Interaction Effects of Information Technologies and Best Practices on Construction Project Performance

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Abstract

This paper assesses the impact of information technology use and Construction Industry Institute defined Best Practices on construction project performance. Using data from 133 projects collected in 2008 and 2009, correlations between Best Practice-use and project performance, and information technology use and project performance are investigated. In addition, interactions between Best Practice and information technology use on project performance in terms of cost, schedule, and rework are tested. The findings highlight the potential for synergistic effects of information technology and Best Practice use on construction project performance.

CE Database subject headings: Information technology, Best Practice, interaction effects, computer-aided projects management, performance evaluation

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Introduction

The relation between information technology (IT) use and project performance has been investigated through numerous studies for both the construction industry and other business sectors. With respect to the general business literature, many studies have concluded that there is a positive effect of IT use on performance. Barki and Pinsonneault (2005) argued that IT use contributes to cost reduction, service quality improvement, sale and revenue increase. Bharadwaj (2000) empirically examined the association between IT capability and business performance and found significant positive association between IT capability and firm performance. However, while many studies found positive effects of IT use on performance, a significant number of studies concluded no association (Aral and Weill, 2007, Powell and Dent-Micallef, 1997, Strassmann, 1990) and at least one found negative correlation (Brynjolfsson, 1993).

In the construction industry literature, case studies of particular technologies such as three-dimensional (3D) and four dimensional (4D) CAD indicate numerous benefits of IT use (Becerik and Pollalis, 2006, Fischer, et al., 2003, Koo and Fischer, 2000). In addition to these case studies, other researchers have attempted to quantitatively capture the benefits of IT use via a direct link between IT use and performance measures (El-Mashaleh, et al., 2006, Kang, et al., 2008, O'Connor and Yang, 2004, Thomas, et al., 2004). Unfortunately, findings reported in these studies have generally not been statistically robust suggesting only relatively low impacts on cost and schedule performance. Such findings have also been inconsistent across studies.

Why have researchers generally found inconclusive results while measuring the impact of information technologies on performance? A simple answer might be that there is no impact, but this contradicts the case studies and anecdotal evidence. The number and variety of studies also suggest that survey and sampling techniques are likely not an issue. More compelling may be the argument that analyzing IT use directly with project performance is too simplistic (Oh and Pinsonneault, 2007, Soh and Markus, 1995). The fundamental insight is that IT does not directly affect performance; rather, IT affects organizational resources (broadly defined) that in turn affect performance. In particular, an authoritative study by Brynjolfsson and Hitt (2000) found that information technologies are having a significant impact on productivity. Key to their findings is the characterization of information technologies as "general purpose" technologies. As such, information technologies tend not to have a direct impact on productivity but rather affect work processes which in turn affect productivity. Studies that directly correlate technology use with performance without investigation of intervening variables may miss important implementation details and the benefits of IT use may be masked.

Such a view is supported by some construction literature. Nitithamyong and Skibniewski (2004) asserted that processes should be considered along with other factors such as people, procurement, legal issues, and knowledge management for successful IT implementation. Taylor (2007) reports on a case study where benefits of investment in 3D CAD technologies were multiplied by complementary investments in work processes. Ekstrom and Bjornsson (2004) propose that re-engineering of procurement processes together with investments in IT could lead to improved productivity. It is particularly noteworthy that prior research has not suggested this proposition and instead pursued only direct correlations between performance and IT use. The lack of recognition of the role of the intervening influences such as work processes may explain the difficulties prior studies have had in showing the significant benefits reported by the case studies.

Research Questions and Methodology

Review of the literature provides a strong case that investigation of the impact of information technologies on performance should include examination of complementary work practices. This paper poses the research question "Is there evidence of a complementary relationship (beneficial interaction) between work processes and use of information technology?" An affirmative answer to this question will not provide the definitive answer to the nature of complementary investments in technology and process, but will provide evidence that such a relationship does exist and can be measured. The research question is explored using Construction Industry Institute (CII) Benchmarking and Metrics (BM&M) data for capital projects. Use of these data has several benefits: first, CII collects a variety of data on performance, technology use and integration (TUI) which is the name of the questionnaire measuring the degree of IT use, and Best Practice use. Second, the CII BM&M data undergoes a validation process for each project that reports, increasing confidence in the source data. And finally, use of these data allow comparison to previous work the authors performed exploring the direct relationship between technology use and performance (Kang, et al., 2008, Thomas, et al., 2004).

Best Practices are defined by CII as "a process or method that, when executed effectively, leads to enhanced project performance." (https://www.construction-institute.org/scriptcontent/bp.cfm?section=Orders) These Best Practices have been proven through extensive industry use and/or validation. As such, Best Practices can be seen as collections of work processes that are recognized by industry to improve performance. Further complementarity benefits from the use of IT may subsequently be expected to show improvements to project performance. As CII collects all three types of data (performance, TUI, and Best Practices) for projects, it provides a good source to address the research question.

Propositions

CII currently recognizes 14 Best Practices. Based on definitions of the practices and review of the literature, the authors identified six specific propositions about the relationship between IT use, Best Practices, and performance. (Descriptions of the Best Practices used in this research are presented in Table 1.) It should be noted that Project Risk Assessment is not technically a CII Best Practice; it is a CII pending Best Practice which means that validation of the benefits of the practice have not been completed. However, given its broad acceptance in the literature and industry, the authors decided to include it in this research.

