Impact of Information Technologies on Performance: Cross Study Comparison

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Abstract: This paper evaluates the use of information technology (IT) and its impact on project and company performance in the construction industry. Using project level data from 139 projects and company level data from 74 companies, the current state of IT use in the construction industry was studied and statistical analyses were performed to assess the correlation between IT use and performance. Analyses are segregated by owner and contractor stakeholder groups and findings suggest that more IT use correlates with improved performance. Schedule performance has a strong positive association with increased IT use, whereas cost performance, although positively correlated, has a weaker relationship. These findings are in line with previous studies, adding to the research that IT has a positive impact on performance. Further comparison is made to show that IT use has increased over time among projects drawn from a similar sample population.

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Introduction

Many authors expect that the capital projects industry will be transformed through the use of Information Technology (IT). Case studies of, e.g., three-dimensional (3D) and four-dimensional (4D) CAD technologies (Koo and Fischer 2000; Becerik and Pollalis 2006; Fischer et al. 2003), have indicated many benefits of advanced information technologies. Nonetheless, the industry tends to be conservative and shows hesitation to adopt new technologies (Andresen et al. 2000; Bjork 2003). The level of IT investment in the construction industry is relatively lower than other industries; such lack of investment is a plausible cause of poor productivity in the construction industry (Ekstrom and Bjornsson 2004; Thomas 1999). This lack of investment may stem from the limited statistical studies that extend the various case examples of IT utilization.

Of the extant statistical studies of IT use, a recent study sponsored by the National Institute of Standards and Technology (NIST) reported that the cost of inadequate interoperability in the U.S. capital facilities is \$15.8 billion per year (Gallaher et al. 2004). This study, which focused primarily on the costs of lack of interoperable systems, can be considered a baseline estimate within the \$500 billion capital projects industry in the United States (the study did not address residential construction). A few studies have focused on quantifying the benefits of IT use with respect to project performance. An early study by Griffis and his colleagues quantified the benefits of 3D CAD on industrial projects with respect to cost growth, schedule growth, and rework (Griffis et al. 1995). Similarly, two studies conducted by the Construction Industry Institute (CII) and sponsored by NIST found that cost and schedule performance improve with increased IT use (Thomas 1999; Thomas et al. 2001). Although compelling, these two studies focused on specific technologies. Using specific technologies for measuring IT use is problematic in the sense that technologies change with time. Two recent studies have focused on capturing the benefits of IT use across project practices or work functions. O'Connor and Yang (2004) found that IT use is positively correlated with cost and schedule success at the project level, using data on IT use across six project phases (front end, design, procurement, construction management, construction execution, and startup/operations/maintenance). Each phase in the study contained several work functions. Using a similar methodology to study IT use, O'Brien and his colleagues found that construction firm level performance in cost, schedule, and across composite metrics improves with increased use of IT (El-Mashaleh et al. 2006).

The purpose of the study is to further our quantitative understanding of the benefits of IT use. Specifically, this investigation identified and documented the benefits of using IT during the project delivery process and across a range of project work processes or functions that are not limited to evaluation of specific technologies. Two data sets are analyzed in this study. The principal one was developed by the CII's Benchmarking and Metrics (BMM) Program and contains detailed performance measures in addition to broadly defined automation/integration technology (A/I tech) metrics. The CII data were reported by owners and

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Table 1. Number of Data: CII Data Set

CII projects	Location		Industry group		Cost category ($ million)			Project nature		
	Domestic	International	Buildings	Industrial	<$15	$15–$50	>$50	Addition	Grass roots	Modernization
Owners	80	15	19	74	30	40	25	27	32	36
Contractors	37	7	0	42	17	12	15	20	18	6
Sum	117	22	19	116	47	52	40	47	50	42

contractors for U.S. domestic and international projects between 2002 and 2004. The final CII data set included data from 139 projects. This work constitutes newly reported data that extends previous publications that report on data from 1997 to 1999 (Thomas 1999; Thomas et al. 2001). In addition to the CII data set, a complementary data set studied by El-Mashaleh et al. (2006) is also reviewed, using the same analysis methods used for the CII data. Company level data collected from 74 companies in the southeastern United States in 2003 extend the study to smaller companies, allowing for comparison across the industry using data developed over a similar time frame. Although the data captured are not directly comparable, some broad findings across the studies are noteworthy. First, there is a general consensus that increased IT use improves cost and schedule performance. Second, there is evidence that companies have increased their use of IT over the past years, implicitly suggesting that companies are observing the benefits of IT investment.

Methodology

The basic research question addressed is "Does IT use impact project performance?" Previous studies suggest a positive association with performance and IT use, particularly around cost and schedule. Past research has used a variety of methods to address this question, including case studies and quantitative analysis. We are particularly interested in quantitative methods given the relative paucity of results as noted earlier. Previous quantitative studies have demonstrated a positive association between cost and schedule performance and we seek to understand if new data support these associations and what changes in trends, if any, can be observed. We principally draw data from the CII BMM Questionnaire (described in the following) and as such use standard to CII analysis techniques, which include correlating practice data (in this case technology use) with project performance data. Per CII reporting standards, these results are described through quartile analysis. We extend this analysis with standard statistical tests of significance. To expand the results from the CII data, we employ an additional data set for cross-sectional comparison with a population of firms that are not CII member companies. We also make some longitudinal comparisons with previous CII studies, although these studies have different questions about technology use, which makes direct comparisons difficult.

Description of the Data Sets

This section provides the descriptive statistics for both the CII data set and the data set developed by O'Brien and his colleagues [hereafter called southeastern (SE) U.S. contractors data set]. The data sets are complementary. The CII data set contains project information from both contractors and owners that are among the larger companies in the capital facilities industry. The SE U.S. contractors data set provides company level data among a range of small and midsize contractors (e.g., firms not typically CII members) drawn primarily from the southeastern United States. These data sets were selected for analysis to report on new data collected by CII and to compare with a complementary study conducted at the same time as the CII study. This allows cross-sectional comparison of results across the two studies and also allowing longitudinal comparison with the previous CII studies.

