Firm Performance and Information Technology Utilization in the Construction Industry

Mohammad El-Mashaleh[1]; William J. O'Brien, A.M.ASCE[2]; and R. Edward Minchin Jr., M.ASCE[3]

Abstract: This paper, which is written to both researchers and practitioners, examines the impact of information technology (IT) on construction firm performance. Based on data collected from 74 construction firms, regression analysis is used to test the relationship between performance and IT. Analysis provides empirical evidence that IT is positively associated with firm performance, schedule performance, and cost performance. Firm performance is a composite score of several metrics of performance: schedule performance, cost performance, customer satisfaction, safety performance, and profit. The regression analysis shows that for every 1 unit increase in IT utilization, there is an increase of about 2, 5, and 3% in firm performance, schedule performance, and cost performance, respectively. No relationship is found between IT use and customer satisfaction, safety performance, and profitability.

DOI: 10.1061/(ASCE)0733-9364(2006)132:5(499)

CE Database subject headings: Construction management; Computer aided operation; Performance evaluation; Construction costs; Construction companies; Information management.

Introduction

While several writers have promoted long-held visions for computer-integrated construction (e.g., Fischer et al. 1993; Brandon et al. 1998), to date there have only been limited studies about construction firms' adoption of information technology (IT) and even fewer studies concerning the impact of IT on firm performance. Indeed, the construction industry has been described as "hesitant" in its adoption of IT tools (Andresen et al. 2000). Mitropoulos and Tatum (2000) suggest two major reasons for reluctance to incorporate technology: Uncertain competitive advantage from using new technologies and lack of information regarding technologies and benefits. Correspondingly, construction researchers have called for improved tools to analyze how technology affects a construction firm's performance on construction projects (O'Connor and Yang 2003).

The benefits of IT utilization have been difficult to measure because IT use has been limited within construction firms. As such, much research in the area is based on case studies with leading firms. While useful, this research is inconclusive for our purposes because the results are difficult to generalize. In particular, it is difficult to tell if the performance improvements observed with technology use are specifically due to the technology or due to increased attention given by managers to the project in question. Of course, firms have been investing in IT to some extent, and it is possible to quantify their expenditures (at least on hardware and software). But expenditures do not capture whether people actually use the technology. As such, it is problematic to relate expenditures to performance. To generalize case findings and to guide managers, there is a need for statistical studies about IT use and performance.

The specific contribution of this research is to provide a statistical sample of IT utilization and relate that to multiple measures of firm performance. Previous research has been limited to project level benefits along limited metrics [for example, among the few statistically oriented studies, O'Connor and Yang (2003) test for the relationship between cost and schedule success and IT use, and Griffis et al. (1995) explore the benefits of three-dimensional visualization technologies with regard to cost growth, schedule slippage, and rework]. The research reported on in this paper captures several performance metrics from the construction benchmarking literature (firm level profitability, safety, customer satisfaction, and cost and schedule performance) to provide a multifactor view of firm level performance. IT use is explored by adoption of the O'Connor et al. (2000) survey of project level work functions. The relationship between IT use and firm performance is explored via regression analysis across single and composite metrics of firm performance. Data envelopment analysis (Cooper et al. 2000) is used to develop single scores for composite metrics. Across 74 construction firms located in the southeastern United States, the analysis shows strong results for the relationship between firm performance and individual cost and schedule performance and IT use. Somewhat surprisingly, given the strong results for cost and schedule, no relation is found between profitability, customer satisfaction, or safety performance and IT use. The research results enable generalization of prior research about the benefits of IT use for project-level cost and schedule performance to firm-level metrics and should encourage both further study and investment in IT by

[1]Assistant Professor, Dept. of Civil Engineering, Hashemite Univ., Jordan, P.O. Box 150459, Zarqa 13115, Jordan. E-mail: mashaleh@hu.edu.jo

[2]Assistant Professor, Dept. of Civil Engineering, Univ. of Texas at Austin, 1 University Station C-1752, Austin, TX 78712. E-mail: wjob@mail.utexas.edu

[3]Assistant Professor, Dept. of Civil and Coastal Engineering, Univ. of Florida, 365 Weil Hall, Gainesville, FL 32611-6580. E-mail: minch@ufl.edu

Note. Discussion open until October 1, 2006. Separate discussions must be submitted for individual papers. To extend the closing date by one month, a written request must be filed with the ASCE Managing Editor. The manuscript for this paper was submitted for review and possible publication on September 7, 2004; approved on October 12, 2005. This paper is part of the ***Journal of Construction Engineering and Management***, Vol. 132, No. 5, May 1, 2006. ©ASCE, ISSN 0733-9364/2006/5-499–507/$25.00.

managers. As such, the resulting paper is meant to help researchers as well as practitioners.

Literature Review

There are relatively few construction-industry-based studies of the impact of IT on performance, and extant focus on the project as opposed to firm performance. Further, many of the studies focus on the impact of specific technologies. Examples of those studies include Back and Bell (1995); Griffis et al. (1995); and Koo and Fischer (2000). Some studies review the current level of IT use (e.g., Rivard 2000; Kumar 2003). The most detailed of these studies, O'Connor et al. (2000), evaluated the use of IT on specific project activities. O'Connor and Yang (2003) build from their evaluation to assess the impact of IT utilization on project cost and schedule success. The following discussion briefly reviews these studies.

Griffis et al. (1995) studied the impact of three-dimensional computer-aided design (3D CAD) on project performance in terms of cost (actual cost/estimated cost), schedule (actual schedule/estimated schedule), and rework (additional labor expenditure due to rework/total labor expenditure of the project). For a sample of 93 projects, Griffis et al. (1995) concluded that projects using 3D model experience 5% reduction in cost growth, 4% reduction in schedule slip, and 65% reduction in rework. Griffis et al. (1995) conducted a case study of a project that used 3D CAD to validate their survey results for cost savings. The project staff was asked to identify incidents of potential problems that were avoided as a result of using 3D CAD. By using conservative estimates, the case study shows a cost savings of 12%, validating the survey results.

