Quantifying Performance for the Integrated Project Delivery System as Compared to Established Delivery Systems

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Abstract: Integrated project delivery (IPD) is an emerging construction project delivery system that collaboratively involves key participants very early in the project timeline, often before the design is started. It is distinguished by a multiparty contractual agreement that typically allows risks and rewards to be shared among project stakeholders. Because IPD is becoming increasingly popular, various organizations are expressing interest in its benefits to the architecture/engineering/construction (AEC) industry. However, no research studies have shown statistically significant performance differences between IPD and more established delivery systems. This study fills that missing gap by evaluating the performance of IPD projects compared to projects delivered using the more traditional design-bid-build, design-build, and construction management at-risk systems, and showing statistically significant improvements for IPD. Relevant literature was analyzed, and a data collection instrument was developed and utilized in detailed interviews to gather quantitative performance data from 35 recently completed projects. Univariate data analyses, such as t-tests and Mann-Whitney-Wilcoxon tests, were performed to evaluate IPD performance. The results indicate that IPD achieves statistically significant improvements in 14 metrics across six performance areas: quality, schedule, project changes, communication among stakeholders, environmental, and financial performance. The major contribution of this paper is demonstrating that IPD provides higher quality facilities faster and at no significant cost premium. These results would be extremely valuable in the hands of decision makers to enable them to choose the appropriate delivery system for their projects. **DOI: 10.1061/(ASCE)CO.1943-7862.0000744.** © *2013 American Society of Civil Engineers.*

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Introduction

Integrated project delivery (IPD) is the subject of great interest in the construction industry today. Numerous organizations, including the Construction Industry Institute (CII), the American Institute of Architects (AIA), and the Construction Users Roundtable (CURT), have weighed in on the topic, as evidenced by the several reports and publications dedicated to IPD or closely related subjects (e.g., CII 2011; AIA 2011; CURT 2007). Additionally, construction magazines, such as *Engineering News Record* (*ENR*) and *Tradeline*, have featured IPD projects (Post 2011; Allen 2007). Articles in several journals, including the *Journal of Construction Engineering and Management*, the *Construction Lawyer*, and the *Lean Construction Journal* (*LCJ*) have commented on experiences and potential benefits of IPD, such as the reduction of project costs and increased cooperation in the construction process (Matthews and Howell 2005). In 2011, *LCJ* dedicated an entire issue to IPD, discussing integrated delivery and its implementation, illustrating barriers to this transition, and suggesting positive outcomes from integration. This paper examines the claims of superiority by statistically studying the performance of IPD.

To ensure the topic is introduced appropriately, this paper will start with a brief section to define IPD and compare it to other project delivery systems. From there, the paper will cover the background and motivation for this study, followed by an analysis of the literature. Then the research objectives and methodology will be discussed before finally presenting detailed results of the study.

Definitions of Terms

There are several existing definitions of a project delivery system. For example, Cho et al. (2010) summarized the different definitions under three components: commercial terms, organizational structure, and management system. However, two elements are consistently found in the majority of delivery systems definitions: (1) relationships of project stakeholders; and (2) their timing of engagement in the project (Sanvido and Konchar 1998), regardless of the tools and processes used. Therefore, this paper defines a project delivery system as a system that determines the relationships between the different project stakeholders and their timing of engagement to provide a built facility.

Several types of project delivery systems are being used today. Fig. 1 displays differences between the traditional design-bid-build (DBB) system, the more collaborative design-build (DB) system, and the emerging IPD system. The two key focus areas are in accordance with the definition stated previously with respect to the relationships between project stakeholders and their timing of engagement. For example, under DBB, the owner contracts with the

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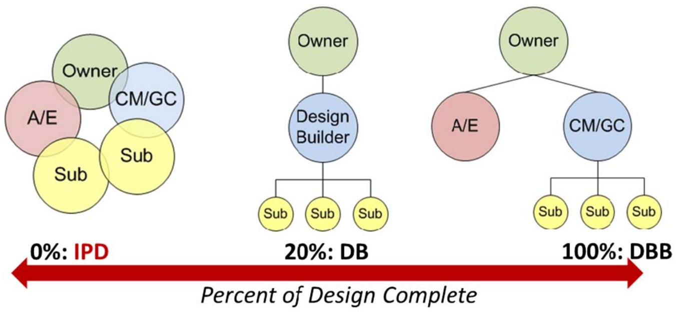

Fig. 1. Differences between DB, DBB, and IPD

designers, and then when the design is 100% complete, the owner contracts separately with a general contractor (GC) to build the facility. In DB, the contractor generally would be involved when the design is approximately 20% complete (the portion of design complete varies based on the project), and the designer and GC would join forces, thereby providing a single point of responsibility for the owner.

In contrast, IPD is different in the following two key aspects: (1) all key project stakeholders sign one multiparty contract (2) before the design even starts, i.e., when 0% of the design is complete. Key stakeholders can include many project parties, such as the owner, GC, architect, consultants, subcontractors, and suppliers. Consequently, this paper defines IPD as a delivery system distinguished by a multiparty agreement and the very early involvement of key participants. The term IPD-ish will be introduced subsequently in the paper to describe projects that, although using the IPD integration concepts and philosophy, do not meet this study's strict definition of IPD because they do not include all the necessary characteristics of the definition, namely, a multiparty contract. It is important to note that IPD is a relatively new concept that is evolving and is still far from being universally standardized. In fact, the literature includes different definitions of IPD. For example, Kent and Becerik-Gerber (2010) stated IPD has three principals: multiparty agreement, early involvement of all parties, and shared risk and rewards. However, other sources, such as AIA (2010), whose IPD definition is still evolving, include additional characteristics, e.g., liability waivers between key participants, fiscal transparency, and jointly developed project goals. To avoid any confusion, this paper defines IPD in accordance with the most widely-accepted definition of a project delivery system, as stated previously in this section: the relationships between key participants are governed by one multiparty agreement, and these key participants are involved very early in the project, typically before the design even starts.

Motivation

Several industry problems and changing factors ultimately led to the development of IPD. The emerging IPD system is believed by many in the industry to be revolutionizing the way projects are delivered by fostering early involvement and collaboration of project stakeholders through the use of different concepts, such as shared project leadership, shared risk and reward between all project participants, and liability waivers. The need for more collaboration in general and for IPD specifically is best expressed by the 2004 and 2007 reports of the CURT (CURT 2004, 2007). The earlier report encouraged owners to drive the construction industry change "by leading the creation of collaborative, cross-functional teams comprised of design, construction, and facility management professionals." The second report specifically spelled out CURT's path toward embarking on IPD projects. Several sources estimate great benefits of utilizing IPD. The United Kingdom's Office of Government Commerce (UKOGC) estimates savings anywhere from 2–10% in the cost of construction for single projects, and up to 30% for strategic partnering in which integrated teams work together for more than a single project (UKOGC 2007). Reports by the American Institute of Architects (e.g., AIA 2010) showcase a handful of successful IPD case studies. Mossman et al. (2010) also discussed potential benefits of integrated delivery through case studies. For example, clients obtain more value and reduced energy costs of use, designers see reduced design documentation time and can keep the design within the target cost, and constructors experience less rework and more buildable facilities.

However, these performance benefits have not yet been validated. Other than individual case studies and anecdotal examples, there are no comprehensive studies that show superior IPD performance through a scientific statistical analysis. There still exists a need to evaluate IPD and understand its true performance based on several important metrics used in the architecture/engineering/construction (AEC) industry. One way to conduct such an evaluation is to compare the performance of IPD projects to the performance of projects delivered with other more traditional delivery systems, which serve as a baseline for this study. A literature review helps understand how project delivery systems have been compared in the past to provide a strong foundation for this paper.

Literature Review: Comparing Project Delivery Systems

Out of the numerous systems being used to deliver facilities around the world, the three delivery systems most commonly employed in the U.S. construction industry are (1) traditional DBB, (2) construction management at risk (CMR), and (3) DB. There is an abundance of construction delivery literature comparing the performance of DBB, CMR, and DB. The studies differ based on specific data set characteristics, such as the types of projects studied and the performance metrics used.