<Table 1 about here>

CII identifies two Best Practices for early project planning: Front End Planning and Alignment during Front End Planning. Information flow during this phase is critical for future project success. George and Back (2007) reported that specific information requirements should be identified and fully satisfied in a timely fashion for effective implementation of Front End Planning. In addition, the information required should be managed both internally and externally, which stresses the importance of intra-organizational and inter-organizational information exchange for Front End Planning. If Front End Planning has a complementary relationship with IT use, the benefits may be shown in terms of cost performance. CII research shows that if wellperformed, Front End Planning can reduce costs by as much as 20% (CII, 1995). This is because decisions and actions taken during the Front End Planning phase, including the use of Best Practices, have the greatest ability to influence costs spent over the life of a capital project (CII, 1986, CII, 2001). Front End Planning is particularly important for project owners because the practice is related with project scoping, project site selection, and developing project alternatives. Similarly, alignment during Front End Planning is another Best Practice conducted in the early stages of the project. For this practice, it may be that external integration is more important and will produce a higher impact on project performance. Front end planning team members are often from different organizations and therefore have conflicting criteria for success of the project, which may cause a communication breakdown (CII, 1997). External integration may facilitate the flow of communication for the stakeholders.

Given the importance of these two front end planning Best Practices, the authors identified two propositions relating IT use, Best Practices, and performance:

Proposition 1: For owners, more use of Front End Planning is positively associated with more use of IT. Also, projects with greater use of Front End Planning and IT have better project performance.

Proposition 2: For owners, more use of Alignment during Front End Planning is positively associated with more use of IT for external integration. Also, projects with greater use of both have better project performance.

Risk management plays an important role during the decision-making process in the capital projects industry and been widely accepted as vital for project management (Kangari, 1995, Wood and Ellis, 2003). As stated in Table 1, Project Risk Assessment deals with the identification, assessment, and management of risk. For Project Risk Assessment, collecting the right information in a timely manner is crucial. Thus, there should be synergistic relationship between IT and Project Risk Assessment which led the authors to establish Proposition 3.

> *Proposition 3: More use of Project Risk Assessment is positively associated with more use of IT. Also, projects with greater use of both have better project performance.*

Planning for startup is challenging because it requires extensive coordination and input early in the project (CII, 1999). Similar to the other planning-related best practices, information technology can contribute to better planning for startup by facilitating information exchange faster and more accurately Successful implementation of Planning for Startup contributes to better project performance as startup costs are significant. As documented by previous studies, startup costs average approximately 5.5% of construction costs (Myers, et al., 1986), and startup delays can be very expensive (CII, 1999, King, 1977).

> *Proposition 4: More use of Planning for Startup is positively associated with more use of IT. Also, projects with greater use of both have better project performance.*

Constructability integrates construction knowledge and experiences into the planning and design phases of projects (CII, 1992). One practical complication of implementing this best practice is that many capital projects do not obtain constructability input because of the lack of available formal and explicit constructability knowledge bases which have the capability of linking constructability issues to design decisions and which can be made available online to interested parties

(Fischer and Tatum, 1997). It is reasonable to assume that this best practice would exhibit a complementary relationship with IT use because IT is an enabler of the knowledge base essential for implementation of the practice. Thus firms wishing to enhance their use of Constructability may tend to be greater users of IT. Through its implementation, companies may realize various benefits including cost saving, schedule and manpower reduction, and better quality (CII, 1986, O'Connor, 1985). For these reasons the authors developed Proposition 5 as shown below:

Proposition 5: More use of Constructability is positively associated with more use of IT and projects with greater use of both have better project performance.

Research shows that design errors are a major source of changes in the capital projects industry is (Hester, et al., 1991, Leonard, et al., 1988). However, with the development of design-enabling information technology, this issue has been improved substantially (CII, 1990, Gao and Fischer, 2008, Khanzode, et al., 2008). In other words, Change Management is highly complemented by IT use. Also, it has been reported that successful implementation of Change Management is associated with various benefits such as cost reduction, duration reduction, reduced requests for information (RFI) and fewer change orders (CII, 1990, CII, 1991, Gao and Fischer, 2008, Khanzode, et al., 2008). For these reasons the authors proposed a 6th and final proposition:

Proposition 6: More use of Change Management is positively associated with more use of IT and projects with greater use of both have better project performance.

These propositions are explored first via simple correlations between IT use (TUI) and performance, Best Practice and performance, and TUI and Best Practices.

They are then further analyzed by assessing the joint correlation between TUI and Best Practices on performance as a measure of the complementary relationship (beneficial interactions) between technology use and work processes. Results of the correlation analysis are given below. For this research simple correlations are considered significant with at $p = 0.1$; this is a level where the chance of a false positive is balanced with the chance of rejecting a positive association. Joint correlations are explored via quadrant analysis following the example of Rimal (2001). Quadrants of high/low BP and TUI data are matched with corresponding performance data to explore in detail the propositions above. Details of the data set and analyses follow in subsequent sections.

Description of the Dataset

Project data in the CII BM&M database are used for this study. Collected in 2008 and 2009, the data are from 133 projects submitted by the CII owner member companies. Table 2 summarizes the projects categorized by industry group. As shown in the table, most of projects are industrial projects.

<Table 2 about here>

Each project contains performance, Best Practice use, and IT use (TUI) information, although not all projects have complete answers to every question. Metrics and descriptive statistics for the three groups are provided below.

Technology Use and Integration

The degree of IT use is surveyed by a questionnaire named Technology Use and Integration (TUI). The TUI questions are a recent development at CII and reflect a change in IT use metrics compared to those used in previous studies (Kang, et al., 2008, Thomas, et al., 2004). In the survey, the 50 work processes are categorized in six work process groups including project management, front end planning, detail design, procurement, construction and startup. The respondent is asked to assess the degree of automation, internal integration, and external integration according to a 1 to 5 scale as shown in Table 3. Automation implies the use of computers and decreasing the time and attention required for engineers to perform a task (Palmer and Mar, 1989). O'Connor and Yang (2004) defines automation as the use of an electronic or computerized tool by a human being to manipulate data or produce a product. In this study, the term is used in a similar manner. It measures the degree of electronic tool uses to reduce manual works. Integration has been used to describe the interconnectedness of an organization's information technologies and the degree to which its data elements share a common conceptual schema (Barki and Pinsonneault, 2005, Chiang, et al., 2000, Goodhue, et al., 1992, Markus, 2000). O'Connor and Yang (2004) defines integration as the sharing of information between project participants or melding of information sourced from separate systems. In the TUI questionnaire, integration is measured by level of interoperability. Internal integration measures the level of intra-organizational integration, whereas external integration deals with inter-organizational integration.