Fischer and his colleagues have conducted a number of case studies on the impact of four-dimensional (4D) CAD on project performance. Koo and Fischer (2000) conducted a case study to demonstrate the feasibility of 4D CAD in commercial construction. For a completed project, the research team looked at the master critical path method (CPM) schedule in an effort to identify any potential problems. The research team found it difficult to conceptualize the construction process by viewing the CPM schedule alone. The research team also had difficulty associating each component in the 2D drawing with its related activity or activities. After generating the 4D model for this project, the research team was able to predict several potential problems. Koo and Fischer (2000) argue that their case study proves the usefulness of 4D models in visualizing and interpreting construction sequence, conveying special constraints of a project, formalizing design and construction information, anticipating safety hazard situations, allocating resources and equipment relative to the work site, and conducting constructability reviews. This visualization, according to Fischer et al. (2003), allows more project stakeholders to understand the construction schedule more quickly and completely compared to the traditional construction management tools. Fischer et al. (2003) report on several other projects with similar benefits, and suggest how these benefits accrue to different participants on a project.

Back and Bell (1995) examined the impact of electronic data management (EDM) technologies on materials management. The writers conduct their examination by simulating four materials management process models. The first model is nonintegrated and intended to represent the baseline condition prior to the implementation of electronic information technologies. The second process model assumes an internal integration of information in the form of a well-developed integrated database system. The third process model includes electronic data interchange (EDI) and bar coding technology. The fourth process model utilizes the concept of reengineering. Back and Bell (1995) collect data from industry practitioners. The data includes durations and personnel cost requirements for the tasks that compromised the materials management process. Based on their simulation, Back and Bell (1995) reported significant time and cost savings when moving from one process model to the next. For example, the reengineered process model exhibits 85% time savings and 75% cost savings compared to the nonintegrated model.

The studies reviewed above relate to specific technologies as opposed to benefits gleaned from adoption of a broader range of technologies. As such, a related stream of research attempts to assess the level of IT utilization. For example, building from the IT-barometer survey developed by Samuelson (2002), Rivard (2000) assessed the level of IT utilization across design and construction firms in Canada. He found the majority of firms were using computers heavily in administrative tasks such as bookkeeping, although fewer firms use IT tools for project management tasks or for electronic document exchange. A recent metastudy of related industry and academic studies by Kumar (2003) reports similar results, finding widespread use of basic IT tools for accounting, word-processing, spreadsheets, and e-mail. A minority of firms have used more advanced tools such as 3D models, although Kumar reports that there is increasing utilization of tools such as project Web sites (particularly among larger firms).

Studies such as those reported on by Kumar (2003) provide a useful albeit broad snapshot of industry IT adoption. To gain a more detailed view, O'Connor et al. (2000) conducted a study of IT utilization for specific tasks on projects. The writers used a survey to collect the data from owners, architects/engineers, contractors, design/build firms, engineering/procurement/construction firms, and construction management firms. O'Connor et al. (2000) divided the project life cycle into six phases: front end, design, procurement, construction management, construction execution, and startup/operations/maintenance. Each phase is comprised of work functions. For example, the procurement phase work functions include: determine the lead time required to order equipment and materials, conduct a quantity survey of drawings, and link quantity survey data to the cost estimating process. The total number of work functions is 68. Based on the responses for each work function, the study utilizes a scoring system to quantify the degree of technology use for the project. Averaging across projects studied, O'Connor et al. (2000) reported that on a 0 to 10 scale, the U.S. construction industry scored 3.85, indicating a relatively low level of overall usage of technology. In a follow-up study, O'Connor and Yang (2003) identify whether project success is associated with level of technology use. Project success|
is quantified as projects with on/under budget cost performance and on/early schedule performance. The sample population of projects is divided into successful and unsuccessful groups based on the definitions for success. O'Connor and Yang found that there is a statistically significant correlation between higher IT use and successful projects.

Research Questions and Methodology

The current literature indicates a positive relationship between IT utilization and project performance. However, there is only

J. Constr. Eng. Manage., 2006, 132(5): 499-507

limited evidence as to the magnitude of the impact [e.g., O'Connor and Yang (2003) test only for significance across populations for general IT use while other studies focus on specific technologies]. Moreover, none of this research tests the degree to which IT utilization affects the performance of the firm as opposed to individual projects. Certainly, the notion of project and firm
performance are related. If IT is utilized on a project and performance improves, then it is reasonable to infer that firms involved with the project should also benefit. However, it is unclear to which firms the benefits of IT accrue. If, for example, project cost is reduced, do the cost savings accrue to the owner, the contractor, or the subcontractors? Hence in an attempt to assess the benefits of IT (and, in turn, guide investment decisions) it is important that firms' managers understand the impact on their firm. Thus the basic research question addressed by this study is "Does IT utilization affect firm performance?"

The researchers address this question by statistical methods, obtaining data about IT utilization and firm performance and seeking to determine a relationship, if any. Data were collected about level of technology use as well as performance data for several metrics. Linear regression is used to investigate the relationship between the variables. Methodologically, a choice was made to investigate a simple linear regression between IT use and firm performance along several metrics. Additional explanatory variables for performance were excluded to allow more detailed focus on IT utilization while still keeping the survey instrument a reasonable length. The sample population was limited to construction firms (design firms were excluded, and design-build firms focused only on construction execution components).

Given the reported prevalence of IT use for basic accounting and related tasks, it is perhaps most useful to investigate the impact of IT utilization for project operations as opposed to office tasks. Hence the researchers limited their investigation to project activities. As O'Connor et al. (2000) have validated use of an extensive research survey to determine IT utilization on project work functions, a choice was made to assume their instrument with as few changes as possible. For this research, the work function sets for the procurement, construction management, construction execution, and start-up phases were adopted directly from O'Connor et al. (2000). As the population for the study is comprised of construction firms, the O'Connor et al. front end and design phases were excluded. While some design build firms may participate in the early project stages, it was felt that limiting the survey to construction phases would allow for the most consistency when employing IT utilization as the independent variable. This provided 48 work functions for participants to evaluate.