Pocock (1996) compared the performance of traditional and alternative project delivery approaches using military construction projects. The metrics used to compare delivery types were (1) schedule growth, for which partnered projects were the most successful; (2) cost growth and (3) design deficiencies, both of which were dominated by DB; and (4) modifications, at which combination projects (hybrid use of delivery systems) had an enhanced performance. Traditional DBB projects were shown to perform the worst when comparing schedule growth, modifications, and design deficiencies. He also measured the degree of team integration, which he demonstrated was directly impacting project performance.

Bennett et al. (1996) compared cost, schedule, and quality performance of DB and DBB projects in the United Kingdom. Their study showed that DB projects result in improvements of delivery speed by 30% and construction speed by 12%, and a 13% reduction in unit cost. A CII study conducted by Sanvido and Konchar (1998) also showed DB has a superior performance over CMR, which in turn performed greater than DBB. The metrics studied for which the results were statistically significant included unit cost, construction speed, and delivery speed.

Molenaar studied DB performance in the public sector (Molenaar 1995; Molenaar et al. 1999) and considered numerous project variables: owner experience, level of design completion, design-builder selection, contract type, method of award, and DB process variations. Performance metrics were both quantitative, including cost and schedule growth, and qualitative, including the measurement of quality with respect to the user's expectations, construction administrative burden, and owner satisfaction with the overall project. Quantitative results show 59% of the DB projects experienced less than 2% cost growth, and 77% of the DB projects experienced less than 2% schedule growth. Qualitative results show most owners were satisfied with the performance of DB.

Ibbs et al. (2003) studied DB and DBB using data from CII projects by comparing cost growth, schedule growth, and productivity as the performance metrics. Schedule growth results confirmed previous findings on the superiority of DB compared to DBB. However, DB was not found superior to DBB when looking at cost growth and productivity.

Riley et al. (2005) studied the effects of using DB mechanical contractors (DBMC) on green building projects through three case studies. Their research showed that early involvement of DBMC resulted in a significant improvement over the DBB approach through initial cost savings and a more efficient final product. One significant trend the study notes is the DBMC's willingness to adopt new technologies and innovative solutions.

More recently, Rojas and Kell (2008) conducted a study focusing on cost performance of CMR and DBB project delivery systems. Their scope was limited to delivering public schools in the U.S. Pacific Northwest. The results show no statistically significant difference between CMR and DBB in construction change order costs, and DBB averages less cost growth than CMR. These results challenge earlier findings regarding CMR cost performance and specifically apply to the construction of Pacific Northwestern public schools.

Korkmaz et al. (2010) studied the influence of project delivery methods on achieving sustainable high performance buildings. Looking at 12 in-depth case studies covering DBB, DB, and CMR, the study investigated the effects of project delivery attributes on project performance at construction completion. Korkmaz et al. (2010) found that CMR and DB outperform DBB projects overall; one specific result suggests that projects adopting the DBB method display higher cost growth. Similar to the Pocock (1996) study, the Korkmaz (2010) study reveals that the level of integration in the delivery process affects final project outcomes. Another study by Korkmaz et al. (2010b) identified key metrics for sustainable building project delivery in the United States. The results show that CMR and DB outperform DBB in the delivery speed metric.

One of the latest studies comparing delivery systems contrasted IPD to other delivery systems. Cho and Ballard (2011) performed t-tests on data from 49 projects to study (1) whether the Last Planner System, a production control tool that levels construction project task workflow, improves project performance; and (2) whether IPD projects show different project performance from non-IPD projects. Although it was shown that the Last Planner System improves performance, the authors were not able to find significant differences in performance between IPD and non-IPD projects. The authors' definition of project performance was restricted to reductions in time and cost, which might not prove comprehensive enough when studying the value-adding IPD system. For example, project owners might decide to reinvest the saved costs back into the project, getting more value out of their facility. This likely situation results in no visible differences in the authors' analysis of cost and time reductions.

To summarize the *Literature Review*, most studies provide some evidence for more collaborative delivery systems being superior to less collaborative systems. The statistical significance of the results varied depending on the type of construction and the scope of the studies performed. A multitude of metrics has been used in the literature, all of which have been included in this study, as will be discussed in the next section.

Problem Statement and Methodology

A survey of the literature to date shows no studies that have statistically compared and quantified the benefits of IPD projects relative to non-IPD projects based on a comprehensive list of performance metrics. Aside from a few case studies and anecdotal examples, no significant literature exists to support the claim of superior IPD performance. In fact, the only research study that statistically investigates this claim found no performance differences between IPD and non-IPD projects. The hypothesis that the implementation of IPD would improve project performance is not supported by any statistical analysis. This is considered the point of departure for this study. Because no solid statistical inference can be made based on previous findings, data collection and analysis of an inclusive set of performance metrics are still necessary to investigate the relationship between IPD and project performance.

When a new delivery system emerges, its performance is typically benchmarked against other systems currently in place, which provide a performance measurement scale. Similar comparisons were performed decades ago when CMR emerged, and then again when DB emerged. However, the performance of today's new system, IPD, has not been studied yet. This paper is a first step in this direction, building on the several studies that compare DB to CMR to DBB and others. The goal of this study is to evaluate the performance of IPD projects by comparing them to projects delivered using other systems, such as CMR, DB, and DBB. The focus extends beyond the commonly analyzed metrics of cost and time to include safety and quality, and less commonly studied metrics, such as changes, process inefficiencies, communication, and profit. This comparison is used to understand if IPD provides a superior performance and is worth the use, research, and investment. The methodology for this study encompasses three distinct stages.

Stage A

Stage A is an assessment of the literature and industry practices that will lay the ground for the rest of the study. Stage A consists of two steps, the first of which is meant to appreciate the current state of knowledge, whereas the second step is meant to identify key variables that need to be analyzed to accomplish the research goal. Quantitative and qualitative project performance metrics are dependent variables measured after project completion. The initial list of performance metrics used for this research was based on the metrics included in previous studies, such as those highlighted previously in the *Literature Review* section of this paper. Additional literature on project performance and project success metrics was also reviewed for comprehensiveness (e.g., Songer and Molenaar 1996; Chan et al. 2002; Debella and Ries 2006; Menches and Hanna 2006; Molenaar and Navarro 2011). This original list is shown in Table 1, and was later complemented with additional factors recommended by this study's three industry panels. The comprehensive list of metrics was further refined based on the project information available for data collection, and the final performance metrics used in this study are presented in the following section of this paper. Because identifying the key variables provides guidance about the type of data that need to be collected,

Table 1. Literature Summary of Performance Metrics

Performance area	Performance metric	Pocock (1996)	Songer and Molenaar (1996)	Sanvido and Konchar (1998)	Chan et al. (2002)	Debella and Ries (2006)	Menches and Hanna (2006)	Rojas and Kell (2008)	Cho and Ballard (2011)	Molenaar and Navarro (2011)
Cost	Unit cost		x	x	x	x		x		x
	Cost growth	x	x	x	x	x	x	x	x	
	Budget factor							x		
Schedule	Construction speed		x	x	x	x	x			x
	Delivery speed			x						
	Schedule growth	x	x	x	x	x	x		x	
Safety					x					x
Productivity	Productivity factor				x					
Business	Profit				x		x			
Quality	Systems			x	x					x
	Turnover			x						
	Defects				x					
	Building ownership				x					
Occupants	Satisfaction				x					
Useability and value	Program spaces									
	Functionality				x					
	Suitability for purpose		x		x					
Other	Claims		x		x	x				
	Changes/modifications	x				x	x			
	Material waste				x					

the completion of the first stage serves as a solid basis for the survey development.