<Table 3 about here>

Based on the raw data, 10 TUI indices are developed; six indices representing the level of technology use for each work process groups, three indices for automation, internal integration, and external integration, and one overall index consolidating all scores for all types of technologies across all work processes surveyed. Scoring for each TUI index were calculated based on the equation below:

$$\text{TUI Score} = 2.5 \times \left(\frac{\sum \text{Work Process Scores}}{\text{Number of Work Process Answered}} - 1\right)$$

In order for a TUI score to be calculated, by rule, the respondent had to answer at least 50% of the response categories for each work process group or technology type. The TUI indices range from 0, indicating virtually no technology use, to 10, indicating full technology use.

Table 4 presents the descriptive statistics for TUI indices. As shown in the table, respondent means are generally below 5, indicating that general level of technology use and integration in the construction industry is moderate. This is consistent with statements found in the literature review arguing that the construction industry has been conservative in adopting new technologies (Andresen, et al., 2000, Bjork, 2003, Ekstrom and Bjornsson, 2004, Thomas, et al., 2004). Based on the data, the detail design phase shows the highest TUI score. This may be related to wide use of CAD technologies in the capital projects industry. In regards to the type of technology implemented, automation received the highest TUI score, whereas external integration had the lowest TUI score.

<Table 4 about here>

Best Practices

In 2007, CII updated its questionnaire to more quantitatively assess the implementation of industry Best Practices. A scoring algorithm was developed by CII BM&M committee members who are industry experts from owner and contractor organizations (CII, 2004). The scores for each Best Practice (BP) range from 0 to 10, 0 representing no use of the practice and 10 indicating full use. It should be noted that comparing the mean values for various BPs is not meaningful as each is assessed using a different set of questions. Table 1 summarizes the six Best Practices identified for research by the propositions above; Table 5 provides descriptive statistics for these six.

<Table 5 about here>

Performance

CII produces a number of performance measures for each project. For this research, the measures cost growth, schedule growth, and rework cost factor are used. The definitions of the metrics are provided in Table 6. Among the various CII metrics for cost and schedule, growth metrics have been widely used for various data analyses - and have also been shown to be influenced by IT use (Kang, et al., 2008, Thomas, et al., 2004). Rework is considered as an intermediate measure and significant factor in the measurement of productivity because some researchers have found rework to be one of the largest contributors to productivity losses in construction (Borcherding and Garner, 1981, Olomolaiye, et al., 1998).

<Table 6 about here>

Growth metrics compare actual and estimated values. The metrics are designed to have smaller values for better performing projects. The rework cost factor measures the amount of direct field rework as a percentage of the actual construction phase cost. As with the growth metrics, smaller rework cost factor indicates better performance. Compared to the growth metrics, the rework cost factor better assesses processes in the construction phase.

Table 7 summarizes the descriptive statistics for the three metrics. Based on the mean values, projects in the data set show an average -4.4% of cost growth, 1.0% of schedule growth, and 0.4% of rework cost factor. This means the projects spent actual project cost less than budget by 4.4% on average, were behind estimated schedule by 1.0%, and spent 0.4% of actual construction phase cost on the direct cost for field rework.

<Table 7 about here>

Correlations with Performance

This section presents the correlation of technology use and performance. The Pearson correlation was used for obtaining simple correlations between IT use and performance and Best Practice and performance. For IT use, four TUI indices (automation, internal integration, external integration, and overall) were used. Note that CII's rules for protecting member confidentiality are applied; if an analysis is based on fewer than 10 projects or projects data are from less than three organizations, no statistical summaries are provided and the code "C.T." (confidentiality test) is marked (CII, 2000).

Table 8 shows the correlations between TUI and performance. For cost growth, all coefficients are negative, meaning that more use of technology is associated with better cost performance, however, the correlations are not statistically significant in the level of $\alpha = 0.1$. For schedule growth, many correlations are positive and not statistically significant. This contradicts previous CII studies that found correlations with cost and schedule performance (schedule performance in particular) (Kang, et al., 2008, Thomas, et al., 2004). For the rework cost factor, many of the coefficients are statistically significant. This makes some logical sense as information technology may improve the quality of information available to designers and contractors, which may lead to less rework. Although statistically significant, the relation shows just a weak association with low explanatory value. Overall, the results do confirm prior research that direct correlations of technology use with performance shows weak results, even when the correlations are significant.

<Table 8 about here>

Correlations between Best Practices and performance are presented in Table 9. The coefficients are negative, indicating that more use of Best Practices is associated with better performance. Significant relationships are as follows: Best Practice use in the early project phase (e.g., Front End Planning, Alignment during FEP) is associated with better cost performance. Partnering and Change Management also have negative association with cost growth. Project Risk Assessment and Planning for Startup are negatively associated with schedule growth. Planning for Startup also has a statistically significant association with the rework cost factor. As with TUI, BP scores have limited correlations with performance. There are a few more significant correlations, and the direction of all correlations shows a desirable relationship that increased use of best practice increases performance.

<Table 9 about here>

Interaction Effects between Information Technologies and Best Practices on Performance

The findings reported on the previous section are perhaps explained by Brynjolfsson and Hitt's (2000) observation that information technologies tend to be general purpose technologies whose effects are manifested indirectly. If technology use is not accompanied by improved work processes, we should not see strong correlations between technology use and performance.