For each firm, the survey asked participants to assess the degree of technology used in executing each work function. Participants could choose one of three levels of technology utilization (O'Connor et al. 2000): Level 1, where no or few electronic tools are used and information is conveyed verbally or on paper. Level 2, where there are uncommon electronic tools involved but human workers dominate the process. Information is stored in a stand-alone electronic format and transmitted via media such as disks and e-mail. Level 3, where near fully automated systems dominate execution of the work function. Information is stored on networked systems accessible by project participants. The work function data is then summarized for each firm and a composite score for IT use, ITindex, is calculated as follows (O'Connor et al. 2000):

Table 1. Metric of Performance That Composes Firm Performance

Metric	Method of measurement
Schedule performance	Percent of the time projects are delivered on/ahead of schedule
Cost performance	Percent of the time projects are delivered on/under budget
Customer satisfaction	Percent of repeat business customers
Safety performance	Experience modification rating
Profit	Net profit after tax as a percent of total sales

$$\begin{aligned}\text{ITindex} = \{[&\text{Sum of work functions scores/} \\ &(\text{Total \# of work functions} - \text{\# of "N/A" responses} \\ &- \text{\# of "Don't know" responses})] - 1\} \times 5 \qquad (1)\end{aligned}$$

The ITindex score for each firm is used for the independent variable in the regression.

The dependent variable for regression is firm performance, a potentially complex measure given the number of factors that contribute to performance. However, the econometrics literature suggests several methods of assessing the performance or multifactor productivity of a firm (Coelli et al. 1998). In particular, an approach known as data envelopment analysis (DEA) has been proposed as a useful method of assessing construction firm performance (El-Mashaleh 2003). DEA is a nonparametric method, and hence does not require a priori knowledge of the shape of the composite productivity function (Cooper et al. 2000). DEA also accepts multiple inputs, and, regardless of units of measurement, outputs a single measure of productive efficiency (e.g., firm performance) for each firm relative to others in the sample. The most efficient firms score 1.0 or 100% and collectively form an efficient frontier in n-space where n is the number of factors. Less efficient firms are scored by measuring the distance from the frontier, where a score of 0.85 indicates that the firm in question is 85% as efficient as the most efficient firms in the sample population. This allows scoring of a dependent variable for each firm that supports regression analysis.

DEA allows simple and repeatable assessment of firm performance, transforming a complex problem into one of selecting a number of input factors that can be reliably measured from the sample population. A review of the related benchmarking literature (Fisher et al. 1995; Hudson 1997; CBPP 1998; CII 2000) indicates the following metrics are consistently used in the industry: Schedule performance, cost performance, customer satisfaction, safety performance, and profit. Definitions for these measures are shown in Table 1. These metrics also support DEA and are consistent with analysis guidelines to capture total factor productivity metrics while limiting the overall number of variables, avoiding requirements for an excessively large number of sample firms (Coelli et al. 1998; Cooper et al. 2000). Most

Table 2. Research Hypotheses

Number	Hypothesis
1	ITindex and firm performance are positively correlated
2	ITindex and schedule performance are positively correlated
3	ITindex and cost performance are positively correlated
4	ITindex and customer satisfaction are positively correlated
5	ITindex and experience modification rating are positively correlated
6	ITindex and profit are positively correlated

J. Constr. Eng. Manage., 2006, 132(5): 499-507

Table 3. Respondent's Beliefs of Impact of IT on Performance (in Percentages)

IT has a positive impact on	Strongly agree	Slightly agree	Slightly disagree	Strongly disagree	No response
Firm's profitability	48	41	2	1	8
Schedule performance	43	39	9	2	7
Cost performance	38	44	9	2	7
Customer satisfaction	26	55	11	1	7
Safety performance	8	52	25	7	8

important, based on the existing literature, these five metrics appear to be easily understood and reportable by practitioners while providing a reasonable picture of firm performance. As such, the chosen metrics provide an adequate picture of firm performance that is comparable across firms while also being accessible to support a large survey size. The choice of these metrics also makes possible future comparisons to studies that use similar metrics.

Collection of multiple metrics for the independent variable enabled the researchers to test six hypotheses: That each of the five individual metrics and the composite performance metric are positively correlated with IT utilization. Each hypothesis is shown in Table 2. These hypotheses support the broader research question of "Does IT utilization affect firm performance with respect to the sample population of construction firms?"

Data Collection, Descriptive Statistics, and Construct Validity

Data for the research were collected through a Web-based survey. Respondents were asked to provide information regarding firm performance metrics (Table 1) and to rate the level of IT utilization for each of the 48 work functions. Additional information was collected about the position held by the respondent and general data about the respondent's firm, including annual revenue, industry sector, and type. After completing the objective rating section of the survey, respondents were asked to subjectively report their beliefs about the impact of IT on firm profitability, schedule performance, cost performance, customer satisfaction, and safety. Results from these questions are shown in Table 3.

The survey questionnaire was posted on the University of Florida Web site. The survey link was e-mailed to 777 construction industry practitioners identified as alumni of the University's Department of Civil and Coastal Engineering or M.E. Rinker, Sr. School of Building Construction. Many e-mails (232) were returned as undeliverable. Of the 545 deliverable e-mails, the researchers received 88 responses, which amounts to a 16.15% response rate. As multiple responses were received from different individuals working for the same firm, the 88 respondents represent 74 firms.

Table 5. Regression Models

Model number	Dependent variable	Explanatory variable	Number of firms
1	SCCP score (composite score of schedule performance, cost performance, customer satisfaction, and profit)	ITindex	47
2	SCCE score (composite score of schedule performance, cost performance, customer satisfaction, and EMR)		34
3	SC score (composite score of schedule performance and cost performance)		46
4	Schedule performance (%)		64
5	Cost performance (%)		64
6	Customer satisfaction (%)		64
7	Profit		64
8	EMR		64

Note: SCCP=schedule, cost, customer satisfaction, and profit; SCCE=schedule, cost, customer satisfaction, and safety; EMR=experience modification rating; and SC=schedule and cost performance.

