and PQR_sig_NEW$ALL_PQR_IPD
W = 71, p-value = 0.7283
alternative hypothesis: true location shift is not equal to 0
```

**Levene’s Test**

```r
> leveneTest(PQR_BOX_NEW$PQR, PQR_BOX_NEW$TYPE, center=median)

Levene's Test for Homogeneity of Variance (center = median)

<table>
<thead>
<tr>
<th></th>
<th>Df</th>
<th>F value</th>
<th>Pr(&gt;F)</th>
</tr>
</thead>
<tbody>
<tr>
<td>group</td>
<td>2</td>
<td>2.6054</td>
<td>0.09108</td>
</tr>
<tr>
<td></td>
<td>29</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
```

**Kruskal-Wallis Test**

```r
> qqPlot(ALL_sigTYPE$Def_Per.1Mil_IPD, dist="norm")

> tapply(PQR_BOX_NEW$PQR, PQR_BOX_NEW$PDS, median, na.rm=TRUE)

<table>
<thead>
<tr>
<th>P1</th>
<th>P2</th>
<th>P3</th>
<th>P4</th>
</tr>
</thead>
<tbody>
<tr>
<td>-1.5706144</td>
<td>0.3520572</td>
<td>0.3083462</td>
<td>0.2040984</td>
</tr>
</tbody>
</table>

> kruskal.test(PQR ~ PDS, data=PQR_BOX_NEW)

Kruskal-Wallis rank sum test

data:  PQR by PDS
Kruskal-Wallis chi-squared = 6.5542, df = 3, p-value = 0.08755
F-test

```r
 summary(AnovaModel.1)
# Df  Sum Sq  Mean Sq  F value  Pr(>F)
PDS           3   9.066    3.0220    3.858   0.0199 *
Residuals   28  21.934    0.7834
7 observations deleted due to missingness
```

```r
 numSummary(PQR_BOX_NEW$PQR, groups=PQR_BOX_NEW$PDS, statistics=c("mean", +  "sd"))
# mean         sd   %  data:n
# P1   -1.4305421  0.9915746  0       3
# P2    0.1566783  1.3960710  0       6
# P3    0.4582363  0.5662390  0       4
# P4    0.1811010  0.7093330  0      12
```

Pairwise t-test

```r
 pairwise.t.test(PQR_BOX_NEW$PQR,PQR_BOX_NEW$PDS,p.adjust.method="none")
# Pairwise comparisons using t tests with pooled SD
# data:  PQR_BOX_NEW$PQR and PQR_BOX_NEW$PDS
# P1  P2  P3
# P2  0.090 - -
# P3  0.023 0.838 -
# P4  0.023 0.838 0.838
```
Input Regression Analysis

Sample Input

> Exp_Past <- lm(PQR~Exp_Past, data=ALL_reg_NEW)

> summary(Exp_Past)

> plot(Exp_Past)

Output:

Past Team Experience

Coefficients:

|         | Estimate | Std. Error | t value | Pr(>|t|) |
|---------|----------|------------|---------|----------|
| (Intercept) | 1.26453  | 0.73643    | 1.717   | 0.0963   |
| Exp_Past  | -0.04396 | 0.02490    | -1.765  | 0.0877   |

Residual standard error: 0.9675 on 30 degrees of freedom
Multiple R-squared: 0.09411 , Adjusted R-squared: 0.06391
F-statistic: 3.117 on 1 and 30 DF,  p-value: 0.08768

> Confint(Exp_Past, level=0.95)

<table>
<thead>
<tr>
<th></th>
<th>Estimate</th>
<th>2.5 %</th>
<th>97.5 %</th>
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</thead>
<tbody>
<tr>
<td>(Intercept)</td>
<td>1.26453302</td>
<td>-0.23946559</td>
<td>2.768531628</td>
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<tr>
<td>Exp_Past</td>
<td>-0.04395748</td>
<td>-0.09480967</td>
<td>0.006894717</td>
</tr>
</tbody>
</table>
Current Team Experience

Coefficients:

|                | Estimate | Std. Error | t value | Pr(>|t|) |
|----------------|----------|------------|---------|----------|
| (Intercept)    | -2.2932  | 1.4172     | -1.618  | 0.116    |
| Exp_New        | 0.2505   | 0.1536     | 1.630   | 0.114    |

Residual standard error: 0.9743 on 30 degrees of freedom
Multiple R-squared: 0.08138, Adjusted R-squared: 0.05076
F-statistic: 2.658 on 1 and 30 DF, p-value: 0.1135

> Confint(Exp_New, level=0.95)