This section investigates the use of Best Practices (BP) and IT use and relates their joint effect on performance. First, the correlations between technology use and Best Practice use are shown. Second, the interaction of BP and TUI with the performance metrics is explored.

Correlations between Best Practice and Information Technologies

Table 10 summarizes the simple correlation coefficients between TUI and BP scores. The four Best Practices related with planning – Front End Planning, Alignment during FEP, Project Risk Assessment, and Planning for Startup – have statistically meaningful positive correlations with all of the TUI indices and these correlations are generally stronger than those depicted in Tables 8 and 9. Change Management also has multiple positive correlations at the significance level of $\alpha = 0.1$. Constructability only has one statistically significant positive correlation with TUI for automation. However, all correlations are positive, indicating that more use of technology is observed with increased practice use. Of course, correlation is not causation and it is unclear that increased use of TUI is causing increased use of Best Practices. But the suggestion that technology use has a beneficial impact on Best Practice use does make sense as the practices have generally been developed independently of information technologies. Insofar as technology supports better communication and analysis, it makes sense that they would support practices (or that the drive to improve practices would involve more technologies). These results support the propositions that technology use is beneficial to practice use.

. <Table 10 about here>

Interactions

The correlations between Best Practices and IT use do not imply a commensurate increase in performance. To examine if benefits are being observed on projects by interaction effects, performance metrics were applied to the combination of Best Practices and TUI. Following the example of Rimal (2001), the authors explore the interaction effects using a quadrant-based approach summarized in Figure 1. All projects included in this analysis have at least one BP score and one TUI score. The sets of TUI and BP values split into high and low halves around a median value. These halves are then paired to create quadrants of high/high, high/low, low/high, and low/low levels of BP and TUI. This process is illustrated in Figures 1 (a) thru 1 (c). For each quadrant, the mean performance metric for the projects in the quadrant is obtained (shown in Figure 1 (d)). This quadrant analysis is a way of showing potential interaction effects between BP and TUI on performance. Cost growth, schedule growth, and rework cost factor are applied in this process and the results are summarized in Tables 11, 12, and 13.

As not all projects in the overall data set have performance responses for all Best Practices or all TUI indices, quadrant sets have different sample populations (median values are determined from the larger population of BP/TUI for the metric under consideration, so splits are comparable across quadrant sets). It should be noted that the minimum number of data for each quadrant was set to three. If any quadrants have fewer than three projects, the analysis results were not provided for confidentiality and shown as C.T. in Tables 11, 12, and 13. In general, the available data for each set of metrics is low and that the difference between the averages could not be statistically tested. As such, the observations should be viewed as possible indicators of interaction effects and further study with more data is warranted.

<Figure 1 about here>

If more use of technology and more use of a BP each have a positive impact on performance, a comparison between each quadrant should show that the high/high quadrant has the best performance (or lowest value), the low/low quadrant has the worst performance (or highest value), and the low/high and high/low quadrants fall somewhere in between. In this case, we observe that the affects of the Best Practices and technologies are additive. It is possible that these additive effects are not necessarily interacting in a synergistic manner and the effects are independent. In such a case however, effects should follow the simple corrections between BP and performance and TUI and performance. As shown in the results below, the findings are different from the simple correlations so this pattern (when observed) does generally indicate the presence of complementarity or interaction effects.

A second view is that if there are significant interaction effects between BP and TUI and that both are required to achieve a beneficial effect, only the high/high quadrant will show the best performance. In other words it takes the input of both to see performance improvement and we will not see a clean pattern of increasing performance from low/low to high/high as in the first view. Both views are shown in Tables 11, 12, and 13 where the first view (high/high best; low/low worst) is shown in bold and the second view is shown in italics. For clarity, cross tabulations that do not meet one of these views are not shown.

Table 11 shows the interaction effects on cost performance. For most cases, improved performance is related to change of Best Practice use from low to high, which was also demonstrated in Table 9. One case is bold in the table. For the test with TUI for automation and the Planning for Startup Best Practice, the improvement in BP use is 0.8%, whereas more TUI use shows a 0.1% improvement. The overall improvement (high-high minus low-low) is 1.5%, which is greater than the sum of each improvement, 0.9%. Therefore, this may be evidence of interaction effects. In terms of Best Practices, Front End Planning, Alignment during Front End Planning, and Planning for Startup show multiple interaction effects with TUI on cost performance.

<Table 11 about here>

Table 12 summarizes the interaction effects on schedule performance. Among the three bolded cases, combined uses of TUI for internal integration and Constructability and TUI for Automation and Change Management show the largest interaction effects (the overall improvement obtained by high-high minus low-low is greater than the improvements from each of TUI and BP uses). For the remaining case (TUI for automation and the Constructability Best Practice), the overall improvement is smaller than the sum of each improvement. Considering that high-high and low-low quadrants have the best and worst performance, respectively, each of the BP and TUI uses contributes to the improvement but the amount of interaction effects may be not strong for the remaining cases. For the two cases with italics, the worst performance quadrant is found in the quadrant with high use of TUI and low use of the Best Practice. This finding seems to be consistent with the conjecture that IT use improves work processes and improved work processes leverage performance improvement. Therefore, more IT use without increased use of Best Practices has inevitably little or no performance improvement. This statement is also supported by the weak direct correlation between IT use and performance as shown in Table 8.

<Table 12 about here>

The rework cost factor shows the broadest number of potential interaction effects with BP and TUI. Table 13 indicates that TUI for automation appears to have interaction effects with several Best Practices (Front End Planning, Constructability, Project Risk Assessment, and Change Management) on rework performance. It also appears to have an interaction effect with Planning for Startup. Several Best Practices show observed interactions with many TUI metrics – in particular Front End Planning, Partnering, Constructability, and Change Management. Among the bolded cases, the combination of TUI for automation and Front End Planning shows strong interaction effects.