The managerial level of the 88 respondents is broadly distributed, although there is a preponderance of responses from senior positions. Fifty-two percent are from top management (i.e., president, vice president, CEO), 28% are from middle management (i.e., director of certain unit within the organization, senior manager, project manager), and 13% are from low management level (i.e., field manager, assistant project manager, project engineer). Seven percent of the respondents hold other positions including estimator, IT specialist, and cost engineer.

The 74 firms (nine firms had multiple respondents) represent a broad cross section of construction firms principally located in the southeastern United States. Thirty-one firms (42%) are general contractors (GC), seven firms (10%) are construction managers (CM), 21 firms (28%) are both GCs and CMs, three firms (4%) are design-build (DB) firms, two firms (3%) are subcontractors, four firms (5%) are GCs, CMs, and D/B firms, and six firms (8%) have other combinations. Across industry sectors, 7% are residential, 31% are commercial, 4% are industrial, 4% are highway and heavy, 8% are residential and commercial, 23% are commercial and industrial, 12% are residential, commercial, and industrial, and 11% have other industry sector combinations. With regard to revenue, 50% of the firms are over $50 million revenue, 18% are

Table 4. ITindex Descriptive Statistics

		ITindex					
Firm revenue	Number of firms	Mean	Standard deviation	Minimum	Maximum	25th quartile	75th quartile
<$1 million	1	1.92	—	—	—	—	—
$1–5 million	6	2.524	0.972	1.061	3.83	1.946	3.478
$5–25 million	15	3.83	1.391	1.143	6.609	2.679	4.21
$25–50 million	12	3.499	1.501	1.064	6.667	2.336	4.203
>$50 million	35	4.277	1.708	0.897	8.205	2.88	5.119
All	69	3.761	1.63	0.897	8.205	2.411	4.785

J. Constr. Eng. Manage., 2006, 132(5): 499-507

in the range of \$25–50 million, 23% are in the range of \$5–25 million, 8% are in the range of \$1–5 million, and 1% are less than \$1 million in revenue.

Table 4 provides ITindex descriptive statistics by firm size and for all sizes combined. Following O'Connor et al. (2000) to ensure that the response data is adequate, a minimum response rate of 70% of work functions is applied per response. Acceptable work function assessments included any of the three technology level responses (1-2-3) or the N/A response. In other words, the number of responses on the 1, 2, and 3 levels, and N/A responses divided by the total number of work functions should be equal to, or exceed, 70%. Five firms did not pass the 70% response rate. This leaves the number of firms with a calculated ITindex at 69 (Table 4 shows only data from these 69 firms). Data from the five firms with a low response rate for work functions was used to score respondent's subjective beliefs about performance and IT use.

The ITindex mean for all firms combined is 3.761 with a standard deviation of 1.63. The minimum and the maximum values of ITindex are 0.897 and 8.205, respectively. Table 4 further shows both the 25th and 75th quartiles of the ITindex. For all firms combined, the 25th and 75th quartiles are 2.411 and 4.785, respectively. The 25th quartile indicates that 25% of the firms have an ITindex of less than 2.411. The 75th quartile, on the other hand, shows that 25% of the firms have an ITindex of more than 4.785.

There are several indications that support the validity of the responses collected by the survey. O'Connor et al. (2000) report a mean and standard deviation of 3.85 and 1.86, respectively. The ITindex mean and standard deviation of this study is 3.76 and 1.63, suggesting accurate responses. Further, the majority of multiple responses per firm report consistent performance metrics and utilization metrics. Moreover, that more than half the respondents are presidents and vice presidents and more than 80% of the respondents are at the middle management level and above add confidence to the data collected. In this regard, the respondents were encouraged not to answer questions that they are not familiar with. One-third of the low management level and no management level (N/A) respondents did not answer the firm performance information, suggesting that the respondents took the questions seriously and provided accurate answers. Collectively the evidence supports the validity of the survey instrument.

Analysis and Test of Hypotheses

Regression analysis was used to investigate the six hypotheses that IT has positive impact on firm performance (see Table 2). Table 5 summarizes the regression models investigated. For all regression models, ITindex is the sole explanatory variable. As several of the respondent firms have missing information for certain performance metrics, it is impossible to generate a statistically valid sample of a composite score of firm performance for all five metrics. Instead, the composite scores for schedule, cost, customer satisfaction, and profit (SCCP) and schedule, cost, customer satisfaction, and safety (SCCE) are used. A further composite model of schedule and cost performance (SC) is also generated. Scoring is performed using DEA. These three sets of scores (SCCP, SCCE, and SC) are used to investigate the first hypothesis that IT utilization is positively associated with firm performance. In addition to the three regression models for composite or firm performance metrics, there are five regression models for the individual performance metrics to test the hypothesis that IT utilization is positively associated with each metric. Table 5 also shows the number of firms that are included in each regression model; note that the 64 firms for the individual metrics represent different sets of firms from the complete sample.

Table 6. Use of Firm Size Indicator Variables

Indicator	Value of indicator variable small	Value of indicator variable midsize
Small firm \$1–5 million	1	0
Midsize firm \$5–50 million	0	1
Large firm over \$50 million	0	0

As the sample contained firms in different industries and of different sizes, eight indicator variables are used to distinguish firms. While indicator variables allow discrimination between different classes in the population, for the purposes of this study they serve primarily as a mechanism to reduce error and potential bias in the regression analysis of the independent and dependent variables (Fox 1997). Tables 6 and 7 summarize the use of these indicator variables. Two indicator variables are used for revenue size: "Small" and "Midsize." The Small indicator variable refers to firms of revenue size \$1–5 million. The Midsize indicator variable refers to firms with revenue size that ranges between \$5 and 50 million. Five indicator variables are used for type of construction as detailed in Table 7. These indicator variables are residential (R), commercial (C), industrial (I), highway and heavy (H), and subcontractor (S).