IT use is measured by the CII BMM questionnaire. The BMM questionnaire addresses a variety of performance metrics as well as practice use (including, e.g., technology, front end planning, etc.). Details of the questionnaire can be found on the CII website (www.construction-institute.org). The questionnaire is developed by an industry committee and is distributed to respondents in CII member companies who are trained how to understand and answer the questions. CII also has a staff member examine each response and look for discrepancies and ask for clarification before entering data in the database. In this way, responses have a high degree of validity and are comparable across projects. Some potential bias issues may remain insofar as companies select projects to report to CII, but their participation in the benchmarking program suggests a strong desire for seeking performance improvements. The CII benchmarking database shows a wide range of performance, suggesting a valid sample to draw from.

The CII BMM questionnaire is large and has evolved over time. With respect to technology, CII modified the questionnaire in 2002 to measure the level of IT use across project work functions instead of specific technologies. The data set used for this study reflects these changes and is different from the data used for the previously CII studies. It represents 139 projects reported over the period 2002–2004, 94 from owners and 45 from contractors. To better ensure that owner and contractor data were comparable in scope, only those projects for which contractors performed both design and construction tasks were included. Typical CII practice is to segregate data by type—owner or contractor (CII 2000). Within the owner and contractor groups, projects categorized by location, industry group, cost, and project nature are summarized in Table 1. Note that in some categories the sample size is smaller than the total number of projects as all respondents did not answer all questions. Statistical outliers and confidentiality issues further reduce the amount of data available for analysis. Applying CII's rules for protecting member confidentiality, if a category contains fewer than 10 projects or if fewer than three companies submitted data, no statistical summaries are provided and the code "C.T." (confidentiality test) was inserted in the tables (CII 2000). Based on this criterion, certain data are excluded from analysis. Hence some of the analyses presented in the following sections do not draw from all 139 projects. Where appropriate in the tables, small samples or data suppression for confidentiality are noted.

Table 2 describes the industry sectors and company sizes for

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Table 2. Number of Data: Southeastern U.S. Contractors Data Set

Southeastern U.S. company	Industry group					Company revenue ($ million)		
	Residential buildings	Nonresidential buildings	Industrial	Infrastructure	Multiple groups	<$15	$15–$50	>$50
Contractors	5	23	3	3	40	7	30	37
Sum			74				74	

Table 3. Task/Work Functions Used to Measure the Degree of Automation and Integration Technology Use

Task/work functions	Use level 1	2	3	4	5	NA	UNK
Business planning and analysis							
Conceptual definition and design							
Project (discipline) definition and facility design							
Supply management							
Project management							
• Coordination system							
• Communication system							
• Cost system							
• Schedule system							
• Quality system							
Off-site/preconstruction							
Construction							
As-built documentation							
Facility start-up and life-cycle support							

74 contractors in the southeastern United States that submitted data on performance and technology use in early 2003. This data set reports company level data whereas the CII data are project level. As shown in Table 2, most of these companies are involved building construction as their primary activity or as part of their service portfolio. Questions about IT use and performance on this data set are focused on aggregate company level performance, and as such eliminate some potential for project specific selection bias. Overall bias by the respondents may globally shift IT use or performance reporting for the firm, although the study was focused specifically on IT use against performance and there was no inherent reason for respondents to have a consistent bias. The study showed a wide range of results and the initial analysis showed statistically significant results (El-Mashaleh et al. 2006). As such, the SE U.S. contractors data set provides a different perspective to the CII data that is useful for cross-sectional comparison.

IT Use in the Construction Industry

This section presents how both data sets measure IT use as well as the base IT use scores collected within each data set. Both data sets used work functions to measure the level of IT use and developed index scores to summarize the results.

CII Automation/Integration Technology

To improve the limitations of the previous CII studies (Thomas 1999; Thomas et al. 2001) which focused on specific technologies, CII developed 13 work functions applied for both A/I tech. As shown in Table 3, respondents were asked to assess their automation and integration technology use for each work function. The work functions were created to cover tasks/work functions common to most construction projects, but not to be specific to individual technologies. It is expected that work functions remain essentially the same over time and therefore assessment of the degree of technology use for each work function offers the potential for more consistent assessments and improved trend analyses. In Table 3, "NA and "UNK" indicate "not applicable" and "unknown," respectively.

Table 4 indicates the use level of automation and integration technologies that was provided to help guide respondents. To help respondents have constant interpretations, the use levels were designed to reference specific yet widely used software or common situations.

The index score named A/I tech represents the overall degree of IT use and is calculated as

$$\text{A/I tech score} = \frac{(\#\text{ of `1'}) \times 0 + (\#\text{ of `2'}) \times 0.25 + (\#\text{ of `3'}) \times 0.50 + (\#\text{ of `4'}) \times 0.75 + (\#\text{ of `5'}) \times 1}{\#\text{ of questions properly answered}} \times 10$$

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Table 4. Definitions of Level of Technology Use

Use levels[a]	Automation technology	Integration technology
1	Little or no utilization beyond e-mail	Little or no integration of electronic systems/applications
2	"Office" equivalent software, 2D CAD for detailed design	Manual transfer or information via hardcopy of e-mail
3	Standalone electronic/automated engineering discipline (3D CAD) and project services systems	Manual and some electronic transfer between automated systems
4	Some automated input/output from multiple databases with automated engineering discipline design and project services systems	Most systems are integrated with significant human intervention for tracking inputs/outputs
5	Fully or nearly fully automated systems dominate execution of all work functions	All information is stored on a network system accessible to all automation systems and users. All routine communications are automated. The automated process and discipline design systems are fully integrated into 3D design, supply management, and project services systems (cost, schedule, quality, and safety)

[a]1=none/minimal; 2=some; 3=moderate; 4=nearly Fully; and 5=Full.