Stage B

Three steps are needed for the completion of Stage B: survey development, pilot testing, and data collection. As discussed previously, the review of literature and consultation with industry partners allowed for the identification of key variables, and then a data collection questionnaire was developed based on these variables. The survey was designed to gather data on quantitative and qualitative performance metrics. It was shared with industry participants, specifically general contractors and construction managers, to act as a roadmap for interviews and to allow for the gathering of data in a consistent format. Before the survey was used to collect data, it went through three specific review stages. The first stage consisted of individual reviews by several industry experts and construction engineering and management faculty members; the second stage consisted of collective reviews by three panels of industry experts, including contractors, designers, and owners; and the third stage consisted of reviews by a professional survey center. Following the thorough survey development stage, the final data collection questionnaire was pilot tested on a limited number of projects to refine the questions and maximize their effectiveness. The resulting comprehensive 13-page survey allowed for an intensive data collection effort targeting performance metrics for individual construction projects. Because there exists only a limited number of IPD projects in the United States, the authors first identified the companies that have completed IPD projects. These companies were asked to identify their IPD projects, along with comparable projects (in terms of type, size, and location) completed in the United States using other project delivery systems. The authors requested that all IPD and non-IPD projects be recently completed (after 2005) vertical construction, as will be discussed in the "Data Characteristics" section of this paper. The developed survey was then used to collect performance data for each of the identified IPD and non-IPD projects. Upon completion of Stage B, the developed questionnaire had been used to gather responses, and the resulting project data had been verified and readied for analysis. The last stage of this research builds on the previous two and consists of analyzing the data collected and developing benchmarks for IPD project performance.

Stage C

The statistical analysis consists of testing whether IPD leads to superior performance. Univariate analyses were performed on the collected project data to compare the various delivery systems and test whether IPD is more successful than other types of project delivery systems based on each individual performance metric. Hypotheses were developed for each performance metric. An example hypothesis is that IPD projects result in a significantly higher delivery speed than non-IPD projects. For each metric, normality tests were conducted, and then two types of analysis were used to provide a comprehensive look at the comparisons between IPD and non-IPD projects: (1) t-tests when the data set can be assumed normally distributed, and (2) the nonparametric Mann-Whitney-Wilcoxon (MWW) tests when the normality assumption does not hold. The t-test is an analysis that can be used to assess the statistical significance of the difference between two sample means. In general terms, a t-test is optimal when each population in the data set is normally distributed. The MWW is a nonparametric statistical hypothesis test used when the data cannot be assumed to be normally distributed. Among tests based on ranks, the MWW test is the most widely used because it is known to be extremely robust against nonnormality and to have asymptotic power of at least 86% of that of the t-test over all distributions (Lehmann 2006). Because of the abundance of previous literature showing the more integrated delivery systems (i.e., CMR and DB) performing superiorly on complex projects (e.g., Molenaar 1995; Bennett et al. 1996; Pocock 1996; Sanvido and Konchar 1998; Molenaar et al. 1999; Riley et al. 2005), one-sided hypotheses were used in this study to test whether the more integrated IPD results in superior performance. However, for comprehensiveness, both one-sided and two-sided tests were conducted. Any two-sided p-value will be double that of a one-sided p-value when a symmetric distribution is used to compute

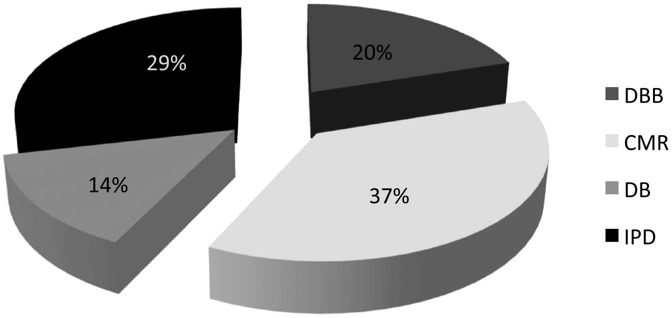

Fig. 2. Project makeup among major delivery systems

them, which is the case for this study. The next section presents the characteristics of the collected data, followed by the results of the analysis.

Data Characteristics

Generous industry collaborators granted access to 35 projects: 12 IPD projects and 23 comparable non-IPD projects. Fig. 2 shows the makeup of delivery systems for the 35 projects. The upside from having strong industry commitment is that it allowed a very thorough data collection effort to take place, gathering information on 304 variables for each project. Since it is very difficult to collect data from all key stakeholders of AEC projects, the construction managers or general contractors were targeted because these parties typically have access to most of the quantitative project data (e.g., cost and schedule) needed for this research effort. The data collection effort took up to two days for a single project. The projects used for this research were predominantly in two geographic locations, as shown in Fig. 3. The first is the U.S. Midwest region (i.e., Minnesota, Wisconsin, Michigan, Indiana, and Missouri), and the second is the state of California. Most IPD work is being conducted in these two geographic locations, largely because organizations that are leading IPD efforts are involved with projects in these two parts of the country. Some additional projects were located in the states of Massachusetts and Colorado. The types of projects were generally complex institutional vertical construction facilities, along with a few commercial facilities. In fact, approximately 50% of the projects in the database were healthcare facilities and approximately 25% were university research laboratories. All projects were completed between 2005 and 2012. The total dollar amount of construction work for all projects combined was close to $3 billion. The cost distribution included project costs ranging from $5 million to around $400 million.

Evaluating IPD through Nine Performance Areas

This section investigates the effect of IPD on all identified performance metrics for which data were available. IPD and non-IPD projects were compared for each performance metric individually using a univariate analysis, which allows for a clear comparison of IPD and non-IPD project performance. Table 2 shows the results of the analyses and is organized by increasing p-values for all 31 performance metrics studied in this paper. For each individual test, a p-value smaller than 0.05 shows significant performance differences between IPD and non-IPD projects. The following nine subsections are split by performance areas that cover related metrics. For instance, the first area consists of metrics related to cost performance, including construction unit cost and cost growth.

Cost Performance Metrics

Data for two standard cost performance metrics were available for most of the projects: (1) unit cost, and (2) construction cost growth. Unit cost is measured in dollars per square foot. Construction cost

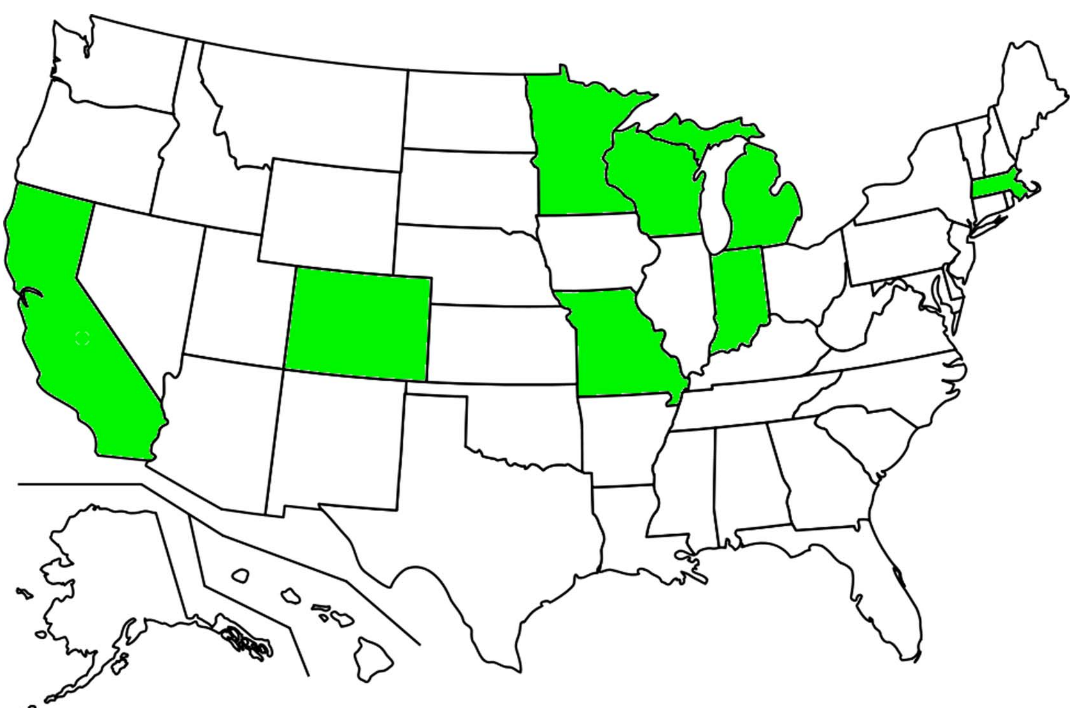

Fig. 3. United States map of respondents

Table 2. Analysis Results for IPD versus Non-IPD Performance

Metric number	Performance metric	p-value
1.	Change order processing time	0.000
2.	Deficiency issues	0.001
3.	Request for information	0.001
4.	Punchlist cost	0.003
5.	Punchlist items	0.013
6.	Resubmittals	0.018
7.	Tons of construction waste	0.022
8.	Overhead and profit	0.024
9.	RFI processing time	0.025
10.	Design changes	0.029
11.	Systems quality	0.032
12.	Warranty costs	0.040
13.	Delivery speed	0.046
14.	Regulatory changes	0.049
15.	PPC trend	0.072
16.	Lost time injuries	0.083
17.	Labor factor	0.094
18.	Construction schedule growth	0.131
19.	Schedule intensity	0.141
20.	Delivery schedule growth	0.145
21.	Construction speed	0.168
22.	Rework	0.173
23.	Return business	0.211
24.	Total percent change	0.224
25.	Additional labor	0.230
26.	Recycling rate	0.242
27.	Unit cost	0.330
28.	Additions/deletions	0.334
29.	Latent defects	0.442
30.	Cost growth	0.471
31.	OSHA recordables	0.491