The regression results for the composite firm performance metrics (SCCP, SCCE, and SC) indicate that IT utilization is positively associated with firm performance, with coefficient of determination (R^2) values between 0.355 and 0.485. As generally interpreted, these R^2 values indicate that 35–48% of firm performance can be explained by the independent variable (IT utilization). Similar findings are found for the individual metrics of schedule cost performance with R^2 values of 0.354 and 0.377, respectively. No significant relation was found between customer satisfaction, safety, and profitability. The R^2 values and the regression equation for each model are summarized in Table 8.

It is useful to discuss one model in more detail. Fig. 1 plots the regression line on a scatter graph for the SCCP model. The regression equation is

$$\text{SCCP} = 0.785 + 0.0241\ \text{ITindex} + 0.0758\ \text{commercial} \qquad (2)$$

The regression equation shows that for every 1 unit increase in the ITindex, holding the commercial variable fixed, there is 2.41% increase in the SCCP score. Compared to the rest of the contractors, commercial contractors have a 7.58% higher SCCP score. No other indicator variables are useful in discriminating between types of firms in the population. Note that in Fig. 1

Table 7. Use of Firm Type Indicator Variables

Indicator	Value of indicator variable "R"	"C"	"I"	"H"	"S"
Residential	1	0	0	0	0
Commercial	0	1	0	0	0
Industrial	0	0	1	0	0
Highway and heavy	0	0	0	1	0
Subcontractor	0	0	0	0	1

J. Constr. Eng. Manage., 2006, 132(5): 499-507

Table 8. Summary Table for Regression Analysis of ITindex and Performance

Model number	Dependent variable	Regression equation	R^2 (%)	Number of firms
1	SCCP score	$=0.785+0.0241$ ITindex$+0.0758$ commercial	35.5	47
2	SCCE score	$=0.893+0.0176$ ITindex-0.110 residential	36.1	34
3	SC score	$=0.714+0.0205$ ITindex$+0.0603$ midsize-0.0772 residential $+0.112$ commercial$+0.0912$ highway and heavy	48.5	46
4	Schedule performance	$=54.9+5.13$ ITindex$+16.2$ commercial-11.8 industrial	35.4	64
5	Cost performance	$=70.2+2.95$ ITindex$+16.1$ small$+10.4$ midsize -7.49 residential-15.9 highway and heavy	37.7	
6	Customer satisfaction	Not significant	0.022	
7	Profit		0.058	
8	EMR		0.013	

Note: SCCP=schedule, cost, customer satisfaction, and profit; SCCE=schedule, cost, customer satisfaction, and safety; EMR=experience modification rating; and SC=schedule and cost performance.

several firms have an SCCP score of 1.0; in the context of the DEA scoring, these firms represent the efficient frontier of the sample studied. Firms with a score less than 1.0 are relatively less efficient than the most efficient firms in the sample.

F- and t-tests are used to assess the reliability of the model and its individual parameters, respectively. Associated with each test is a p-value or probability that the results of the test are not significant. A probability of less than 0.05 is generally considered an acceptable standard of significance (Fox 1997). For the SCCP regression model, the p-values are 0.000 for the F-test and 0.001 for the t-test. These low probabilities allow exclusion of the null hypothesis and inference that the model and parameters are adequate.

Analysis of the residual errors provides further confidence in the SCCP regression model. Figs. 2 and 3 show that the underlying assumptions of linear regression (linearity, equal variance, and independence of errors) are not violated as the residuals are randomly scattered with no particular trend. Fig. 4 is the normal probability plot of residuals. This plot does not indicate any violation of the normality assumption. Similar findings for the other models are described in more detail in El-Mashaleh (2003).

Table 9 summarizes regression results for each model, including R^2, F- and t-tests, and associated p-values. For the composite or firm performance metrics SCCP, SCCE, and SC, as well as for the metrics for schedule and cost performance, the t-test and the F-test indicate that the regression terms and the regression model are significant at the 0.05 level of significance. Supporting plots of the regression line and scatter graph for SCCE, SC, schedule, and cost are shown in Figs. 5–8. Regression models for the individual metrics of customer satisfaction, profit, and safety do not show any significant relationship between ITindex and performance, with low R^2 values and high p-values for the F- and t-tests. As such, based on the data available, Hypotheses 1, 2, and 3 (that IT utilization is positively correlated with firm, schedule, and cost performance) are answered affirmatively. However, Hypotheses 4, 5, and 6 (that IT utilization is positively correlated with customer satisfaction, profit, and safety) cannot be supported. With respect to the significant findings (models 1–5), the regression equation for each model shows some indicator variables are active (see Table 8). However, there is no pattern across the models suggesting that certain indicators are consistently higher or lower than the main population. Hence the available data do not support further extension of the research hypothesis for subsets of the population studied.

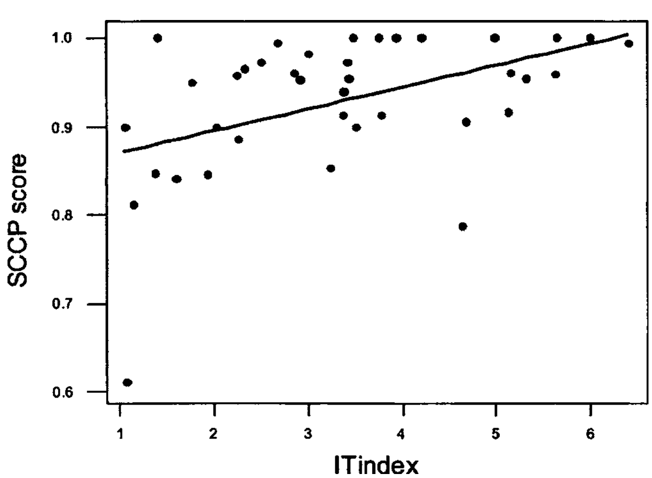

Fig. 1. Regression plot for schedule, cost, customer satisfaction, and profit (SCCP) score and ITindex

Discussion

The regression findings provide strong evidence of a significant positive correlation between firm, schedule, and cost performance and use of IT. Given the number of likely drivers of performance, and the general limitations of this type of study (e.g., limited time