A/I tech score was designed to give equal weights to all work functions and have a range from 0 to 10 with higher scores indicating more technology use. The A/I Tech scores are then ranked by percentiles.

SE U.S. Contractors Data Set

The SE U.S. contractors data set employed a subset of the work functions developed by O'Connor et al. (2000), using 48 work functions for four phases: procurement, construction management, construction execution, and start up. Front end and design phases were not included, as the focus of the SE U.S. study was on contractors. For each of the work functions, respondents gauged their level of IT use on a one to three scale, where one was the least and three represented the highest level of IT use. Comparing to the work functions used by CII, the work functions selected by this data set are more specific yet not specific technology oriented.

The index developed with this data set is named as the IT index. Like A/I Tech score, the IT index is unweighted aggregations of the level of IT use scored on a scale from 0 to 10, with higher scores indicating more IT use. However, as the underlying questions and scales are different, the A/I tech scores and IT indices are not directly comparable.

IT Use

Tables 5–7 summarize IT use for the two data sets. On the tables, associated with each percentile is the corresponding A/I tech score for each data type. We begin with a discussion of results reported by CII owners summarized in Table 5. The CII data processing rule is applied where an asterisk is inserted indicating statistical warning if the number of respondents in the category is less than 20. Industrial projects reported higher A/I tech scores than building projects, which is consistent with expectations and findings of previous CII research where the greater complexity of industrial projects correlated with increased use of technology. The average size of industrial and building projects in the owner data set happens to be very similar at approximately $48 million total installed cost, suggesting that cost, or project size, is not driving observed differences in A/I tech use. Also of interest, small and midsize projects by cost category reported somewhat more use of A/I tech than did larger projects. This is counterintuitive and bears more investigation in future data sets, as previous studies at CII have shown good correlations between project size and technology use with larger projects making greater use of technology. It would be convenient to dismiss this observation based on a lack of statistical significance; however, the pattern is consistent throughout the data distribution. Similarly, addition and

Table 5. Summary of A/I Tech Index Scores: CII Owners

Percentile ranking	All owners	Industry group		Cost category ($ millions)			Project nature		
		Buildings	Industrial	<$15	$15–$50	>$50	Add	Grass	Modern
100	9.688	7.5*	**9.688**	**9.688**	**9.688**	7.5	**9.688**	8.452	**9.688**
90	7.183	6.737*	**7.385**	**7.606**	6.931	7.003	**7.612**	7.094	7.138
75	6.010	5.326*	**5.577**	5.000	**6.178**	5.849	**6.010**	5.691	5.745
50	4.050	3.798*	**4.050**	3.798	**4.351**	4.183	4.082	3.894	**4.392**
25	3.368	**3.561***	3.341	3.385	**3.726**	2.716	**3.665**	2.716	3.568
10	2.558	**2.837***	2.558	**2.967**	2.875	1.917	**3.370**	2.125	2.911
0	0	**2.083***	0	1.827	**2.083**	0	**2.692**	0	1.827
Mean	4.638	4.435*	**4.624**	4.654	**4.843**	4.276	**4.911**	4.249	4.786
Standard deviation	1.930	1.575*	2.002	2.011	1.792	2.075	1.932	2.054	1.809
n	94	18*	74	30	40	24	26	32	36

Note: *=statistical warning indicator (less than 20 projects) and boldface indicates best performance within category.

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Table 6. Summary of A/I Tech Index Scores: CII Contractors

Percentile ranking	All contractors	Industry group		Cost category ($ millions)			Project nature		
		Buildings	Industrial	<$15	$15–$50	>$50	Add	Grass	Modern
100	10	C.T.	10	9.231*	9.231*	**10***	9.231*	**10***	C.T.
90	8.964	C.T.	9.082	7.284*	**9.228***	7.646*	**9.231***	7.208*	C.T.
75	6.547	C.T.	6.583	6.198*	**7.925***	6.372*	**7.857***	6.380*	C.T.
50	5.481	C.T.	5.581	9.904*	5.553*	**5.682***	5*	**5.877***	C.T.
25	4.322	C.T.	4.535	4.031*	3.698*	**4.891***	3.75*	**4.827***	C.T.
10	3.542	C.T.	3.547	3.347*	2.691*	**4.545***	2.98*	**3.688***	C.T.
0	1.094	C.T.	2.5	2.5*	1.094*	**3.542***	1.094*	**2.596***	C.T.
Mean	5.596	C.T.	5.703	5.282*	5.623*	**5.909***	5.640*	**5.742***	C.T.
Standard deviation	2.016	C.T.	1.913	1.772*	2.785*	1.587*	2.529*	1.656*	C.T.
n	43	0	42	16*	12*	15*	19*	18*	6

Note: *=statistical warning indicator (less than 20 projects); bold face indicates best performance within category; C.T.=confidentiality test, data not shown per CII confidentiality policy (less than 10 projects or data submitted by less than three companies).

modernization projects reported more technology use than grass roots projects producing another inconsistency with earlier research.

Table 6 summarizes the A/I tech use for contractors. By cost category, larger projects generally used A/I tech more than small and midsize projects. By project nature, grass roots reported slightly more use, but the small sample makes it impossible to draw conclusions with any significance. These findings are different from those shown in the owners' data but are much more consistent with previous CII research findings. The mean value of A/I tech use for all projects in the contractor data is 5.596, whereas the mean value for all owners was 4.638.

Technology use for the SE U.S. contractors is depicted in Table 7 by the IT index score. As shown in Table 7, larger companies showed the highest level of IT use, similar to the reported use in the CII contractor data set. Note, however, that there are only seven samples in the small firm category.