<table>
<thead>
<tr>
<th></th>
<th>Estimate</th>
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<th>97.5 %</th>
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</thead>
<tbody>
<tr>
<td>(Intercept)</td>
<td>-2.2931875</td>
<td>-5.18744189</td>
<td>0.6010669</td>
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<tr>
<td>Exp_New</td>
<td>0.2504505</td>
<td>-0.06330248</td>
<td>0.5642035</td>
</tr>
</tbody>
</table>

Involvement

Coefficients:

|               | Estimate  | Std. Error | t value | Pr(>|t|) |
|---------------|-----------|------------|---------|----------|
| (Intercept)   | -3.21557  | 1.14114    | -2.818  | 0.00847 **|
| Involvement   | 0.19162   | 0.06733    | 2.846   | 0.00791 **|

Residual standard error: 0.902 on 30 degrees of freedom
Multiple R-squared: 0.2126, Adjusted R-squared: 0.1863
F-statistic: 8.098 on 1 and 30 DF, p-value: 0.007913

> Confint(Involvement, level=0.95)

<table>
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<tr>
<th></th>
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</thead>
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<tr>
<td>(Intercept)</td>
<td>-3.215567</td>
<td>-5.54608675</td>
<td>-0.8850447</td>
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<tr>
<td>Involvement</td>
<td>0.1916166</td>
<td>0.05410267</td>
<td>0.3291305</td>
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</tbody>
</table>
Percent Design Complete

Coefficients:

|                | Estimate | Std. Error | t value | Pr(>|t|) |
|----------------|----------|------------|---------|----------|
| (Intercept)    | 0.5602   | 0.3173     | 1.766   | 0.0880   |
| X.des_compl    | -1.1096  | 0.5729     | -1.937  | 0.0625   |

Residual standard error: 0.9461 on 29 degrees of freedom
Multiple R-squared: 0.1146, Adjusted R-squared: 0.08402
F-statistic: 3.752 on 1 and 29 DF, p-value: 0.06254

> Confint(des_com, level=0.90)

<table>
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<tr>
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<tr>
<td>(Intercept)</td>
<td>0.5601955</td>
<td>0.02108119</td>
<td>1.0993098</td>
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<tr>
<td>X.des_compl</td>
<td>-1.1096206</td>
<td>-2.08297601</td>
<td>-0.1362652</td>
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</tbody>
</table>

Core Team Score

Coefficients:

|                | Estimate | Std. Error | t value | Pr(>|t|) |
|----------------|----------|------------|---------|----------|
| (Intercept)    | -0.180984 | 0.502555  | -0.360  | 0.721    |
| CoreT          | 0.005112  | 0.013260  | 0.385   | 0.703    |

Residual standard error: 1.014 on 30 degrees of freedom
Multiple R-squared: 0.004929, Adjusted R-squared: -0.02824
F-statistic: 0.1486 on 1 and 30 DF, p-value: 0.7026

> Confint(CoreT, level=0.95)

<table>
<thead>
<tr>
<th></th>
<th>Estimate</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>(Intercept)</td>
<td>-0.180983796</td>
<td>-1.20733720</td>
<td>0.84536961</td>
</tr>
<tr>
<td>CoreT</td>
<td>0.005111634</td>
<td>-0.02196956</td>
<td>0.03219282</td>
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</tbody>
</table>
Management Structure Score

Coefficients:

|                | Estimate | Std. Error | t value | Pr(>|t|) |
|----------------|----------|------------|---------|----------|
| (Intercept)    | -0.263585| 0.505066   | -0.522  | 0.606    |
| Management_Structure | 0.005938 | 0.010641   | 0.558   | 0.581    |

Residual standard error: 1.011 on 30 degrees of freedom
Multiple R-squared: 0.01027, Adjusted R-squared: -0.02272
F-statistic: 0.3114 on 1 and 30 DF, p-value: 0.581

> Confint(mang, level=0.95)

<table>
<thead>
<tr>
<th></th>
<th>Estimate</th>
<th>2.5 %</th>
<th>97.5 %</th>
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</thead>
<tbody>
<tr>
<td>(Intercept)</td>
<td>-0.26358463</td>
<td>-1.29506679</td>
<td>0.76789753</td>
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<tr>
<td>Management_Structure</td>
<td>0.005937845</td>
<td>-0.01579432</td>
<td>0.02767001</td>
</tr>
</tbody>
</table>