Note: Ordered by increasing p-value.

growth is measured in percentage terms by comparing the final construction costs to the original estimated construction costs. The MWW tests and t-tests are used to determine whether there are any significant differences in cost performance between IPD and non-IPD projects. The tests result in a p-value, and a commonly used threshold is 0.05, below which the performance differences between the two samples are considered statistically significant. In the tests conducted here, the p-values were higher than 0.05, denoting no significant differences in cost performance. The results for the cost performance metrics are shown in rows 27 and 30 of Table 2. This subsection confirms the findings of previous literature that found no significant differences in cost performance for IPD projects.

Quality Performance Metrics

The previous subsection showed there are no statistically significant differences in cost performance between IPD and non-IPD projects. However, as mentioned previously, the cost discussion is incomplete without considering project quality to conduct a fair comparison. Because quality is difficult to measure, both qualitative and quantitative performance metrics were evaluated to provide a comprehensive understanding of quality performance. The quality performance metrics include (1) the as-built quality of major building systems, (2) the number of deficiency issues, (3) the number and cost of punchlist items, and (4) the costs of warranty and latent defects. Most major building systems were surveyed, including building finishes, structure, and mechanical systems. Respondents were asked to provide the quality of each system on a scale of 1–5, representing economy, standard, high quality, premium, or high efficiency premium. Deficiency issues are issues that arise during the course of construction and can be related to numerous reasons, such as failed field inspections and jurisdiction problems related to code observance. Punchlist items are the uncompleted or unsatisfactory items remaining after the substantial completion of a project, such as components needing minor repairs or replacement. Warranty costs are measured in the first year of occupancy, and latent defect costs are measured after the end of the one year warranty period.

All of the aforementioned items can serve as indicators of the building quality. For these items to be compared across projects of different sizes, their values were normalized. For example, the number of deficiency issues per million dollars was obtained by dividing the total number of deficiency issues for a project by the final construction cost of the project. The number of punchlist items per million dollars was calculated in a similar manner. However, the costs of warranty and latent defects were both measured on an ordinal scale based on cost percentages relative to total construction costs. For example, if the warranty costs are 0% of the construction cost, the value is coded to 0; however, if they equal between 0 and 0.5% of construction costs, the value is coded to 1, and 0.6–1% is coded to 2, etc.

Before discussing the results of the statistical analysis, boxplots of the data are presented. A boxplot is a nonparametric graphical summary of data, displaying the sample minimum, lower quartile, median, upper quartile, and maximum. The median value is represented by a thick black line, dividing the data set in half, and the box represents the 50% of the data around the median, whereas the remaining 50% of the data are divided equally above and below the box. Boxplots give a visual representation of the data set and provide insights regarding the distribution of the data.

Fig. 4 includes four boxplots depicting quality performance. The upper left corner of Fig. 4 shows the boxplots for overall project quality combining all major building systems. The horizontal axis separates the non-IPD, IPD-ish, and IPD projects. The vertical axis corresponds to systems quality, and the boxplots show a clear superiority in quality performance for the IPD projects when compared to the non-IPD projects, whereas the quality scores for IPD-ish projects were in between. This is shown by the median scores being higher for IPD projects, as represented by the thick horizontal lines around the middle of each boxplot.

The upper right corner of Fig. 4 shows the boxplots for the number of deficiency issues per million dollars. Even before performing any statistical analyses, one can see that IPD projects experience considerably less deficiency issues than their non-IPD counterparts. Additionally, IPD projects in this sample have considerably less punchlist items than non-IPD projects (and a much smaller variance), as shown in the lower left corner of Fig. 4. Finally, the interpretation of the warranty costs and latent defects is not very obvious and will need statistical testing. These findings are only based on plots of the raw quality performance data; any visual differences need to be tested for statistical significance.

The MWW and t-tests were conducted to statistically verify the significance of the differences observed when comparing quality metrics between the IPD sample and the non-IPD sample. Most tests showed significant differences; the test for systems quality showed a p-value of 0.032. This result is statistically significant at the 0.05 level and indicates that IPD projects have a higher systems quality than their non-IPD counterparts. Similarly, MWW and t-tests were conducted for deficiency issues and showed significant differences between IPD and non-IPD projects; the resulting p-value was 0.001, indicating IPD projects have significantly less deficiency issues than non-IPD projects. This result is significant at

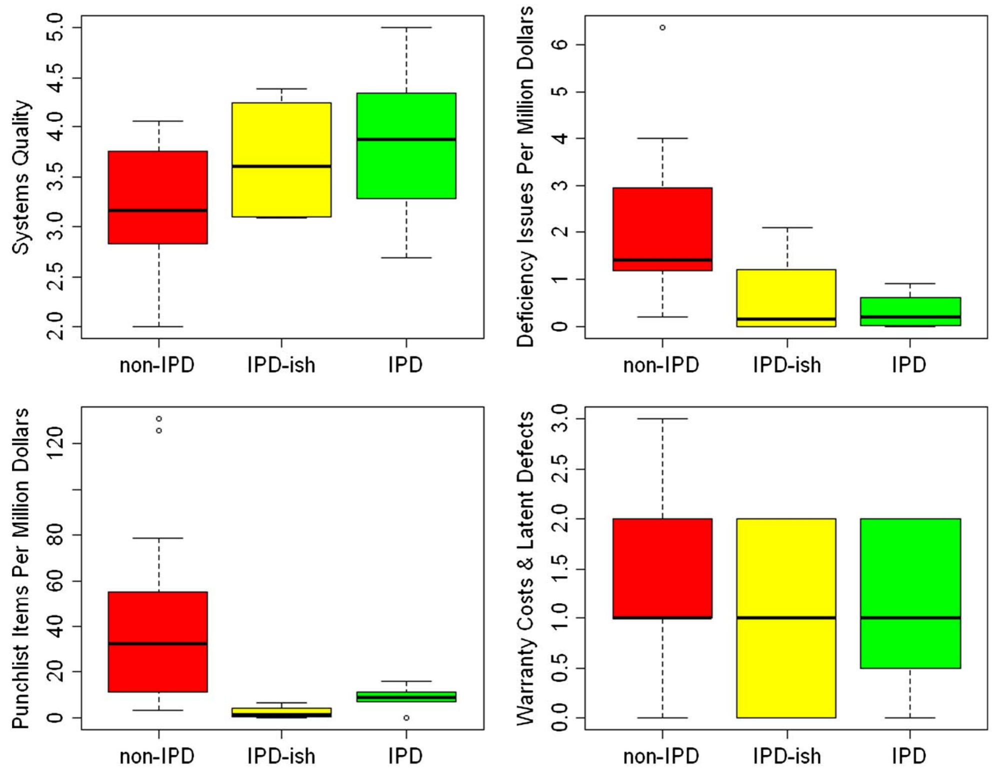

Fig. 4. Boxplots for quality metrics

the 0.05 level and the more conservative 0.01 level. In fact, the median value for non-IPD projects is 1.4 deficiency issues per million dollars versus 0.2 deficiency issues for the IPD projects. The MWW estimate for the difference is 1.4 issues per million dollars with a 95% confidence interval ranging between 0.5 and 3.0 deficiency issues.