Table 7. Summary of IT Index Scores: Southeastern U.S. Contractors

Percentile ranking	All companies	Company revenue ($ millions)		
		<$5	$5–$50	>$50
100	8.205	3.830	6.667	**8.205**
90	5.636	3.555	5.160	**5.984**
75	4.392	2.847	3.988	**4.840**
50	3.421	2.321	3.313	**3.930**
25	2.250	2.082	2.277	**2.768**
10	1.185	**1.578**	1.135	1.384
0	0.484	**1.061**	0.484	0.690
Mean	3.496	2.439	3.221	**3.930**
Standard deviation	1.672	0.916	1.502	1.804
n	73	7	30	36

Note: Boldface indicates best performance within category.

Project and Company Performance Measure and Outcomes

This section presents how the two data sets measure performance as well as performance results. CII has 19 types of metrics to measure project performances in terms of cost, schedule, safety, change, and rework. SE U.S. contractor data set measures cost, schedule, customer satisfaction, safety performance, and profit. In this paper, only cost and schedule performance are presented. This is to compare the results from the two difference data sets consistently. Even though both data sets measured safety performance, it is not presented here because of limited data.

Table 8 illustrates the metrics used to measure project and company performance for both data sets. For the CII metrics there are different definitions for each stakeholder group; definitions are given in Table 9. Project cost growth and project schedule growth compare actual values and estimated values. The metrics are de-

Table 8. Definition of Performance Metrics

Data set		Metric definition
CII	Cost	Project cost growth $= \frac{\text{Actual total project cost} - \text{Initial predicted project cost}}{\text{Initial predicted project cost}}$
		Delta project cost growth $= \lvert\text{Cost growth}\rvert$
	Schedule	Project schedule growth $= \frac{\text{Actual total project duration} - \text{Initial predicted project duration}}{\text{Initial predicted project duration}}$
		Delta project schedule growth $= \lvert\text{Schedule growth}\rvert$
Southeastern U.S. contractors	Cost	% of the time projects are delivered on/under budget
	Schedule	% of the time projects are delivered on/ahead of schedule

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Table 9. Definition of Terms Used in CII Metrics

Metric	Term		Metric definition
Project cost growth	Actual total project cost	Owner	All actual project cost from front end planning through startup. It excludes land costs but includes in-house salaries, overhead, travel, etc.
		Contractor	Total cost of the final scope of work
	Initial predicted project cost	Owner	Budget at the time of authorization
		Contractor	Cost estimate used as the basis of contract award
Project schedule growth	Actual total project duration	Owner	Duration from beginning of detail engineering to turnover to user
		Contractor	Total duration for the final scope of work from mobilization to completion
	Initial predicted project duration	Owner	Predicted duration at the time of authorization
		Contractor	The contractor's duration estimate at the time of contract award

signed to have smaller values for better performed projects. Delta growth metrics are to check how accurate the initially estimated values are. For these metrics, a value approaching zero indicates better performance. The two metrics used for SE U.S. Contractors dataset compare the number of projects which performed on/under budget or on/ahead of initially estimated schedule and the number of overall projects that a company conducted. Thus, higher percentages indicate having better performance.

To better understand the data sets, it is helpful to view the performance outcomes in terms of different categories. Tables 10 and 11 summarize the performance outcomes for CII and SE U.S. contractor data sets, respectively. We start with performance of owners in the CII dataset. The bold cells indicate better performance within the category and values marked with asterisks indicate that the number of data available for the category is less than 20. Findings from these small samples should be interpreted with caution. Overall, the owner projects reported cost growth of −0.1%; however, schedule growth at 11.4% indicated an opportunity for improvement. Analysis by industry group is limited by the small building sample of only 19 projects. Generally, industrial projects reported better cost and schedule performance than building projects as indicated by lower numbers on the project cost and schedule growth metrics, which measure growth from target budgets and schedules. These findings are consistent with most CII benchmarking results, which indicate that larger and more complex heavy industrial projects typically report better performance (Thomas 1999; Thomas et al. 2001). Alternative project assessment of cost and schedule performance is provided

Table 10. Summary of Mean Project Performance Outcomes: CII Data Set

	Performance metrics	Overall mean	Industry group		Cost category ($ millions)			Project nature		
			Buildings	Industrial	<$15	$15–$50	>$50	Addition	Grass	Modern
Owner	**Cost**									
	Project cost growth	−0.001	0.023*	**−0.079**	0.029	**−0.057**	0.027	0.000	0.019	**−0.020**
	Delta project cost growth	0.097	**0.091***	0.099	0.111	**0.075**	0.115	0.093	**0.082**	0.112
	Schedule									
	Project schedule growth	0.114	0.188*	**0.100**	0.132	**0.081**	0.151	**0.094**	0.115	0.128
	Delta project schedule growth	0.185	0.218*	**0.182**	0.250	**0.139**	0.181	0.160	**0.147**	0.236
Contractor	**Cost**									
	Project cost growth	−0.032		**−0.035**	−0.014*	**−0.077***	−0.014*	**−0.055***	−0.011*	C.T.
	Delta project cost growth	0.081		**0.082**	**0.064***	0.105*	0.081*	**0.083***	0.089*	C.T.
	Schedule									
	Project schedule growth	−0.007		**−0.007**	−0.002*	C.T.	**−0.005***	0.001*	**−0.023***	C.T.
	Delta project schedule growth	0.080		**0.073**	**0.076***	0.077*	0.087*	**0.063***	0.098*	C.T.

Note: *=statistical warning indicator (less than 20 projects); boldface indicates best performance within category; and C.T.=confidentiality test, data not shown as per Construction Industry Institute confidentiality policy (fewer than 10 projects or data submitted by fewer than three companies).