<Table 13 about here>

Discussion

The previous sections investigate the correlation of Best Practice use, IT use, and the interaction of Best Practice and IT uses with various performance metrics. This section provides implications and thoughts based on the comparison of all analyses in this study.

Table 14 summarizes the propositions and findings from them. Proposition 1, which asserts the complementary relationship between IT use and Front End Planning was supported by the findings. All TUI indices were found to have positive correlations with Front End Planning and were statistically significant. Also, except schedule performance, the project group using both high use of IT and Front End Planning generally showed better cost and rework performance than other project groups. Based on these two findings, it is reasonable to assert that complementarity between IT use and the Frond End Planning Best Practice exists in the capital projects industry and this relationship manifests benefits in terms of capital project cost and rework performance.

<Table 14 about here>

The second and third propositions asserting IT complementarity with Alignment during Front End Planning and Project Risk Assessment were supported in a limited way. While all TUI indices showed positive and statistically significant correlations, benefits for the project group using both high use of IT and Best Practices were limited or not tested because of small sample sizes. For Proposition 4, complementarity between Planning for Startup and IT use was shown to be positively correlated between the BP and TUI indices and all were statistically significant. However, only two TUI indices demonstrated benefits in terms of cost performance.

Proposition 5 was not supported because the correlations between the Constructability best practice and TUI indices were weak and not statistically significant. According to Pocock, et al. (2006), three major obstacles in implementing constructability are the lack of open communications between designers and constructors, inadequate construction experience, and difficulty coordinating disciplines. This indicates that the practice issue discussed in Fischer and Tatum (1997) still remains unresolved. In other words, perhaps most capital projects still do not obtain construability input because of the lack of formal and explicit constructability knowledge bases, which is the presumed role of IT in supporting Constructability. This conjecture is in line with the weak correlations between TUI indices and Constructability found in this research. For the sixth proposition, the correlation coefficient for TUI indices and Change Management were all positive and statistically significant except for the correlation between TUI for automation and Change Management. Interestingly, no benefit in terms of cost performance was found but two TUI indices showed benefits in terms of schedule performance and rework performance. Nonetheless, TUI for automation, whose correlation coefficient with Change

Management was not found to be statistically significant, is involved in the benefits found from two performance measures. The p-value for the correlation coefficient was 0.106, which is only slightly higher than the threshold value, 0.1. Therefore because the value is close to the threshold value, it is likely that the result will change once more data are obtained.

In addition to discussing the propositions, it may be interesting to check the portion of TUI-BP combinations showing the complementary benefits. Table 15 summarizes the percentage of TUI-BP combinations showing benefits of complementarity. Each performance measure can have 24 TUI-BP combinations (4 TUI indices multiplied by 6 BPs with propositions). The column A in Table 15 is determined by counting the number of combinations used for analyses (24 minus combinations excluded because of the CII's confidentiality policy). Column B presents the number of combinations showing benefits of complementarity. Values in the right-most column are obtained by dividing values in column B by those in column A. If there was not complementarity found between IT use and Best Practices, values in the right-most column should be around 25% because each combination has four groups. As shown in the table, the percentages for the three performance measures are remarkably high, which can be an indicator showing that there exist benefits of complementarity between IT use and Best Practices.

<Table 15 about here>

Comparing the three performance measures, rework cost factor shows stronger impacts than the other performance measures. Measurement may be one issue worth to discuss. Measurement errors on inputs and outputs were conjectured in the literature review as a possible reason why researchers end up with different findings in the relationship between IT use and performance (Brynjolfsson and Hitt, 1994). Also, the choice of dependent variable is thought to be related to this apparent inconsistency (Kohli and Devaraj, 2003). Some researchers assert that process-level analysis is more appropriate to measure the benefits of IT use than measurement at the macro or organizational level (Barua, et al., 1995, Kelley, 1994, Pavlou and El Sawy, 2006, Peacock and Tanniru, 2005). Barua et al. (1995) empirically found that many of the substantial IT impacts occur at low levels, near or at the site of their implementation. They argued if the distance between a first-order effect and higher levels increases, the ability to detect and measure an impact of IT decreases, perhaps rapidly. Applying this to the performance measures in this study, the rework cost factor may be closer to the place where benefits from IT use accrues and this attributes to more meaningful results in the rework cost factor than in cost or schedule growth. Thus if the impact of IT on the three performance measures is identical, it may be seen more obviously on the rework cost factor than the growth metrics. The data set used in this study lacks sufficient data to validate this statement. But, in the future research, using an intermediate factor (i.e., rework cost factor) between IT use and overall performance such as cost growth would be helpful to study the overall impact of IT.

For the individual impacts, Best Practice has greater impact than IT use on performance measures. For the IT use, the direct impact on performance is not significant. These findings are in line with the view of Brynjolfsson and Hitt (2002) that information technologies tend not to have a direct impact on performance but rather affect work processes which lead performance improvements. The statement is also supported by the correlations between IT and BP uses shown in Table 10 which shows more use of Best Practice is associated with more use of IT. Although the direct association of IT use on performance is weak, this study captures a snapshot of indirect impacts of IT use on performance via Best Practices. For the cases with italics in Tables 11, 12, and 13, the worst performance quadrant is mostly found in the quadrant with high use of TUI and low use of Best Practice. This means more IT use without increased use of Best Practices has no performance improvement. However, when high use of IT is combined with high use of Best Practice, performance tends to be better than when Best Practice is solely used significantly.

By examining the six propositions, interaction effects of IT use and BP on project performance was investigated. Most of the Best Practices analyzed in the propositions showed positive association with IT use and the associations are generally related with superior project performance. Also, a high percentage of TUI-BP combinations demonstrates the benefits of interaction of IT use and BP. These may suggest evidence for synergistic relationship between IT use and Best Practice in the construction industry.