Additionally, MWW and t-tests were conducted for the two metrics measuring punchlist items: (1) the number of punchlist items per million dollars, and (2) the cost of punchlist items in percentage of total construction cost. The tests show significant differences between IPD and non-IPD projects. The test for number of items per million dollars shows a p-value of 0.013, indicating IPD projects have significantly fewer punchlist items than non-IPD projects. This result is significant at the 0.05 level, and the median value for non-IPD projects is 32.39 items per million dollars, versus 8.98 for the IPD projects. The MWW estimate for the difference is 23.05 items per million dollars, with a 95% confidence interval for the difference ranging between 2.82 and 48.18 items. The width of this confidence interval is a function of the sample size and the variance of the data.

The tests conducted for the latent defects variable do not show significant differences between IPD and non-IPD projects, but the individual test for warranty costs shows differences in performance with a p-value of 0.040, indicating IPD projects have lower warranty costs than non-IPD projects, and this result is significant at the 0.05 level. A point estimate for warranty costs is not provided here because the data collected for this metric were ordinal.

This subsection provides the first quantitative proof that the IPD delivery system has superior performance compared to traditional delivery systems. Combined with the previous subsection on cost performance, these results provide a better understanding of IPD project performance by demonstrating that IPD delivery systems result in higher quality projects at no significant cost premiums. The results for the quality performance metrics are shown in rows 2, 4, 5, 11, 12, and 29 of Table 2. The next subsection investigates IPD schedule performance.

Schedule Performance Metrics

Data for three standard schedule performance metrics were available for most of the projects: delivery speed, construction speed, and construction schedule growth. Delivery speed is measured in square feet per day, starting from the design start date and ending at the occupancy date. It is arguably the most important schedule metric because it encompasses all the other metrics (e.g., construction speed and schedule growth). Construction speed is also measured in square feet per day, starting from the construction notice to proceed and ending at the project substantial completion. Construction schedule growth is measured in percentage terms by comparing the final construction schedule to the original estimated construction schedule. In addition to these typical schedule performance metrics, a supplementary metric was used to gauge the intensity of the construction schedule by measuring the average dollar value of construction work completed per day. This metric is called intensity. The rationale behind measuring schedule intensity is the fact that schedules are based on estimates, and some estimates are more aggressive than others. The intensity metric will provide another comparison of construction speed by normalizing with respect to the amount of construction work put in place during the same time frame.

The boxplots in the upper left corner of Fig. 5 show data for construction speed, and the boxplots on the upper right corner show data for delivery speed. In both cases, one can see that the median represented by the thick black line in the middle of the IPD sample is higher than the median in the middle of the non-IPD sample. The boxplots show that IPD projects have a slightly superior schedule performance over the non-IPD projects. Furthermore, the boxplots on the lower left side show data for the schedule intensity metric, and the boxplots on the lower right side show data for construction

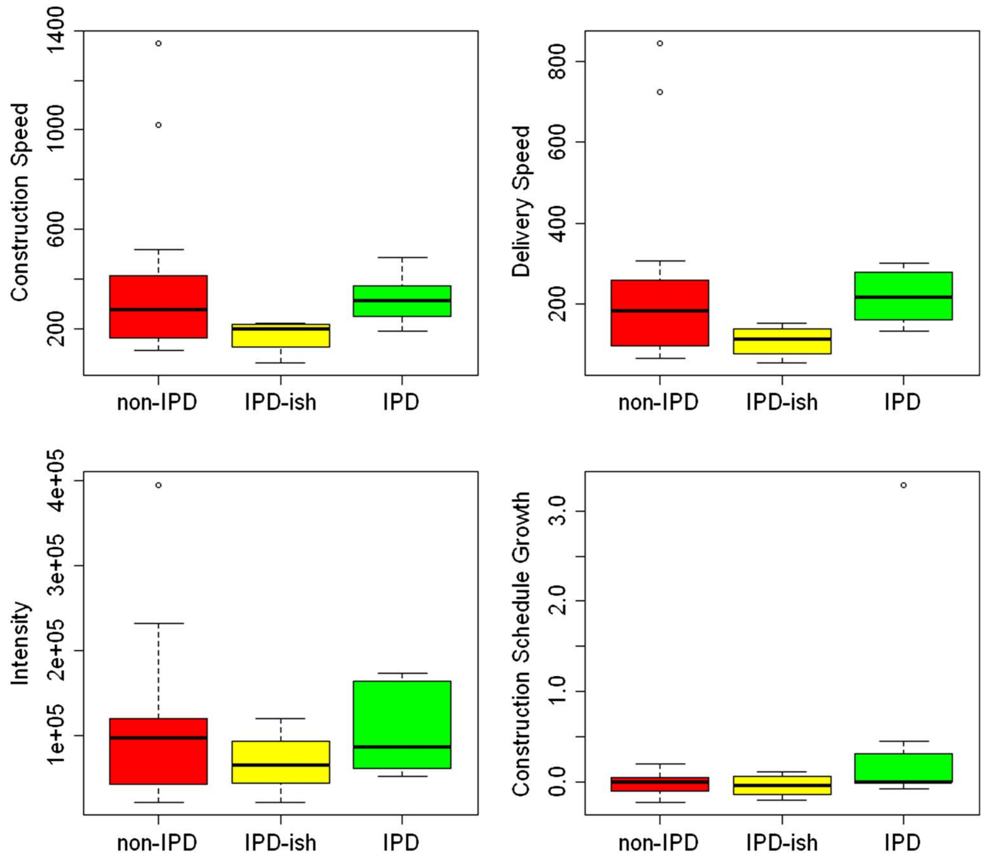

Fig. 5. Boxplots for schedule metrics

schedule growth in percent of the initial estimate. Based on these boxplots, IPD projects seem to have a higher intensity, but also a larger construction schedule growth. A statistical analysis was conducted to examine these claims.

Similar to the analysis conducted for cost and quality performance, MWW and t-tests were conducted to compare schedule performance for the IPD sample and the non-IPD sample. The tests for construction speed and for construction intensity showed no significant differences. However, the test conducted for delivery speed shows a p-value of 0.046, which means differences in delivery speed are statistically significant. Moreover, the estimate for the difference is approximately 54 square feet per day, and the 95% confidence interval for the difference is (−9.7, 117.5). Although the interval includes zero and possible negative values, most of it is positive and can get up to 117.5 additional square feet per day for IPD projects. As discussed previously, delivery speed is considered the most important schedule metric because it is at the highest level of scheduling and encompasses the whole construction phase and all schedule growths. Tests also were conducted for delivery schedule growth and construction schedule growth, which showed no significant differences between IPD and non-IPD projects. However, even with no statistically significant differences in lower level schedule performance metrics, IPD projects still have a statistically superior overall delivery speed. The results for the schedule performance metrics are shown in rows 13, 18, 19, 20, and 21 of Table 2.

Safety Performance Metrics

Three safety metrics were measured: (1) the number of occupational safety and health administration (OSHA) recordables, (2) the number of lost-time injuries (LTI), and (3) the number of fatalities. Fortunately, there were no fatalities on any of the projects surveyed; therefore, fatalities are not included in this analysis. Incidence rates were calculated for both the recordables and LTI. Per the Bureau of Labor Statistics (BLS) formula, incidence rates are computed by multiplying the number of recordables or LTI by 200,000, and then dividing by the total hours worked (BLS 2012). The 200,000 h represent the equivalent of 100 employees working 40 h per week. This computation provides a means to normalize the values for projects of different sizes. Because the total project hours were not always available, another type of normalization was used by dividing the number of recordables or LTI by the cost of the project. Similar to the cost metrics, boxplots are not shown for the safety metrics because no major visual differences can be seen on the plots. The only noticeable difference for the safety metrics is that distributions are wider for non-IPD projects, allowing for more extreme values.