Table 11. Summary of Mean Company Performance Outcomes: Southeastern U.S. Contractors

Performance metrics	n	All companies	Company revenue ($ millions)		
			<$5	$5–$50	>$50
Cost					
Percent on/under budget	68	**81.6**	**85.7** (7)	84.2 (27)	78.8 (34)
Schedule					
Percent on/ahead of schedule	68	79.3	72.9 (7)	79.8 (28)	**80.2** (33)

Note: Boldface indicates the best performances within category.

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Table 12. Correlation of A/I Tech Use with Project Performance Outcomes: CII Owners

Performance metrics		A/I tech use Low use ↔ High use: Investment stage		Benefit stage		
Name	n	Fourth quartile	Third quartile	Second quartile	First quartile	No use to greatest benefit[a]
Cost						
Project cost growth	86	0.007	−0.011	0.019*	**−0.012**	0.019
Delta project cost growth	89	0.104	0.106	0.105	**0.074**	0.030
Schedule						
Project schedule growth	83	0.233*	0.078	0.111*	**0.060**	0.173
Delta project schedule growth	86	0.289	0.143	0.144	**0.130**	0.153

Note: *=statistical warning indicator (less than 20 projects) and C.T. data not shown per CII Confidentiality Policy (less than 10 projects or data submitted by less than three companies) and boldface indicates the quartile of the best performance in the benefit stage if the performance is better than that in the investment stage.

[a]Maximum potential improvement from no use (4th quartile).

by the "Delta" metrics, which measure performance as absolute deviation from targets. By this measure, buildings actually outperformed industrial projects by a slight margin (lower numbers are better for all CII performance metrics); however, these findings lack statistical significance. By cost category, surprisingly, larger projects (those costing over $50 million) did not demonstrate superior performance compared to midsize and smaller projects. This is unusual as CII data routinely show that larger projects tend to employ performance enhancing practices to a greater degree than smaller projects. Overall, midsize projects (costs ranging between $15 million and $50 million) showed the best performance in project cost growth and project schedule growth. By project nature, owner modernization projects exhibited the best overall cost performance as indicated by the cost growth metrics, which, as noted earlier illustrate exceptional characteristics of the data set. Grass roots projects, having less impact from interferences and interface complexities, do report more predictable cost and schedule performance according to the delta metrics. Additions, despite many of the issues common to modernization projects, actually reported better performance on the project schedule growth. It is possible that other factors are influencing the somewhat surprising results seen by project nature. Recognizing the complexities caused by additions and modernizations, owners may be requiring performance enhancing procedures that include more sophisticated IT systems.

For the contractors' outcomes in CII data set, all projects are drawn from the industrial sector; however, given that there are only 45 projects, division by cost and nature categories produces very small samples and requires the suppression of many results. As such, few conclusions can be drawn, although there are some opportunities for comparisons to the owner data and general conclusions are possible on overall contractor project performance. In general, contractor performance for industrial projects is very good. Cost growth of −3.5% is excellent, even exceeding the good performance of owners. On average the reported schedule performance of the contractors is also excellent and is about 10% better than owners. A closer examination of the delta metrics reveals that contractors cost and schedule performance are also more predictable than that of the owners. Although very little can be said from the cost category and project nature breakouts of Table 10, the bold pattern of cost and schedule growth metrics (bold indicating better performance) appears as expected. Larger, grass roots projects tend to perform better, which often relates to their greater use of best practices.

Table 11 shows performance outcomes for the SE U.S. contractors data set. [Note that the analysis of this data set follows the method used for CII data, and varies from the methods used in the previous publication, El-Mashaleh et al. (2006).] Only company revenue can be categorized; project nature data were not collected. As all companies did not report complete performance data for each metric, there are fewer than 74 samples per metric as indicated by the n value in the table. As shown in Table 11, small companies reported better cost performance, whereas large companies reported better schedule performance.

Correlation between IT Use and Performance

This section presents the correlations of A/I tech index scores and performance for the CII data set and the correlation of IT index scores and performance for the SE U.S. contractors data set. As both A/I tech and IT indices measure the use of information technologies from different perspectives (the former at project level and the latter at company level) their correlations with their respective performance metrics provide different indicators of potential value derived through association of performance and IT use. Such different perspectives make it difficult to directly relate quantitative results, but trends in performance can be compared.

Correlations are shown through quartile analysis for CII owners and by halves for CII contractors and SE U.S. contractors. In Table 12 for CII owners, the fourth (4th) quartile indicates low A/I tech use, whereas the first (1st) quartile indicates high use of A/I tech. The smaller data samples for CII contractors and SE U.S. contractors are presented and analyzed by the lower half and the upper half rather than in quartiles. The first two columns list the performance metrics and the number of projects available for analysis. The third through sixth columns of Table 12 (third and fourth columns of Table 15) show the mean value for each performance metric by category of A/I tech use. For quartile analysis, the third (3rd) and 4th quartiles are characterized as the investment stage of A/I tech use, in which owners and contractors have begun to use the technologies, but have not necessarily experienced measurable benefit from them in terms of improved performance. The 1st and second (2nd) quartiles are characterized as the benefit stage, in which the benefits of increased A/I tech use have accrued via improved performance. The last column shows the increase in performance that was realized from the 4th quar-

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Table 13. Results of ANOVA Test for CII Owners

Metric	ANOVA result					
	Comparison	Sum of squares	Degree of freedom	Mean square	F	Significance
Cost growth	Between groups	0.013	3	0.004	0.301	0.825
	Within groups	1.185	82	0.014		
	Total	1.195	85			
Delta cost growth	Between groups	0.017	3	0.006	0.639	0.592
	Within groups	0.732	85	0.009		
	Total	0.749	88			
Schedule growth	Between groups	0.321	3	0.107	3.750	0.014
	Within groups	2.338	82	0.029		
	Total	2.658	85			
Delta schedule growth	Between groups	0.352	3	0.117	3.166	0.029
	Within groups	2.931	79	0.037		
	Total	3.284	82			

tile of use to the quartile of greatest benefit. Cases where no improvement was observed are designated by the entry of dashed line ("—") in the last column.