Of course, the correlations and patterns reported in this study do not detail the mechanisms by which synergistic interaction occurs between IT use and Best Practice. Case studies examining the interaction effects between IT use and other resources are encouraged (Melville, et al., 2004). Retrospective examination of existing cases using the concepts of this study – principally, there is a pathway of benefits to work processes that in turn lead to performance improvements – could help expose mechanisms and suggest more refined measures for future statistical analysis.

Conclusions

This study explores the view that construction projects performance is enhanced by the interaction of the use of industry Best Practices together with the use of information technologies. Using project data in the Construction Industry Institute's Benchmarking and Metrics database, the impact of Best Practices use, IT use, and the interaction of the two on three performance measures was investigated. The findings support that technology use enhances the application of a range of industry Best Practices. The findings also suggest that in many cases the synergistic application of technology and specific work practices improves performance. While the assessment of interaction effects was performed with limited data, the findings are broadly supportive of the research propositions and bear further study. It is important to note that there are also broad similar effects seen for the three performance measures, although the interaction findings are stronger for rework performance than cost and schedule performance.

This study represents a new direction for investigating the impact of technology use on construction projects performance. The inclusion of Best Practices data offers a statistical approach to explain the mechanisms by which technology use may impact performance. As such, it represents an important departure from previous research that has attempted to directly relate technology use to performance. While the findings are limited by available data, the results are encouraging and supportive of further study. Industry efforts in improving both Best Practice use and information technologies are supported by these findings.

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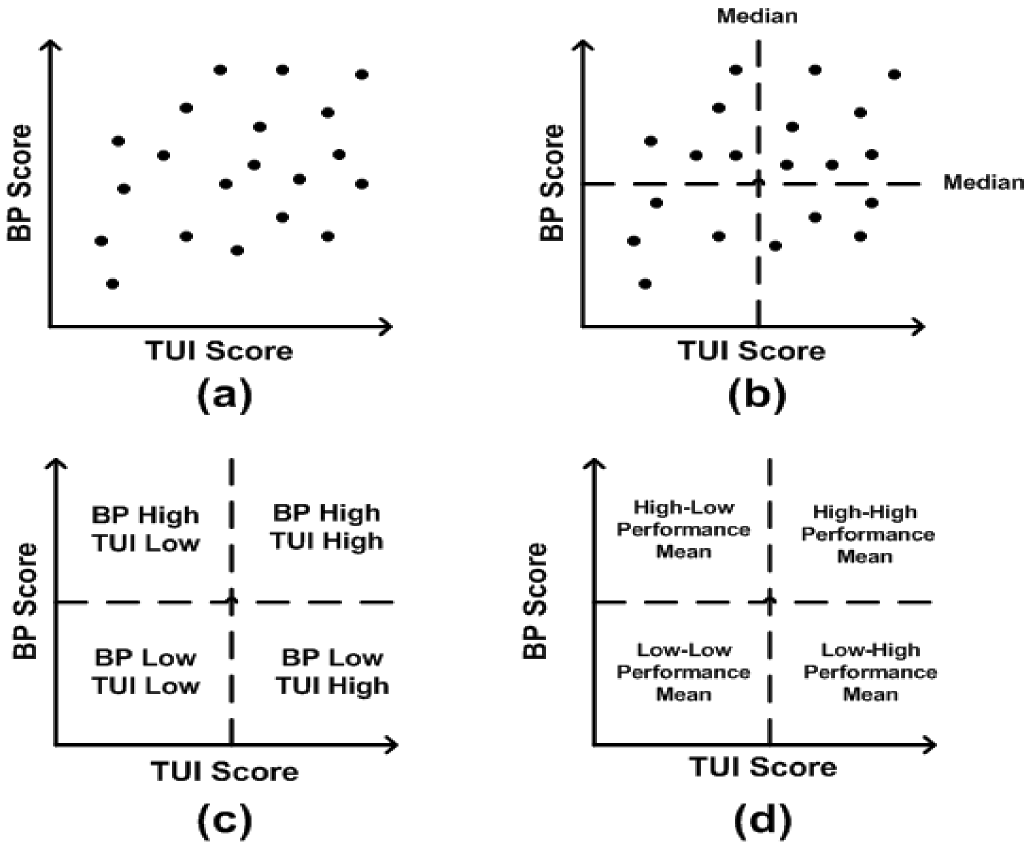

Figure 1. Procedure to determine interaction effects between BP and TUI on performance

Table 1. CII Best Practice Descriptions

Best Practice	Description
Front End Planning	**Front End Planning** involves the process of developing sufficient strategic information such that owners can address risk and decide to commit resources to maximize the chance for a successful project. Front-End Planning includes putting together the project team, selecting technology, selecting the project site, developing project scope, and developing project alternatives. Front-End Planning is often perceived as synonymous with front-end loading, pre-project planning, feasibility analysis, and conceptual planning.
Alignment During Front End Planning	**Alignment** is the condition where appropriate project participants are working within acceptable tolerances to develop and meet a uniformly defined and understood set of project objectives.
Constructability	**Constructability** is the effective and timely integration of construction knowledge into the conceptual planning, design, construction and field operations of a project to achieve the overall project objectives in the best possible time and accuracy, at the most cost-effective levels.
Project Risk Assessment	**Project Risk Assessment** is the process to identify, assess and manage risk. The project team evaluates risk exposure for potential project impact to provide focus for mitigation strategies.
Change Management	**Change Management** is the process of incorporating a balanced change culture of recognition, planning and evaluation of project changes in an organization to effectively manage project changes.
Planning for Startup	**Startup** is the transitional phase between plant construction completion and commercial operations, including all of the activities that bridge these two phases. **Planning for Startup** consists of a sequence of activities that begins during requirements definition and extends through initial operations. This section assesses the level of Startup Planning by evaluating the degree of implementation of specific activities throughout the various phases of a project.