Fiscal Transparency Score

Coefficients:

|                | Estimate | Std. Error | t value | Pr(>|t|) |
|----------------|----------|------------|---------|----------|
| (Intercept)    | -0.10601 | 0.38996    | -0.272  | 0.788    |
| Transparency   | 0.01576  | 0.05147    | 0.306   | 0.762    |

Residual standard error: 1.015 on 30 degrees of freedom
Multiple R-squared: 0.003115, Adjusted R-squared: -0.03011
F-statistic: 0.09375 on 1 and 30 DF, p-value: 0.7616

> Confint(transp, level=0.95)

<table>
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<tr>
<th></th>
<th>Estimate</th>
<th>2.5 %</th>
<th>97.5 %</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Intercept)</td>
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<td>-0.90242453</td>
<td>0.6904030</td>
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<tr>
<td>Transparency</td>
<td>0.01576002</td>
<td>-0.08936258</td>
<td>0.1208826</td>
</tr>
</tbody>
</table>
Lean Principles Score

Coefficients:

|            | Estimate | Std. Error | t value | Pr(>|t|) |
|------------|----------|------------|---------|----------|
| (Intercept)| -0.70484 | 0.35676    | -1.976  | 0.0575   |
| LEAN       | 0.02417  | 0.01082    | 2.233   | 0.0331*  |

Residual standard error: 0.9413 on 30 degrees of freedom
Multiple R-squared: 0.1426, Adjusted R-squared: 0.114
F-statistic: 4.989 on 1 and 30 DF, p-value: 0.03312

> Confint(lean, level=0.95)

<table>
<thead>
<tr>
<th>Estimate</th>
<th>2.5 %</th>
<th>97.5 %</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Intercept)</td>
<td>-0.7048447</td>
<td>-1.433445882</td>
</tr>
<tr>
<td>LEAN</td>
<td>0.0241661</td>
<td>0.002069026</td>
</tr>
</tbody>
</table>

BIM Use Score

Coefficients:

|            | Estimate | Std. Error | t value | Pr(>|t|) |
|------------|----------|------------|---------|----------|
| (Intercept)| -0.09700 | 0.23815    | -0.407  | 0.687    |
| BIM_SCORE  | 0.00851  | 0.01382    | 0.616   | 0.543    |

Residual standard error: 1.01 on 30 degrees of freedom
Multiple R-squared: 0.01247, Adjusted R-squared: -0.02044
F-statistic: 0.379 on 1 and 30 DF, p-value: 0.5428

> Confint(BIM, level=0.95)

<table>
<thead>
<tr>
<th>Estimate</th>
<th>2.5 %</th>
<th>97.5 %</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Intercept)</td>
<td>-0.09700999</td>
<td>-0.58337576</td>
</tr>
<tr>
<td>BIM_SCORE</td>
<td>0.00851039</td>
<td>-0.01972286</td>
</tr>
</tbody>
</table>
**Input Binary MWW Tests and t-tests**

**Sample Input**

```r
> wilcox.test(ALL_binary_NEW$NoIncentives, ALL_binary_NEW$Incentives,
+ alternative='two.sided', paired=FALSE)
```

```r
> t.test(ALL_binary_NEW$NoIncentives, ALL_binary_NEW$Incentives,
+ alternative='two.sided', paired=FALSE)
```

**Output**

**Incentives:**

- data: ALL_binary_NEW$NoIncentives and ALL_binary_NEW$Incentives
  - W = 127, p-value = 0.6174
  - alternative hypothesis: true location shift is not equal to 0

- data: ALL_binary_NEW$NoIncentives and ALL_binary_NEW$Incentives
  - t = -0.197, df = 28.5, p-value = 0.8452
  - alternative hypothesis: true difference in means is not equal to 0

**Sub Risk Evaluation**

- data: ALL_binary_NEW$NoSubRisk and ALL_binary_NEW$SubRisk
  - W = 124, p-value = 0.583
  - alternative hypothesis: true location shift is not equal to 0

- data: ALL_binary_NEW$NoSubRisk and ALL_binary_NEW$SubRisk
  - t = 1.0727, df = 28.842, p-value = 0.2923
  - alternative hypothesis: true difference in means is not equal to 0

**Lump Sum Compensation**

- data: ALL_binary_NEW$NoLumpSum and ALL_binary_NEW$LumpSum
  - W = 133, p-value = 0.1134
  - alternative hypothesis: true location shift is not equal to 0

- data: ALL_binary_NEW$NoLumpSum and ALL_binary_NEW$LumpSum
  - t = 1.7296, df = 8.086, p-value = 0.1215
  - alternative hypothesis: true difference in means is not equal to 0
Input Difference between IPD and Non-IPD – MWW and T-tests