Quartile analysis of performance outcomes and the use of A/I tech for CII owner projects is presented in Table 12. As the technology use advances from the 4th quartile (indicating low use) to the 1st quartile (indicating high use), the outcome values should decrease, reflecting improved performance with increased technology use if performance and technology use are positively correlated. Examination of the relationships for A/I tech reveals a general cost performance improvement with increased technology use, although it is not consistent quartile to quartile. Owners reported a decrease of 1.9% in project cost growth with more use of A/I tech as measured by the improvement in cost growth from the 4th to 1st quartiles of A/I tech use. In many cases, improvements in performance from quartile to quartile were not observed as IT use increased. In some cases, a decrease in performance can be observed as companies initiated use of new technologies when moving from the 4th quartile to the 3rd quartile of A/I tech use. This suggests a performance penalty associated with a learning curve for new technologies; however, the learning curve effect is not as widely observed as in previous CII studies (Thomas 1999; Thomas et al. 2001). Further study is needed to evaluate the patterns of IT use and their correlation with performance across quartiles. Many factors beyond technology use affect project performance and those have not been considered in the analyses presented here. Failure to address the impacts of these factors and in many cases small samples may be attributing to the inconsistent patterns observed for some metrics. A significant direction for future study is to combine the impact of technology use with other project practices, such as front end planning. This will require a considerably larger data set, however.

The impact of A/I tech use on owner schedule performance is more pronounced than for other metrics. As shown in Table 12, owners reported project schedule growth improvement of 17.3% from lowest to highest A/I tech use. Schedules also became more predictable as shown by reductions in the delta project schedule growth metric.

To test statistical significance of the quartile analysis, one-way analysis of variance (ANOVA) was conducted. The results of the ANOVA shown in Table 13 indicate that for cost performance, as expected by the results of quartile analysis, there is no statistically significant mean difference between each group. This means that there is no cost benefit that can be proven statistically. However, the effect of IT use on the two metrics measuring schedule performance is statistically significant, $F(3,82)=3.75$, $p<0.05$ and $F(3,79)=3.17$, $p<0.05$ for delta project schedule growth and project schedule growth, respectively. These results indicate that among the four groups divided according to the degree of IT use, there are some groups whose mean values of delta project schedule growth and project schedule growth are different from those of other groups and these differences are statistically significant at the significance level of $\alpha=0.05$.

Based on the results, a post-hoc test was performed for delta project schedule growth and schedule project growth. Comparisons of means using the Tukey HSD approach are illustrated in Table 14. These comparisons indicate that for the two metrics, there are statistically significant differences between the means of 1st quartile and those of 4th quartile at the 0.05 level. Based on this result and the mean difference shown in Table 14, it is reasonable to conclude that the schedule performance of the 1st quartile is better than the schedule performance of the 4th quartile. One interesting result in Table 14 is the comparison of delta project schedule growth performance. Two quartiles (1st and 3rd) show better performance than the 4th quartile and these results are statistically significant at the level of $\alpha=0.05$. Even for the 2nd quartile, the p-value of the mean difference between the 2nd and 4th quartiles is 0.053, slightly higher than 0.05. With these results, it is observed that the benefit of IT use in terms of schedule predictability is achieved in the very early stage of IT use and this benefit tends to be constant even after using IT more.

Analysis of performance outcomes and the use of A/I tech for CII contractor projects is presented in Table 15. As there are only 45 contractor projects in the CII data set, quartile analysis was not used as the sample size for each quartile is not adequate for analysis. Instead, the data are divided into two halves for characterization as investment and benefit stages. Contractors reporting higher use of A/I tech also reported 3.3% better cost performance with low use. For the schedule performance, both investment stage and benefit stage have negative mean schedule growth values that are essentially the same indicating that contractors managed schedule performance well, irrespective of technology use. Although the difference in schedule growth between investment and benefit stages lacks any practical significance at only 0.2%, there may be some evidence to support schedule compression benefits.

A t-test was conducted to test the previous analysis and the result is summarized in Table 16. As expected from the results of

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Table 14. Results of Post-Hoc Test for CII Owners

Metric	Comparison (quartile)	Mean difference	Standard error	Significance	95% confidence interval
Project schedule growth	1st–2nd	−0.050	0.059	0.829	−0.201~0.105
	1st–3rd	−0.175	0.057	0.990	−0.167~0.132
	1st–4th	−0.173	0.060	0.026*	−0.330~−0.015
	2nd–3rd	0.033	0.060	0.947	−0.125~0.191
	2nd–4th	−0.122	0.063	0.225	−0.288~0.044
	3rd–4th	−0.155	0.061	0.063	−0.316~0.006
Delta project schedule growth	1st–2nd	−0.013	0.051	0.994	−0.148~0.121
	1st–3rd	−0.012	0.050	0.995	−0.143~0.118
	1st–4th	−0.153	0.051	0.020*	−0.286~−0.018
	2nd–3rd	0.001	0.052	1.000	−0.136~0.138
	2nd–4th	−0.1398	0.053	0.053	−0.279~0.001
	3rd–4th	−0.140	0.052	0.043*	−0.277~−0.003

the previous analysis, there is no mean difference that can be statistically significant at the level of $\alpha = 0.05$.