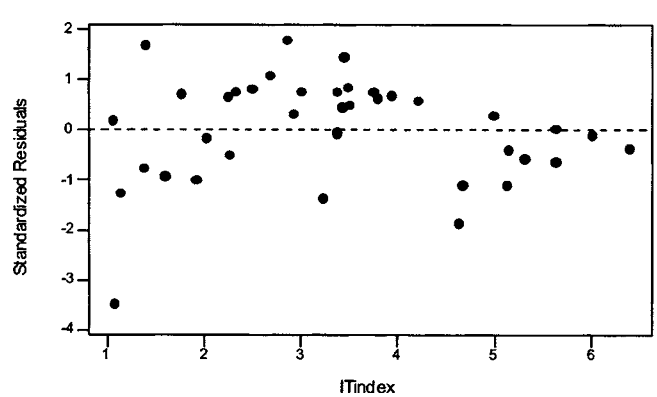

Fig. 2. Standardized residuals versus ITindex

J. Constr. Eng. Manage., 2006, 132(5): 499-507

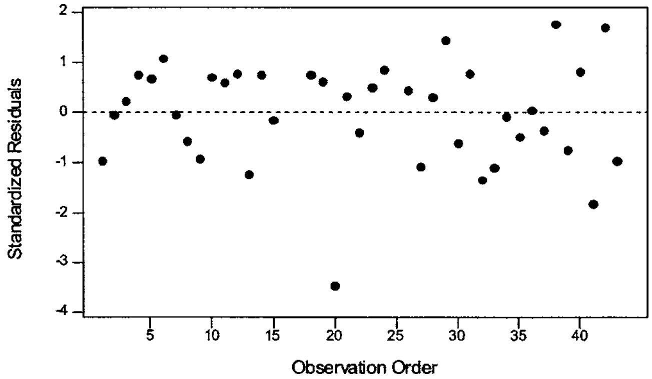

Fig. 3. Standardized residuals versus the order of the data

frame, some expected noise in reported data), the writers find the R^2 values of 35–48% highly significant. It is worth noting that different research traditions have different interpretations of acceptable values for R^2. While engineering models seek a high degree of explanatory power for use in design, social science models are more necessarily limited. Kennedy (1998) provides some guidance, suggesting that time-series models tend to have a high R^2 of 0.5–0.7 whereas "for cross-sectional data, typical R^2's are not so high" (p. 26). Overall, it is important to judge the quality of the regression model. As discussed above, the F- and t-tests for the models, as well as tests of the residuals, provide a high degree of confidence in the models.

Of course, correlation is not causation. A visual inspection of the scatter plots (Figs. 1 and 5–8) indicates that several highly efficient firms have low ITindex scores. However, further inspection shows that the high ITindex/low performance portion of the scatter plots are empty. At the least, we can conclude that IT utilization does not detract from performance, and better performing firms have a strong tendency to make increasing use of IT. These results also correspond with previous research (reviewed above) that indicates IT use has a beneficial impact on cost and schedule. It is worth noting that further examination of the work function data on IT use does not show unusual clusters of dominant work functions that drive performance, suggesting a broad range of mechanisms by which firms achieve the benefits of IT use. Given the findings and the limitations of a single factor input study, further research may seek to extend the findings to correlate IT use with firms' cost and schedule management procedures to determine if there are systematic relationships between procedures, IT use, and performance.

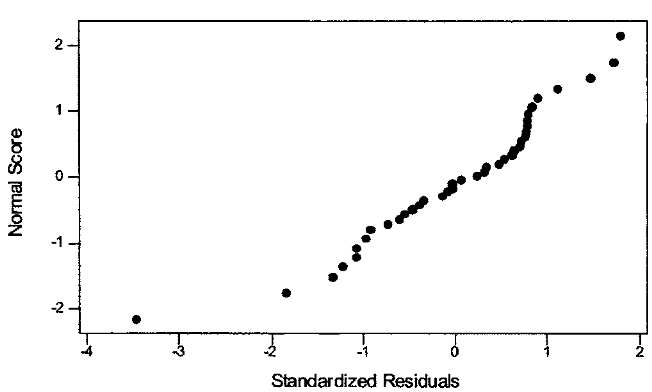

Fig. 4. Normal probability plot of the residuals

Table 9. Summary of Regression Results for Each Model

Model number	Dependent variable	R^2	ITindex F	ITindex p	ITindex t	ITindex p
1	SCCP	0.355	10.17	0.000	3.44	0.001
2	SCCE	0.361	7.34	0.003	2.48	0.020
3	SC	0.485	6.41	0.000	2.39	0.023
4	Schedule	0.354	10.43	0.000	3.75	0.000
5	Cost	0.377	6.53	0.000	2.82	0.007
6	Customer satisfaction	0.022	1.36	0.249	1.16	0.249
7	Profit	0.058	2.34	0.134	−1.53	0.134
8	EMR	0.013	0.41	0.528	−0.64	0.528

Note: SCCP=schedule, cost, customer satisfaction, and profit; SCCE=schedule, cost, customer satisfaction, and safety; EMR=experience modification rating; and SC=schedule and cost performance.

The regression results generally correspond with the respondents' beliefs about the impact of IT on cost and schedule performance (Table 3, above). There is less correlation with respondents' beliefs that profitability, customer satisfaction, and safety improve with increased IT use. Regression analysis found no relationship for profitability, safety performance as defined by the experience modification rating (EMR), or customer satisfaction. Some discussion about each of these is warranted.