The MWW and t-tests were conducted to statistically compare OSHA recordables for the IPD and non-IPD samples. Both the incidence rates and the number of recordables per million dollars were compared. The tests showed no significant differences in recordables between the IPD and non-IPD samples. Similarly, MWW and t-tests were conducted for the two metrics measuring LTI: incidence rate and LTI per million dollars. Tests on the incidence rate did not show significant results. However, the test on the LTI per million dollars, for which more data were available, showed a p-value of 0.083. Although this value is not enough to show significant differences between IPD and non-IPD projects at the 0.05 level, this finding warrants further discussion. This result is significant at the more lenient 0.10 level. In fact, the 95% confidence interval for the difference ranges from 0.001–2.739 LTI per million dollars. A larger data set could possibly substantiate these claims at the 0.05 significance level. The results for the safety performance metrics are shown in rows 16 and 31 of Table 2.

Project Change Performance Metrics

In addition to cost, quality, schedule, and safety metrics, several project change performance metrics were targeted for data collection. Overall, change performance data included three types of metrics:

1. Total percent of change in the project;
2. Reason for the changes: CII Research Report 158-11 (2001) shows the two key reasons for changes are project additions and design-related changes (including design changes, design coordination, and design errors). Data were collected to assess these two types of changes for each project. In addition, the industry panel for this research requested that data be collected for changes attributable to code or major regulatory agencies; and
3. Average change order processing time, defined as the period of time between the initiation of the change order and the owner's approval of the change order.

Data for total change and reasons for the change orders were gathered in percentage terms, whereas data for the average change order processing time were collected in weeks.

The boxplots in the upper left corner of Fig. 6 show data for the overall percent change experienced by the IPD and non-IPD projects. One can notice the wider distribution and the higher median for non-IPD projects, so the figure clearly shows IPD projects experience fewer changes than their non-IPD counterparts. The boxplots in the upper right corner show the data for the changes related to design issues, again showing IPD projects experience considerably less design changes. The lower left corner shows program changes related to additions and modifications, and IPD projects seem to have a slightly lower median. Finally, the change order processing time is displayed in the boxplots in the lower right corner. The units for the y-axis are weeks, and the difference between the IPD and non-IPD processing times are clearly visible. In fact, the median value for IPD projects is approximately one week, whereas change orders need four times longer to be processed for non-IPD projects.

The MWW and t-tests were conducted to statistically compare project change performance metrics for the IPD and non-IPD project samples. All previously introduced metrics were analyzed. The differences in total percent change were not significant at the 0.05 level with a p-value of 0.224. The differences in changes attributable to additions and deletions also were insignificant with a p-value of 0.334. However, the differences in design changes were significant at the 0.05 level with a p-value 0.029. The median value for non-IPD projects is 10% versus 1.8% for the IPD projects. The MWW estimate for the difference is only 5%, with a 95% confidence interval ranging between 0 and 25%. The difference in changes stemming from major regulatory agencies is also significant at the 0.05 level, with a p-value of 0.049. The median value for non-IPD projects is 5% versus 0 for the IPD projects. The MWW estimate for the difference is only 1.2%, with a 95% confidence interval ranging between 0 and 5%. Even more noteworthy are the differences in change order processing times, which also are statistically significant at the 0.05 level and the more conservative 0.01 level, with a p-value of 0.0003. As stated previously, the median value for non-IPD projects is 4 weeks versus 1 week for the IPD projects. The MWW estimate for the difference is 3 weeks with a 95% confidence interval ranging between 2 and 5 weeks. The results for the change performance metrics are shown in rows 1, 11, 14, 24, and 28 of Table 2.

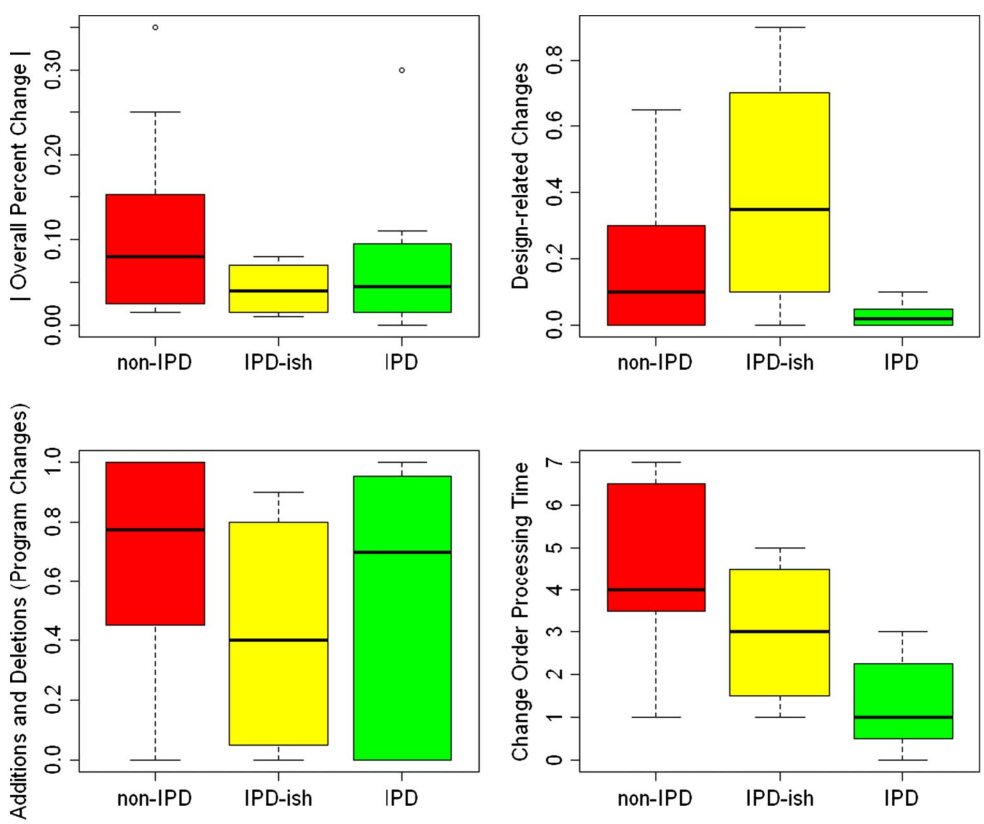

Fig. 6. Boxplots for change metrics

In summary, IPD reduces design-related changes, regulatory changes and change order processing time. The decrease in design changes and regulatory changes for IPD can be attributable to the high level of involvement of key project stakeholders throughout the entire project timeline. For example, the contractors' involvement in the design phase and the designers' involvement in the construction phase can result in an increased common understanding of the project, and therefore a reduction in design-related changes. The same phenomenon happens when regulatory officials are continuously involved throughout the project, which leads to fewer changes because of code and regulations. Additionally, the much faster processing time for changes can be associated with the weekly meetings of the core groups leading IPD projects, which have the authority needed to make most project-related decisions, such as approving and processing change orders.

Communication Performance Metrics

This study offers a broad definition of project performance, beyond the typical triangle of cost, schedule, and quality. Thus far, safety and changes have been discussed, and next are communication performance metrics. Communication performance refers to direct means of communication and process inefficiencies. This subsection focuses on requests for information (RFI), rework, and resubmittals. Requests for information are considered a communication performance metric because they can be an important source of waste for projects. The reason is simple: crews lose productivity while waiting for information, especially when it takes weeks for other project parties to respond. Often, these crews have to demobilize and remobilize more than once, which can add costs to the project. Although this paper considers RFI a reflection of communication performance, RFI also have been used as an indicator of quality performance in other references, specifically for design quality (e.g., Tilley et al. 1997). The RFI data include two metrics: (1) the number of RFI, and (2) the RFI processing time. To normalize the RFI values to compare projects of different sizes, the number of RFI is divided by the project construction cost. The boxplots in the upper left corner of Fig. 7 show data for the number of RFI for IPD and non-IPD projects. The difference in the medians is straightforward: there are approximately ten RFI per million dollars for non-IPD projects, compared to approximately two RFI for IPD projects. The upper right corner of Fig. 7 shows the boxplots for the RFI processing time. Again, IPD projects have much lower values than their non-IPD counterparts. The lower left corner of Fig. 7 shows comparable median values for rework, and the lower right corner shows considerably less resubmittals for IPD projects. These findings need to be confirmed with statistical testing.