Performance of the SE U.S. contractors is correlated with the IT index to relate company performance and technology utilization. The analysis methodology used for CII data was applied to this data set, with only the IT index used to assess technology use. As the number of data points, n, for each metric in the data set is provided, there is no statistical warning indicator or confidentiality policy indicator provided. The data available are small in some cases, therefore the analysis is performed by halves rather than quartiles. Table 17 summarizes the results, showing, in particular, strong correlation between schedule and increased IT use. There is a 16% schedule benefit with increased IT use, 3% cost savings. These results are comparable to those reported by El-Masheleh et al. (2006) who used regression analysis to correlate individual and composite metrics with IT use.

A t-test was also conducted for this data set and the result is summarized in Table 18. For cost performance, the mean difference between the upper half and lower half is not statistically significant. However, the results indicate that the mean difference for schedule performance is statistically significant at the level of $\alpha = 0.05$. It is worth noting, however, that the regression results for cost and schedule described by El-Mashaleh et al. (2006) show very strong results with significance at the 0.05 level.

Table 15. Correlation of A/I Tech Use with Project Performance Outcomes: CII Contractors

Performance metrics		A/I tech use: Low use ↔	High use	
Name	n	Investment stage Lower half	Benefit stage Upper half	No use to greatest benefit[a]
Cost				
Project cost growth	41	−0.015	**−0.048**	0.033
Delta project cost growth	40	0.081	0.092	—
Schedule				
Project schedule growth	31	−0.013*	−0.011*	—
Delta project schedule growth	42	0.083	**0.077**	0.006

Note: *=statistical warning indicator (less than 20 projects) and C.T. data not shown per CII Confidentiality Policy (less than 10 projects or data submitted by less than three companies) and boldface indicates the quartile of the best performance in the benefit stage if the performance is better than that in the investment stage.

[a]Maximum potential improvement from no use.

Discussion

Table 19 summarizes the results of analyses for the two data sets. As described earlier, the two data sets are very different even though the goal and analyses of the two data sets are conceptually similar. Although the underlying metrics are different and a direct comparison of absolute numbers is not reasonable across the data sets, similar findings in the broader performance categories of cost and schedule are encouraging and help to generalize the findings that IT use has benefits across projects and companies of all sizes.

It is clear that both CII owners and contractors report similar cost savings with increased use of technology. The expected improvement for CII owners is about 2% for cost growth and 3% for cost predictability. CII contractor cost growth benefits were about 3%. Even though the cost metric for the SE U.S. contractors data set is different from that for the CII data set, the amount of benefit from the SE U.S. contractors data set was 3%, same as that from

Table 16. Results of t-Test for CII Contractors

	t-test for equality of means					
Metric	t	Degree of freedom	Significance (two-tailed)	Mean difference	Standard error difference	95% confidence interval
Cost growth	−0.936	39	0.355	−0.033	−0.035	−0.104~0.038
Delta cost growth	0.561	38	0.578	0.011	0.020	−0.029~0.051
Schedule growth	0.132	29	0.896	0.002	0.029	−0.032~0.036
Delta schedule growth	−0.190	40	0.851	−0.005	0.017	−0.064~0.053

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Table 17. Correlation of IT Use with Company Performance Outcomes: Southeastern U.S. Contractors

Performance metrics		IT use Low use ↔ High use		Low use to greatest benefit[a]
Category	n	Investment stage Lower half	Benefit stage Upper half	
Cost				
Percent on/under budget	69	80.729 (35)	**82.809** (34)	2.080 (2.6%[b])
Schedule				
Percent on/ahead of schedule	70	73.375 (36)	**85.265** (34)	11.890 (16.2%[b])

Note: Boldface indicates the performance in the benefit stage is better than that in the investment stage.

[a]Maximum potential improvement from no use.

[b]Percentage is calculated by {(mean value of first)-(mean value of second)}/(mean value of second).

Table 19. Summary of Performance Improvement Results

Performance metrics		CII (%) Owners	CII (%) Contractors	SE U.S. contractor companies (%)
Cost	Saving	2	3	3
	Predictability	3	No benefit	Not applicable
Schedule	Compression	17	No benefit[a]	16
	Predictability	15	<1	Not applicable

[a]No benefit when projects are ahead of schedule.

the CII data set. Comparing the cost savings, contractors achieve slightly more benefits than owners. For cost predictability, on the other hand, owners achieved 3% of benefit, whereas contractors did not. Even though both data sets show similar benefits in terms of cost, the results are not statistically significant. However, the similar benefit levels and trend are a strong sign that some benefits to IT use are accrued by projects and firms; further research is needed to increase sample sizes and explore the results in more detail. There are costs to increased use of IT, which may be counteracting cost savings and weakening the observed results.

Schedule benefits correlated with technology use appear to accrue to the CII owners. CII owners reported a 17% improvement in schedule growth and more than a 20% improvement in schedule compression in terms of overall duration decrease. Further, owners experienced 15% improvement of schedule predictability, whereas contractors experienced less than 1% of improvement. Although CII contractors report no noticeable improvement in schedule performance, this may be due to the already excellent schedule performance of the projects in the data set. When performance is already excellent, there may be little additional benefit from added technology use. For SE U.S. contractors, schedule benefits were approximately 16%, very much in line with CII owners. Also similar to the CII owners, the schedule benefits are statistically significant. It should be noted that the definition of schedule performance in the SE U.S. contractors data set (on or ahead of schedule) supports the supposition that for contractors IT use may increase the likelihood of projects completing ahead of schedule. The benefits are may be masked if all projects in the sample have excellent schedule performance.

IT Use over Time

It is useful to briefly compare the scores from A/I tech use to findings from two previous CII automation and integration technology studies (Thomas 1999; Thomas et al. 2001). The first study contained data collected in 1997 and 1998 and the second study contained data collected between 1997 and 1999. These studies surveyed and reported on the use of four distinct technologies: 3D CAD, electrical data interchange (EDI), bar coding, and integrated databases. The indices produced in these studies, named D/IT for design and information technologies, were scored similarly to A/I tech using a scale of 0–10. Scores by percentile ranking for D/IT and A/I tech are shown for both owners and contractors in Tables 20 and 21, respectively.