Of the results, the lack of correlation between profitability and IT use is perhaps most surprising given the strong correlation between cost and schedule performance and IT use. A priori, it is reasonable to expect that firms with strong cost and schedule performance would also show strong profitability and hence the correlation with IT use would carry over. Not surprisingly, a high percentage or respondents (89%) held this view. Beyond possible problems with the survey instrument and responses, there are three possible explanations for lack of correlation in the sample: First, that there is no relationship. Second, that the client or other firms on the project are capturing the benefits and that the firms in the sample population—largely general contractors and construction managers—are not benefiting. Third, that the cost of investment in IT (both in terms of hardware and systems and in terms of training) is offsetting the benefits of IT use. As this study collected data about IT use as opposed to investment, and as the study captured data about only a brief time frame, the writers

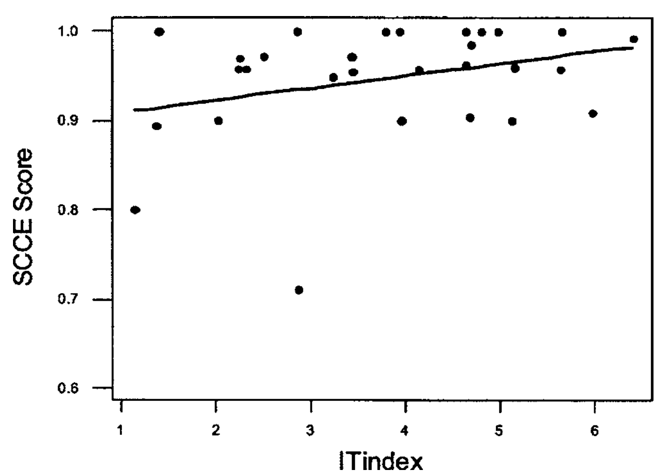

Fig. 5. Regression plot for SCCE score and ITindex

J. Constr. Eng. Manage., 2006, 132(5): 499-507

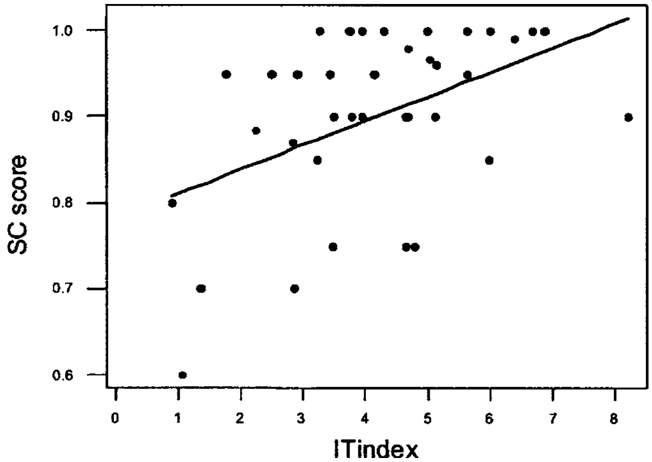

Fig. 6. Regression plot for SC score and ITindex

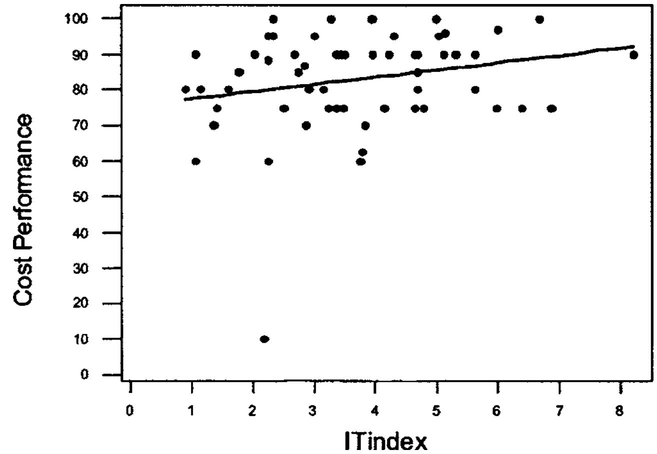

Fig. 8. Regression plot for cost performance and ITindex

have no data suggesting which of these explanations may be correct. However, any explanation is potentially of general importance to managers and follow-on research in this area is a priority.

The belief by 81% of the respondents that IT has a positive impact on customer satisfaction is not supported by the empirical analysis. As the work functions relate to project execution, it is possible that much of the IT use reported on in this study was not directly visible to clients and hence the relationship was not adequately captured by the study. Similarly, customer satisfaction is a difficult metric and this study only reports on one aspect (repeat clients). As such, we find the regression results inconclusive and suggest that follow-on research to investigate the relation between profitability and performance also include customer satisfaction.

The regression analysis shows no association between safety performance (as measured by EMR) and IT use. While 60% of the respondents believe that IT has a positive impact on safety performance, only 8% strongly agreed that there is a strong relationship between IT use and safety. Thirty-two percent of the respondents disagreed that IT use enhances safety performance, a significantly higher percentage than for the other performance measures (see Table 3). Previous research indicates a positive correlation; Koo and Fischer (2000) argue that the use of 4D helps to anticipate safety hazard situations. Fischer et al. (2003) report that participants of a workshop hosted by Walt Disney Imagineering and Center of Integrated Facility Engineering at Stanford University in 1999 identify increased site safety as one of the benefits of 3D and 4D use. With respect to this study, it is possible that the work functions used to record IT use do not adequately reflect safety performance. It is also plausible that the relation between safety and IT use is too low to be significant at this time. In particular, as EMR is a historical metric, it is possible that the positive benefits of IT have not yet been reflected in firm performance. As such, a long-term study of IT use and performance is needed.

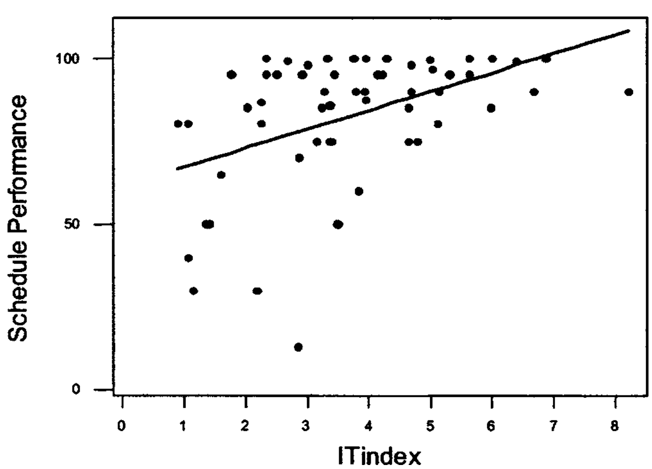

Fig. 7. Regression plot for schedule performance and ITindex

Conclusions

To the writers' knowledge, this research is the first quantitative assessment of the impact of IT on construction firm performance across several metrics. Based on data collected from 74 construction firms, this paper provides empirical evidence that IT has a positive impact on performance. For every increase in ITindex (IT utilization), there is a positive increase in firm performance, schedule performance, and cost performance. Firm performance measures used in this study are composite scores of several metrics of performance: schedule performance, cost performance, customer satisfaction, EMR, and profit. This builds on and enhances prior research that investigates IT use in the industry, as well as makes a case for generalizing the IT research for specific technologies that suggest IT use is positively correlated with cost and schedule performance on projects.

