Project Performance versus Use of Technologies at Project and Phase Levels

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Abstract: Lack of information regarding technology benefits along with uncertain competitive advantage from new technology have resulted in industry reluctance to implement new technologies. An industry-wide survey was used to collect project data from more than 200 capital facility projects on the issue of technology usage and overall project success. Twenty-two research hypotheses are presented and analyzed according to five different data class variables: industry sector, total installed cost, public versus private, greenfield versus expansion versus renovation, and typical versus advanced projects. Findings pertaining to associations between project success and technology usage at the project and phase level are discussed. The results of this research indicate that several technologies may contribute significantly to project performance in terms of cost and schedule success, particularly for certain types of projects. In addition, project schedule success is more closely associated with technology utilization than is project cost success. Findings from this study can provide companies with information on technology benefits and whether to use certain technologies.

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Introduction

The construction industry has been criticized for its slow adoption of emerging technologies. However, it is believed that in recent years this trend has been changing. Greater demands for more cost-effective and schedule-efficient projects have led to new project delivery processes, many of which exploit technologies that serve to either automate or integrate tasks. Several researchers have identified the effects of automation and integration technologies. Fergusson (1993) investigated the relationships between facility integration and quality. His research first defined facility quality and integration and then determined a measure for the two variables. Finally, the study attempted to determine the impacts of integration on facility quality. The results of this study indicated a strong correlation between quality and integration. Back and Bell (1994) attempted to identify the impacts of use of electronic data interchange (EDI) in bulk materials management. A process model was developed during this research. In order to identify technology benefits, the analysis results from integrated models were compared with those from nonintegrated models. The findings indicated that integration resulted in a cycle time reduction in bulk materials process. Griffis et al. (1995) studied the impacts of using three dimensional (3D) computer models on cost, schedule duration, and rework metrics. A survey instrument was used to collect data from Construction Industry Institute member companies. The study concluded that projects using 3D models experienced reduction in cost growth, schedule slip, and rework. Back et al. (1996) undertook a study to determine the impact of information management on project schedule and cost. In this study, the baseline engineer/procure/construct (EPC) process was modeled using a visual basic program. The results from the baseline process were compared with those from an information technology model. The finding from the simulations indicated that implementation of a single information technology solution may not result in a significant project-level impact. Johnson and Clayton (1998) contended that information technology can improve productivity of teams and management procedures. Back and Moreau (2000) suggested that improving internal information exchange and integrating project-based information across organizational boundaries may result in project cost and schedule reductions. Additionally, Thomas et al. (2001) evaluated the impacts of design/information technologies by connecting their use to project performance in terms of cost growth, schedule growth, and safety success. The design/information technologies measured included integrated databases, EDI, 3D, (computer aided design) modeling, and bar coding. The results indicated that use of the design/information technologies may result in cost savings and schedule reductions. These and other earlier studies identified many advantages by adopting technology. However, there are few studies with quantifiable information on how emerging technology has affected project success.

In the highly competitive construction industry, the best companies are constantly searching for proven technologies that offer a competitive advantage. These companies generally avoid technologies that do not provide some proven added value. Even though some technologies have been adopted and others abandoned, however, no industry-wide benchmarking study has been done on the levels of technology used on projects. In addition, there has been no comprehensive industry-wide study on the im-

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J. Constr. Eng. Manage., 2004, 130(3): 322-329

pacts of technology usage on project outcomes. This lack of information regarding technology benefits along with uncertain competitive advantage from new technology have resulted in industry reluctance to implement new technologies. Thus, a study of the relationship between technology utilization and project success is necessary. Quantitative analysis of the effects of integration and automation (IA) technologies on the success of projects should provide companies with additional information on whether to use certain technologies.

The primary objective of this study was to determine the extent, if any, to which IA technologies contribute to project success. Before attempting to measure integration and automation, it is necessary to define both concepts. For the purposes of this research, integration and automation are defined as follows:

1. Integration: the sharing of information between project participants or melding of information sourced from separate systems and
2. Automation: the use of an electronic or computerized tool by a human being to manipulate data or produce a product.