Sample Input

```r
> wilcox.test(ALL_input_sig_NEW$Exp_Past, ALL_input_sig_NEW$Exp_Past_IPD,
+ alternative="two.sided", paired=FALSE)
>
> t.test(ALL_input_sig_NEW$Exp_Past, ALL_input_sig_NEW$Exp_Past_IPD,
+ alternative="two.sided", paired=FALSE)
```

Output

Past Team Experience

data:  ALL_input_sig_NEW$Exp_Past and ALL_input_sig_NEW$Exp_Past_IPD

W = 87.5, p-value = 0.6243
alternative hypothesis: true location shift is not equal to 0

data:  ALL_input_sig_NEW$Exp_Past and ALL_input_sig_NEW$Exp_Past_IPD

t = 1.0143, df = 20.024, p-value = 0.3225
alternative hypothesis: true difference in means is not equal to 0

Current Team Experience

data:  ALL_input_sig_NEW$Exp_New and ALL_input_sig_NEW$Exp_New_IPD

W = 89, p-value = 0.534
alternative hypothesis: true location shift is not equal to 0

data:  ALL_input_sig_NEW$Exp_New and ALL_input_sig_NEW$Exp_New_IPD

t = 0.5132, df = 22.765, p-value = 0.6128
alternative hypothesis: true difference in means is not equal to 0

Involvement

data:  ALL_input_sig_NEW$Involvement and ALL_input_sig_NEW$Involvement_IPD

W = 65.5, p-value = 0.5072
alternative hypothesis: true location shift is not equal to 0

data:  ALL_input_sig_NEW$Involvement and ALL_input_sig_NEW$Involvement_IPD

t = -1.6006, df = 15.882, p-value = 0.1292
alternative hypothesis: true difference in means is not equal to 0
Percent Design Complete

data: ALL_input_sig_NEWSX.des_compl and ALL_input_sig_NEWSX.des_compl_IPD
W = 111, p-value = 0.02346
alternative hypothesis: true location shift is not equal to 0

data: ALL_input_sig_NEWSX.des_compl and ALL_input_sig_NEWSX.des_compl_IPD
t = 2.5152, df = 21.561, p-value = 0.01988
alternative hypothesis: true difference in means is not equal to 0

Core Team Score

data: ALL_input_sig_NEWSCoreT and ALL_input_sig_NEWSCoreT_IPD
W = 93, p-value = 0.4297
alternative hypothesis: true location shift is not equal to 0

data: ALL_input_sig_NEWSCoreT and ALL_input_sig_NEWSCoreT_IPD
t = 0.1987, df = 21.883, p-value = 0.8443
alternative hypothesis: true difference in means is not equal to 0

Management Structure Score

data: ALL_input_sig_NEWSManagement_Structure and
ALL_input_sig_NEWSManagement_Structure_IPD
W = 89.5, p-value = 0.5494
alternative hypothesis: true location shift is not equal to 0

data: ALL_input_sig_NEWSManagement_Structure and
ALL_input_sig_NEWSManagement_Structure_IPD
t = 0.2795, df = 21.51, p-value = 0.7825
alternative hypothesis: true difference in means is not equal to 0

Fiscal Transparency Score

data: ALL_input_sig_NEWSTransparency and ALL_input_sig_NEWSTransparency_IPD
W = 49, p-value = 0.07117
alternative hypothesis: true location shift is not equal to 0

data: ALL_input_sig_NEWSTransparency and ALL_input_sig_NEWSTransparency_IPD
t = -1.9005, df = 22.005, p-value = 0.07054
alternative hypothesis: true difference in means is not equal to 0
**Lean Principles Score**

data: ALL_input_sig_NEW$LEAN and ALL_input_sig_NEW$LEAN_IPD  
W = 46.5, p-value = 0.09132  
alternative hypothesis: true location shift is not equal to 0

data: ALL_input_sig_NEW$LEAN and ALL_input_sig_NEW$LEAN_IPD  
t = -1.5074, df = 22.973, p-value = 0.1453  
alternative hypothesis: true difference in means is not equal to 0

**BIM Use Score**

data: ALL_input_sig_NEW$BIM_SCORE and ALL_input_sig_NEW$BIM_SCORE_IPD  
W = 97.5, p-value = 0.2935  
alternative hypothesis: true location shift is not equal to 0

data: ALL_input_sig_NEW$BIM_SCORE and ALL_input_sig_NEW$BIM_SCORE_IPD  
t = 1.0015, df = 20.61, p-value = 0.3282  
alternative hypothesis: true difference in means is not equal to 0