Of course, this research is only a starting point. It perhaps is best considered a snapshot of IT use and performance reported by firms in the southeastern United States. The writers do find the regression results strong enough (i.e., 35–48% of performance explained by a single factor suggests that regression is significant given the likely number of drivers of performance) to warrant that the research be extended to a larger population and to a long-term study. A larger population would generalize the findings and may provide better insight into the relationship between profitability and performance, particularly if the population included more subcontractors. A longitudinal study would also allow tracking of firms' IT implementation levels and success over time, enabling identification of learning effects as well as better capture the relation between IT use and safety.

With respect to management decisions about investment in IT, this study generally supports increased investment. The writers' caution managers that the findings relate to IT use as opposed to

J. Constr. Eng. Manage., 2006, 132(5): 499-507

investment, and hence the study does not directly support return on investment calculations. At the same time, some managers may find the lack of observed correlation between profitability and IT use among the sample population (primarily general contractors and construction managers) as indication that investment in IT is not justified. Such an opinion is not supported by the data as no significant positive or negative relationship was found. As a strong correlation is found between IT use and schedule and cost performance, it is the writers' opinion that managers would be wise to continue to invest in IT, however judiciously.

References

Andresen, J., et al. (2000). "A framework for measuring IT innovation benefits." *Electron J. Inf. Technol. Constr.*, ⟨http://itcon.org⟩, 5, 57–72.

Back, W., and Bell, L. (1995). "Quantifying process benefits of electronic data management technologies." *J. Constr. Eng. Manage.*, 121(4), 415–421.

Brandon, P., Betts, M., and Wamelink, H. (1998). "Information technology to support construction design and production." *Comput Ind.*, 35, 1–12.

Coelli, T., Rao, D. S. P., and Battese, G. E. (1998). *An introduction to efficiency and productivity analysis*, Kluwer Academic, Boston.

Construction Best Practice Program (CBPP). (1998). *Key performance indicators. Project delivery and company performance*, Watford, U.K.

Construction Industry Institute (CII). (2000). *Benchmarking and metrics, Data Rep.* (CD-ROM), *Service Release 10.10.2000*, Univ. of Texas at Austin, Austin, Tex.

Cooper, W., Seiford, L., and Tone, K. (2000). *Data envelopment analysis: A comprehensive text with models, applications, references and DEA-solver software*, Kluwer Academic, Boston.

El-Mashaleh, M. (2003). "Firm performance and information technology utilization in the construction industry: An empirical study." Ph.D. dissertation, Univ. of Florida, Gainesville, Fla.

Fischer, M., Betts, M., Hannus, M., Yamazaki, Y., and Laitinen, J. (1993). "Goals, dimensions, and approaches for computer integrated construction." *Management of information technology for construction*, K. S. Mathur, M. P. Betts, and K. W. Tham, eds., World Scientific, Singapore, 421–433.

Fischer, M., Haymaker, J., and Liston, K. (2003). "Benefits of 3D and 4D models for facility owners and AEC service providers." *4D CAD and visualization in construction: Developments and applications*, R. Issa, I. Flood and W. O'Brien, eds., Balkema, Lisse, The Netherlands, 1–33.

Fisher, D., Miertschin, S., and Pollock, D. (1995). "Benchmarking in construction industry." *J. Manage. Eng.*, 11(1), 50–57.

Fox, J. (1997). *Applied regression analysis, linear models, and related methods*, Sage, Thousand Oaks, Calif.

Griffis, F., Hogan, D., and Li, W. (1995). "An analysis of the impacts of using three dimensional computer models in the management of construction." *Research Rep. 106-11*, Construction Industry Institute, Univ. of Texas at Austin, Austin, Tex.

Hudson, D. (1997). "Benchmarking construction project execution." Ph.D. dissertation, Univ. of Texas at Austin, Austin, Tex.

Kennedy, P. (1998). *A guide to econometrics*, 4th Ed., The MIT Press, Cambridge, Mass.

Koo, B., and Fischer, M. (2000). "Feasibility study of 4D CAD in commercial construction." *J. Constr. Eng. Manage.*, 126(4), 251–260.

Kumar, B. (2003). "A tale of two SITIES." *4th Joint Symposium on IT in Civil Engineering*, ASCE, Reston, Va.

Mitropoulos, P., and Tatum, C. (2000). "Forces driving adoption of new information technologies." *J. Constr. Eng. Manage.*, 126(5), 340–348.

O'Connor, J., et al. (2000). "Project-and phase-level technology use metrics for capital facility projects." *Rep. No. 16*, Center for Construction Industry Studies, Univ. of Texas at Austin, Austin, Tex.

O'Connor, J. T., and Yang, L.-R. (2003). "Impact of integration and automation technology on project success measures." *4th Joint Symposium on IT in Civil Engineering*, ASCE, Reston, Va.

Rivard, H. (2000). "A survey on the impact of information technology on the Canadian architecture, engineering, and construction industry." *Electron J. Inf. Technol. Constr.*, ⟨http://itcon.org⟩ 5, 37–56.

Samuelson, O. (2002). "IT-barometer 2000—The use of IT in the Nordic construction industry." *Electron J. Inf. Technol. Constr.*, ⟨http://itcon.org⟩ 7, 1–25.

J. Constr. Eng. Manage., 2006, 132(5): 499-507