The MWW and t-tests were conducted to statistically compare RFI for the IPD and non-IPD samples. Both the number of RFI per million dollars and the RFI processing times were compared. The differences in the number of RFI were significant at the 0.05 level and the more stringent 0.01 significance level, with a p-value of 0.001. The median for IPD projects was approximately 9.61 RFI per million dollars, compared to 1.81 RFI for non-IPD projects. The MWW estimate for the difference is 8.23 RFI with a 95% confidence interval ranging between 4.10 and 14.88 RFI per million dollars. Data were also collected for work-arounds, or alternative means used to avoid RFI, such as phone calls or emails. There were no significant differences in work-arounds between IPD and non-IPD projects, which further strengthens the RFI results. The differences in the RFI processing times were significant at the 0.05 level with a p-value of 0.025. The median for non-IPD projects was 2 weeks compared to 1 week for IPD projects. The point estimate for the difference is 1 week with a 95% confidence interval ranging between 0 and 2 weeks. Rework can be simply defined as construction work that had to be redone because of several potential causes, such as changes, design issues, and

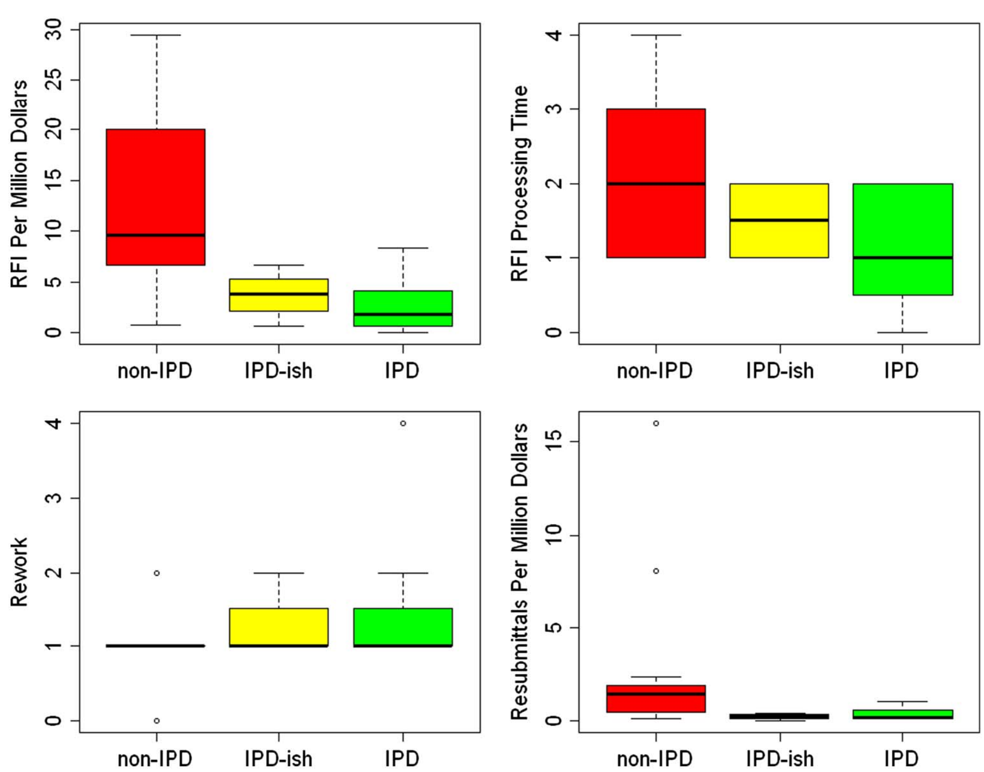

Fig. 7. Boxplots for communication metrics

installation defects. Rework was tracked in percent of overall cost, and MWW tests were conducted to statistically compare performance between the IPD and non-IPD samples. The differences in rework are not statistically significant at a 0.05 level with a p-value of 0.173. The number of resubmittals was divided by the project construction cost in millions of dollars to normalize the data for projects of different sizes. The differences in the number of resubmittals between IPD and non-IPD projects are statistically significant at the 0.05 level with a p-value of 0.018. The median for IPD projects is approximately 0.20 resubmittals per million dollars compared to 1.44 resubmittals for non-IPD projects. The MWW estimate for the difference is 0.94 resubmittals with a 95% confidence interval ranging between 0.01 and 1.80 resubmittals per million dollars. Claims and litigations can also be discussed as part of this subsection. In the whole data set, no IPD projects experienced any claims, whereas three non-IPD projects experienced claims. The analysis of communication performance metrics demonstrates significant improvements for IPD projects with respect to all tested communication metrics except rework, which did not show any significant differences in performance. The results for the communication performance metrics are shown in rows 3, 6, 9, and 22 of Table 2.

Labor Performance Metrics

Labor is often one of the high risk items on construction projects, especially given that labor costs can constitute up to half of the total project cost. Therefore, labor performance is an important aspect of overall project success. Three labor performance metrics were available for data collection: (1) the extent to which additional labor is used, in terms of overtime, second shift work, and over-manning; (2) trend of percent plan complete (PPC), or the measure of work flow reliability, which is calculated by dividing the number of actual task completions by the number of planned tasks; and (3) labor factor, measured as a ratio of the total cost of self-performed work divided by the labor cost of self-performed work.

The boxplots in the upper left corner of Fig. 8 show that IPD projects use less extra labor than non-IPD projects. The boxplots in the upper right corner show that IPD projects have a positive PPC trend, as compared to the not so encouraging stagnant PPC for non-IPD projects. Finally, one can see that the labor factor for IPD projects is higher than for non-IPD projects, potentially meaning IPD projects use labor more efficiently.

The MWW and t-tests were conducted to statistically compare labor performance metrics. The tests resulted in no significant differences between the IPD sample and the non-IPD sample at the 0.05 level. However, PPC and labor factor results were significant at the 0.10 level. The test for labor factor gave a p-value of 0.094 (with 1.76 as the median for non-IPD and 2.53 as the median for IPD projects) and the test for PPC trend gave a p-value of 0.072, potentially indicating superior labor performance, but only at the 0.10 significance level. The results for the labor performance metrics are shown in rows 15, 17, and 25 of Table 2.

Environmental Performance Metrics

In addition to project-specific performance metrics, the impact a construction project has on the environment also needs to be analyzed. The available data included two metrics: (1) total value of construction material waste (in tons, normalized per million dollars); and (2) percentage of waste recycled as opposed to waste sent to landfills. Fig. 9 shows the boxplots for tons of material waste and for percentages of waste recycled for IPD and non-IPD projects. The difference in the medians is quite visible for total material waste, in which non-IPD projects produce about twice as much waste as IPD projects. The distribution is also much wider for non-IPD projects. The difference is not that obvious for the recycling rate, with IPD projects recycling only slightly more. The MWW and t-tests were conducted to statistically compare material waste and recycling performance metrics. There were no statistically significant differences in the recycling rates; however, the tests for total tons of material waste resulted in a p-value of