Table 2. Number of Data: CII Data Set

CII Projects	Industry Group			
	Buildings	**Heavy Industrial**	**Light Industrial**	**Infrastructure**
Number of Project	18	31	75	9

Table 3. Description of Scales for Automation and Integration

Scale		**Description**
Automation	None (1)	No electronic tools or commonly used electronic tools, all processes completed manually
	Minimal (2)	Checklists or simple tools are available to help complete the process
	Moderate (3)	Electronic tools are available to help complete part of the work
	Extensive (4)	Electronic tools complete most of the work after entering input data, with minimal amount of manual work after data are entered
	Complete (5)	Entire process automatically completed after input data are entered
Integration	None (1)	No data communication or sharing with other electronic tools
	Minimal (2)	Data (or information) produced from the work function are transferred manually because the data are rarely interoperable
	Moderate (3)	Data (or information) produced from the work function are still manually transferred but some data are somewhat interoperable with other functions/stakeholders.
	Extensive (4)	Data (or information) produced from the work function are mostly interoperable with other functions/stakeholders do not require manual transfer.
	Complete (5)	Data (or information) produced from the work function are seamlessly interoperable with other functions/stakeholders and no manual data transfer is required.

Table 4. Use of Technology Use and Integration

	Sample Size	**Mean**	**S.D.**
Overall	62	4.18	1.62
Project Management	66	4.26	1.86
Front End Planning	61	4.22	1.94
Detail Design	61	4.61	1.85
Procurement	53	4.25	1.92
Construction	61	3.86	1.66
Startup	55	4.09	1.70
Automation	60	4.54	1.59
Internal Integration	57	4.23	1.70
External Integration	55	4.04	1.85

Table 5. Use of Best Practices

	Sample Size	Mean	S.D.
Front End Planning (FEP)	92	7.19	1.53
Alignment during FEP	91	6.67	1.63
Constructability	86	5.25	2.19
Change Management	84	4.81	2.63
Project Risk Assessment	89	7.97	2.60
Planning for Startup	73	7.49	1.44

Table 6. Definition of Performance Metrics

Performance	Metric
Cost	• Metric Project Cost Growth = $\frac{\text{Actual Total Project Cost} - \text{Initial Predicted Project Cost}}{\text{Initial Predicted Project Cost}}$ • Definition of Terms o Actual Total Project Cost: All actual project cost from front end planning through startup. It excludes land costs but includes in-house salaries, overhead, travel, etc. o Initial Predicted Project Cost: Budget at the time of authorization
Schedule	• Metric Project Schedule Growth = $\frac{\text{Actual Total Project Duration} - \text{Initial Predicted Project Duration}}{\text{Initial Predicted Project Duration}}$ • Definition of Terms o Actual Total Project Duration: Duration from beginning of detail engineering to turnover to user o Initial Predicted Project Duration: Predicted duration at the time of authorization
Rework	• Metric Rework Cost Factor = $\frac{\text{Total Direct Cost of Field Rework}}{\text{Actual Construction Phase Cost}}$

Table 7. Descriptive Statistics: Performance Metrics

	Sample Size	Mean	S.D.
Cost Cost Growth	117	-0.044	0.13
Schedule Schedule Growth	95	0.010	0.14
Rework Rework Cost Factor	41	0.004	0.01

Table 8. Correlation Coefficients between Technology Use and Integration and Performance

TUI Index	Performance		
	Cost Growth	**Schedule Growth**	**Rework Cost Factor**
Overall	-0.046	0.033	**-0.359**
Automation	-0.136	-0.048	**-0.349**
Internal Integration	-0.035	0.079	**-0.360**
External Integration	-0.060	0.053	-0.319

Bold indicates p-value is lower than 0.1. Sample sizes for each correlation range from 27 to 57.

Table 9. Correlation Coefficients between Best Practice and Performance

Best Practice	Performance		
	Cost Growth	**Schedule Growth**	**Rework Cost Factor**
Front End Planning	**-0.386**	-0.169	-0.266
Alignment During Front End Planning	**-0.295**	-0.170	-0.273
Constructability	0.108	-0.135	-0.096
Project Risk Assessment	-0.114	**-0.257**	-0.130
Change Management	**-0.216**	-0.161	-0.039
Planning for Startup	-0.137	**-0.262**	**-0.427**

Bold indicates p-value is lower than 0.1. Sample sizes for each correlation range from 30 to 77.

Table 10. Correlation Coefficients between Best Practice and Technology Use and Integration

Best Practice	TUI Index			
	Overall	Technology Type		
		Automation	Internal Integration	External Integration
Front End Planning	**0.372**	**0.384**	**0.331**	**0.400**
Alignment During Front End Planning	**0.436**	**0.397**	**0.428**	**0.448**
Constructability	0.210	**0.254**	0.198	0.171
Project Risk Assessment	**0.424**	**0.379**	**0.354**	**0.430**
Change Management	**0.314**	0.234	**0.269**	**0.408**
Planning for Startup	**0.284**	**0.300**	**0.259**	**0.307**

Bold indicates p-value is lower than 0.1. Sample sizes for each correlation range from 44 to 50.