Although the D/IT and A/I tech scores cannot be compared directly as the underlying metrics are different, some observations about the use of IT can be made. First, both of the previous (D/IT) studies indicated that 25% of respondents reported no use of the technologies. An interesting contrast with the previous studies is that only 1 project out of 139 in the A/I, tech population reported no use of technologies. Given an overlapping population of CII member companies, this is strong evidence that use of IT has at least broadened among larger owners and contractors. Second, there are some consistent results across the studies in terms of standard deviation in the indices. In each study, contractors consistently show a somewhat higher variance in technology use than do owners. Third, contractors also report a higher technology use in each study for each percentile. These results suggest that contractors have made more varied and aggressive use of technology over time than have owners, although the results bear further investigation.

Conclusion

In this study, the impacts of information technology on project and company performance in the construction industry are investigated. Data are drawn from 139 projects in the CII Benchmarking and Metrics database (newly reported in this study) and from 74 contractors in the southeastern United States. Analysis of these data sets reveals some broad conclusions. First, increased IT use is generally correlated with improved performance. This is particularly true for schedule performance, although some lesser benefits are observed with cost performance. Both the CII and SE U.S. contractors data sets show similar findings, although their sample populations, metrics, and IT work function questions vary greatly. These complementary findings strengthen the overall

Table 18. Results of t-Test for SE U.S. Contractors

Metric	t	Degree of freedom	Significance (2-tailed)	Mean difference	Standard error difference	95% Confidence interval
	t-test for equality of means					
Cost	0.565	67	0.574	2.080	3.684	−5.274~9.434
Schedule	2.044	68	0.043	11.890	5.817	0.283~23.497

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Table 20. IT Use with Time: CII Owners

Percentile ranking	D/IT score: Thomas 1999	D/IT score: Thomas et al. 2001	A/I tech score: Current study
100	7.88	9.38	9.688
90	3.64	4.00	7.183
75	1.79	2.15	6.010
50	0.75	0.86	4.050
25	0.00	0.00	3.368
10	0.00	0.00	2.558
0	0.00	0.00	0
Mean	1.28	1.45	4.638
Standard deviation	1.59	1.76	1.930
n	183	316	94

Note: D/IT and A/I tech scores are not comparable.

premise of this research that increased use of technology correlates with improved project performance. Further, the complementary findings from the SE U.S. contractors data set indicate that the benefits of IT are being experienced by smaller firms than the larger CII member companies. This is logical as smaller firms have gained access to IT as technology prices fell.

Specific findings are that for CII member company projects, cost savings are on the order of 2%, and for SE U.S. contractors, cost savings were about 3% with increased use of IT. Predictability, measured by the CII delta cost growth metric, showed a 3% benefit to owners, but none were observed by contractors. Schedule compression for CII owners was observed at 17%, whereas SE U.S. contractors benefited by a 16% improvement in schedule performance. Predictability for owners, as measured by the CII delta schedule growth metric, improved by 15%. No schedule benefits were found for CII contractors, although it must be noted that the sample had uniformly good schedule performance and hence less of an opportunity for schedule improvement.

It must be noted that there is considerable variance in the data sets. IT is not the sole driver of project performance and as such it is difficult to clearly identify the relationship between project performance and IT utilization. This variance can be seen, e.g., in the CII owner project analysis that is broken into quartiles of IT use. In many cases performance does not improve uniformly from lowest to highest use. This may be, in some cases, due to learning effects where there is a dip in performance after initial usage until firms learn better how to fully incorporate new technologies. In other cases, the second quartile for owners shows mildly better performance compared to the first or highest quartile of IT use. It is possible that in the top quartiles the performance benefits due to IT are largely achieved and other factors are responsible for differences in measured performance. Alternately, the costs of using IT at the highest level may incur added costs offsetting the gains. Further research is warranted to investigate and track the level of IT use and associated benefits over time.

Table 21. IT Use with Time: CII Contractors

Percentile ranking	D/IT score: Thomas 1999	D/IT score: Thomas et al. 2001	A/I tech score: Current study
100	8.23	9.85	10
90	4.94	5.06	8.964
75	2.88	3.43	6.547
50	1.48	1.63	5.481
25	0.56	0.66	4.322
10	0.00	0.00	3.542
0	0.00	0.00	1.094
Mean	2.01	2.19	5.596
Standard deviation	1.99	2.02	2.016
n	114	201	43

Note: D/IT and A/I tech scores are not comparable.

Beyond the variability of individual metrics, most meaningful is the consistency of broad findings across studies with different metrics. Other researchers have noted the difficulties of measuring any benefit from IT use, and have further observed that important innovations have taken years for industry to fully and productively incorporate into their operations (Attewell 1996; Brynjolfsson 1993; King 1996). As the capital facilities industry is still in reasonably early stages of incorporating information technologies, considerable variation and noise are to be expected. Beyond correlations with performance, the finding that more CII member companies are using IT compared with studies five years previous is strong evidence that the industry is perceiving value. Hence, although the verdict on the impact of information technology on performance has not yet been delivered, it is reasonable to conclude that benefits do exist and are being observed by projects and companies involved on these projects. As such, the basic recommendation is that companies should continue to invest in these technologies.

The findings also drive the need for further studies in this area. Beyond a need for further data collection to drive statistical significance, a major next step in advancing our understanding of the impact of technology use on project performance is to cross-correlate technology use with other practice use—ideally in a form of multivariate analysis. Such a data set, which would incorporate practice use with project performance metrics, would need to be quite large. Intermediate steps may be to correlate technology use with other practice use to find correlations and combine these observations with qualitative studies to gain further insight into the quantitative as well as causative direction of technology use on performance.

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