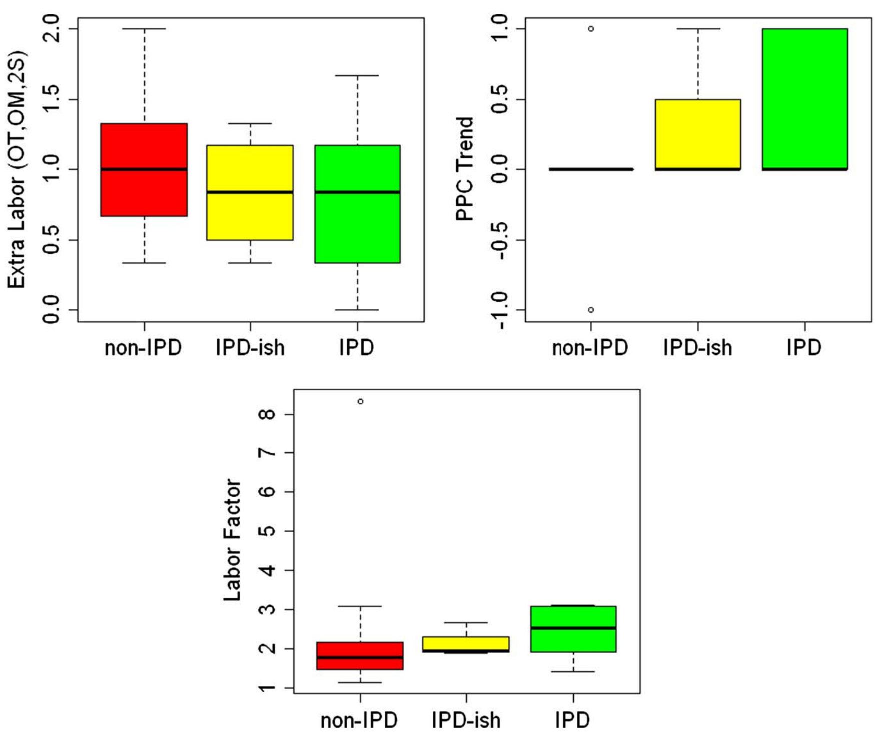

Fig. 8. Boxplots for labor metrics

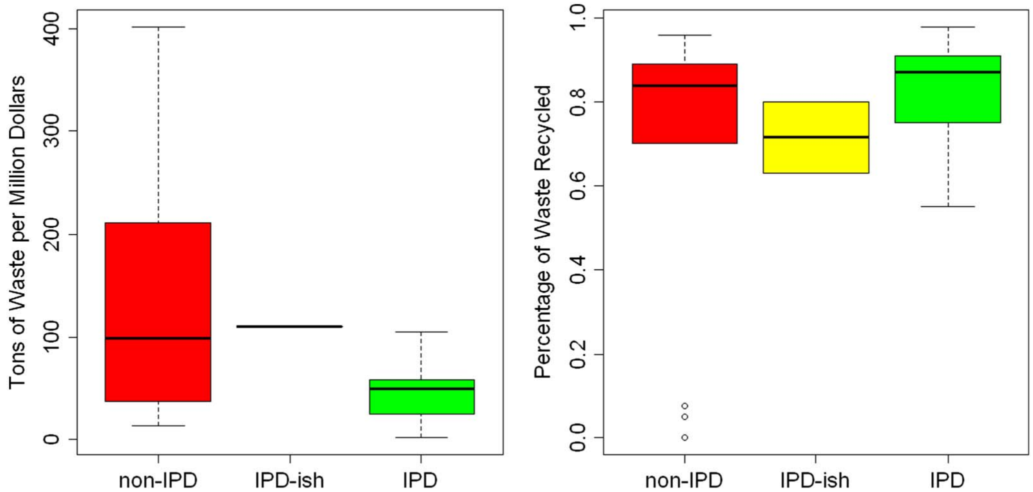

Fig. 9. Boxplots for environmental metrics

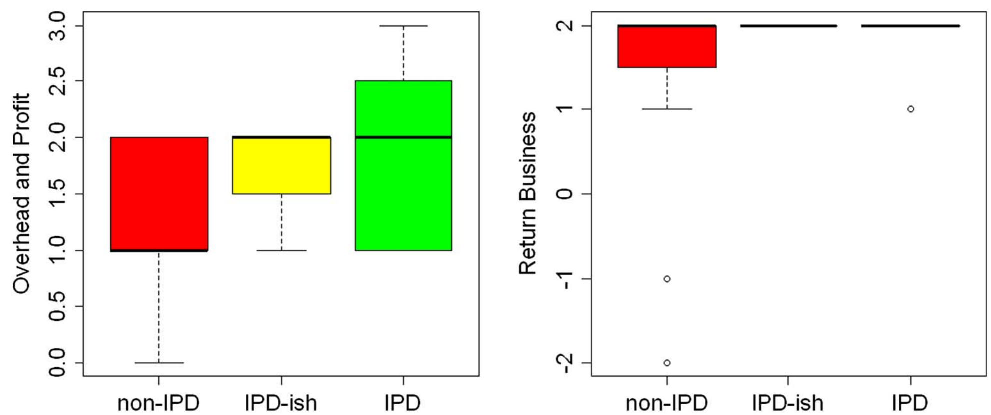

Fig. 10. Boxplots for business metrics

0.022, which means the differences are significant and IPD projects produce considerably less construction waste than non-IPD projects. The results for the environmental performance metrics are shown in rows 7 and 26 of Table 2.

Business Performance Metrics

Like any for-profit organization, contractors can only afford to remain in the construction business if they make a reasonable monetary profit. Therefore, profit is a key performance metric from the contractors' perspective. However, it is impractical to ask contractors how much profit they made on specific projects. The simplest way to avoid blank responses (and awkward interview moments) is to group job overhead and profit (OH&P) together into the same metric. Obviously, this metric would be sensitive to the changes in overhead from project to project, and therefore the results from this variable need to be interpreted in the right context. Business performance data included one additional metric: the potential for return business. Although qualitative, this metric identifies projects that lead to immediate return business and others that lead to a bad working relationship with clients.

The left side of Fig. 10 shows the boxplots for OH&P for IPD and non-IPD projects. The values on the vertical axis represent windows of values (0 for negative OH&P, 1 for less than 5%, 2 for 5–10%, and 3 for 11–15%.) The median for non-IPD projects was less than 5%, whereas the median for IPD projects was 5–10%. A few IPD projects had 11–15% OH&P, whereas non-IPD projects did not have any projects with values above 10%. The right side of Fig. 10 shows responses for return business. Here the values on the vertical axis represent the potential of the project for return business, from -2 for very negative to $+2$ for very positive. The non-IPD projects experience some negative and very negative responses, whereas even the lowest response for IPD projects was still positive.

The MWW tests were conducted for the IPD sample and the non-IPD sample to statistically compare OH&P and the project's potential for return business. The differences in return business had a p-value of 0.211, which is not considered significant at the 0.05 significance level. The differences in OH&P were significant at the 0.05 level with a p-value of 0.024. The results for the business performance metrics are shown in rows 8 and 23 of Table 2.

Conclusion

This study provided the first quantitative understanding of IPD performance through presenting a comprehensive statistical comparison of IPD and non-IPD projects. The IPD projects displayed a superior performance on 14 different metrics belonging to six out of the nine performance areas investigated. If the more lenient 0.10 significance level was used instead of the 0.05 level, then eight out of nine performance areas would show significant differences for IPD. Using a very strict threshold in which p-values need to be less than 0.01, IPD was proven to have a superior performance in metrics related to quality, communication, and change performance. The quality of the facility is arguably the most important metric that IPD enhances. IPD projects also see less changes, faster processing times, and significantly faster delivery times. Although the first few cost performance results seemed to confirm findings of a previous study that shows no performance differences between IPD and non-IPD projects, comprehensively looking at the remaining performance metrics strongly contradicts the previous literature. Not only does IPD provide schedule and quality improvements, it also offers enhancements on many additional performance metrics.

Furthermore, there are no known benchmarks for IPD projects. The IPD performance data set that was collected for this research presents an opportunity to provide the first set of IPD benchmarks. For example, when working on an IPD project, one should expect to see around seven punchlist items and 0.2 deficiency issues for each million dollars of construction. Additionally, IPD projects experience less than two RFI per million dollars and a remarkable 1-week processing time for both change orders and RFI, which can result in a much smoother project. These are just a few examples; the results of all the metrics discussed in this paper also can be used as IPD benchmarks to assist industry professionals in gauging their project performance when implementing IPD.

The results of this study specifically stem from relatively complex vertical construction projects, largely healthcare and higher education research facilities in the U.S. Midwest and California, because of the availability of IPD projects. Integrated project delivery has largely been used on these types of projects because they tend to benefit highly from innovations in multitrade settings, which therefore justify the upfront investments often required for IPD. The authors attempted to collect data from every IPD project available at the time, knowing that the pool of projects that utilized a multiparty contract was very scarce. With more and more IPD projects being completed, this study can be expanded upon in future research, which would ideally use a larger data set to include new IPD project types in different geographical locations. Additionally, conducting a univariate analysis was the first step of this research project; the next step consists of a multivariate data analysis.

This research study offers a major contribution to the construction engineering and management literature and to the AEC industry by demonstrating superior IPD performance to guide project stakeholders in making informed decisions. The main conclusion is that IPD delivers higher quality projects faster and at no significant cost premium. These results would be extremely impactful and valuable in the hands of decision makers, helping them choose the appropriate delivery system for their projects.

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