Table 11. Joint Result of Best Practice and Technology Use and Integration on Cost Growth (in %)

Best Practice		**TUI Index**							
		Overall		**Automation**		**Internal Integration**		**External Integration**	
		Low Use	High Use	Low Use	High Use	Low Use	High Use	Low Use	High Use
Front End Planning	High Use	*-7.0*	*-8.1*			*-7.2*	*-8.1*	*-7.0*	*-8.0*
	Low Use	*-3.0*	*-1.4*			*-2.6*	*-2.2*	*-3.7*	*-0.3*
Alignment During Front End Planning	High Use	*-6.2*	*-6.9*					*-6.0*	*-6.5*
	Low Use	*-3.3*	*-3.0*					*-4.4*	*-0.6*
Constructability	High Use								
	Low Use								
Project Risk Assessment	High Use					C.T.			
	Low Use								
Change Management	High Use								
	Low Use								
Planning for Startup	High Use	*-3.6*	*-6.1*	**-4.9**	**-5.6**				
	Low Use	*-4.9*	*-4.9*	**-4.1**	**-4.2**				

Bold indicates high/high quadrant shows the best performance (or lowest value) and low/low quadrant shows the worst performance (or highest value)
Italic indicates high/high quadrant shows the best performance but low/low quadrant does not show the worst performance.
Number of data used for each calculation ranges 40 to 46. Number of data for each quadrant ranges 3 to 19.
C.T. Data withheld per CII Confidentiality policy (less than 10 projects or data submitted by less than three companies).

Table 12. Joint Result of Best Practice and Technology Use and Integration on Schedule Growth (in %)

Best Practice		**TUI Index**							
		Overall		**Automation**		**Internal Integration**		**External Integration**	
		Low Use	High Use	Low Use	High Use	Low Use	High Use	Low Use	High Use
Front End Planning	High Use							*-3.7*	*-3.8*
	Low Use							*1.8*	*15.0*
Alignment During Front End Planning	High Use			C.T.					
	Low Use								
Constructability	High Use			**0.2**	**-1.6**	**1.6**	**-2.1**		
	Low Use			**2.7**	**-1.3**	**1.9**	**0.5**		
Project Risk Assessment	High Use	C.T.		C.T.		C.T.		C.T.	
	Low Use								
Change Management	High Use			**-3.0**	**-4.8**	*-3.3*	*-4.2*		
	Low Use			**5.0**	**4.8**	*4.1*	*5.2*		
Planning for Startup	High Use			C.T.					
	Low Use								

Bold indicates high/high quadrant shows the best performance (or lowest value) and low/low quadrant shows the worst performance (or highest value)
Italic indicates high/high quadrant shows the best performance but low/low quadrant does not show the worst performance.
Number of data used for each calculation ranges 29 to 35. Number of data for each quadrant ranges 3 to 13.
C.T. Data withheld per CII Confidentiality policy (less than 10 projects or data submitted by less than three companies).

Table 13. Joint Result of Best Practice and Technology Use and Integration on Rework Cost Factor (in %)

Best Practice		TUI Index							
		Overall		**Automation**		**Internal Integration**		**External Integration**	
		Low Use	High Use	Low Use	High Use	Low Use	High Use	Low Use	High Use
Front End Planning	High Use	C.T.		**0.50**	**0.01**	**0.31**	**0.02**	*0.31*	*0.02*
	Low Use			**0.75**	**0.56**	**1.01**	**0.10**	*0.56*	*1.01*
Alignment During Front End Planning	High Use	C.T.		C.T.				C.T.	
	Low Use								
Constructability	High Use			**0.32**	**0.03**			*0.26*	*0.04*
	Low Use			**0.81**	**0.23**			*0.51*	*0.53*
Project Risk Assessment	High Use	C.T.		**0.08**	**0.06**	C.T.		C.T.	
	Low Use			**1.23**	**0.46**				
Change Management	High Use			**0.42**	**0.05**			**0.25**	**0.13**
	Low Use			**0.87**	**0.40**			**0.74**	**0.56**
Planning for Startup	High Use	C.T.		*0.68*	*0.01*	C.T.		C.T.	
	Low Use			*0.62*	*0.75*				

Bold indicates high/high quadrant shows the best performance (or lowest value) and low/low quadrant shows the worst performance (or highest value)

Italic indicates high/high quadrant shows the best performance but low/low quadrant does not show the worst performance.

Number of data used for each calculation ranges 22 to 25. Number of data for each quadrant ranges 3 to 11.

C.T. Data withheld per CII Confidentiality policy (less than 10 projects or data submitted by less than three companies).

Table 14 Testing Propositions

Proposition 1 • All TUI indices show positive correlations with Front End Planning and are statistically significant. • Three TUI indices except TUI for automation show cost performance improvement with high use of Front End Planning and IT. • Three TUI indices except TUI for overall show rework performance improvement with high use of Front End Planning and IT.
Proposition 2 • All TUI indices show positive correlations with Alignment during Front End Planning and are statistically significant. • Projects with high use of Alignment during FEP and TUI for overall and external integration show improved cost growth.
Proposition 3 • All owner TUI indices show positive correlations with Project Risk Assessment and are statistically significant. • Projects with high use of Project Risk Assessment and TUI for automation show better rework performance. (Other TUI indices were not tested because of small sample size.)
Proposition 4 • All TUI indices show positive correlations with Planning for Startup and are statistically significant. • Two TUI indices (TUI for overall and automation) show benefits in terms of cost growth. But, no TUI indices show schedule performance improvement.
Proposition 5 • All correlations are positive but only TUI for automation shows a statistically significant correlation. • It is found that there's no benefit in terms of cost growth. But, two TUI indices show schedule performance improvement and rework performance improvement.
Proposition 6 • Three TUI indices except TUI for automation show positive correlations and are statistically significant. • No benefit in terms of cost growth was found but, two TUI indices show schedule performance improvement and rework performance improvement

Table 15 Percentage of TUI-BP Combinations Showing Benefits of Complementarity

Performance Measure	Number of TUI-BP combinations		Percentage (B/A%)
	tested (A)	showing benefits of complementarity (B)	
Cost Growth	23	7	30.4%
Schedule Growth	18	5	27.8%
Rework Cost Factor	14	9	64.3%