The data collection tool was used on all types of projects in the building, industrial and infrastructure sectors. Only low-volume home-building operations were deliberately neglected. The data obtained and analyzed in this study are project-specific, meaning the data are representative of the levels of IA technologies used on projects (rather than that used organization-wide, for example). Work function (WF) technologies that are not related to project delivery are outside the scope of this study. The survey was designed to include work functions that were thought to have substantial impact on projects. The original listing of work functions, which resulted from both brainstorming and a literature search, contained over 200 items. This list was too long to allow respondents to complete the survey in a reasonable amount of time. Therefore, a systematic method for eliminating some of the less important work functions was developed. Each work function was then tested to ensure it was fundamental to the project delivery process. Finally, the data collection tool makes use of 68 common project WFs in assessing levels of technology usage. Owing to the fundamental differences in projects, not all of the 68 WFs are applicable to all projects. Accordingly, steps were taken to help ensure that computed IA indices are representative of the levels of IA technology used on projects.

This paper addresses associations between technology usage and project performance. Technology usage metrics analyzed include those at the project level, the phase level, the task automation (TA) level, the integration link (IL) level, and those for industry-wide high-tech and industry-wide low-tech work functions. The project performance variables analyzed include project cost performance and project schedule performance. Cost success is defined to have occurred when the total installed cost was significantly *under* authorized budget. Cost failure occurs when the total installed cost was significantly *over* authorized budget. Schedule success is defined to have occurred when the actual project completion date was significantly *earlier* than planned. Schedule failure occurs when the actual project completion date was significantly *later* than planned. This study examined stakeholders' relative perceptions of project success rather than specific absolute measures of project performance. Questions assessing project cost and schedule performance on the survey are based on respondents' relative perceptions. The survey allowed the responders to make their own judgment in determining the meaning of "significantly" for overall project success measures.

Research Process

The research was divided into four phases. Phase 1 entailed developing the scope of the study, conducting a literature review, developing the data collection tool, and outlining the methodology for the analysis of the data. Phase 2 involved collecting the data, modeling, and developing the database. Phase 3 consisted of developing descriptive statistics. Included in the descriptive statistics are the frequencies, means, and standard deviations of the computed indices for each data class variable. The purpose of generating the descriptive statistics was to determine the levels of IA technologies in use according to project-level, phase-level, and work function-level data class variables. In the final stage of this research, the impacts of technology usage on project success were investigated. After descriptive statistics were generated and analyzed, research hypotheses were formulated for testing. These hypotheses were tested to determine the statistical significance of the hypothetical relationships.

Research Hypotheses

Table 1 shows the 22 research hypotheses. The hypotheses are presented and analyzed according to five different data class variables: industry sector, total installed cost (TIC), owner regulation, initial site, and project typicality. These variables are defined as follows:

1. Industry Sector—The architecture/engineering/construction (A/E/C) industry was divided into three main industry sectors: building, industrial, and infrastructure. Each sector includes several project types:
   - Building—residential, hotel, office, retailed, parking garage, medical, laboratory, educational, etc.
   - Industrial—foods, consumer products manufacturing, automotive assembly, pulp and paper, oil production, environmental, metals refining, etc.
   - Infrastructure—water, electrical distribution, communications, tunneling, highway, airport, rail, flood control, navigation, marine facilities, mining, etc.
2. Total installed cost (i.e., project size)—The TIC cost variable was divided into five categories on the survey: <\$5 million, \$5–20 million, \$20–50 million, \$50–100 million, and >100 million. The number of size classifications was reduced from five to three in order to obtain a sufficiently large sample for analysis. The three categories with a large sample size include: small-sized projects (total installed cost <\$5 million), medium-sized projects (total installed cost = \$5–50 million), and large-sized projects (total installed cost >\$50 million). The small projects were excluded from the analysis.
3. Project typicality—Respondents were asked to compare the subject project to other company projects relative to overall technology usage. Two optional responses were provided: typical or advanced.
4. Owner regulation—This variable allowed researchers to distinguish private from public projects.
5. Initial site—Participants were provided with three optional responses: Greenfield (or new), Renovation, or Expansion.

Survey Structure and Process

This survey was developed to measure the degree of use of IA technologies on projects and the impact of IA technologies on project outcomes. The survey requests the participant to provide

J. Constr. Eng. Manage., 2004, 130(3): 322-329

Table 1. List of Research Hypotheses

Number	Hypothesis
1	Higher levels of project cost success are associated with high levels of project technology usage
2	Higher levels of project cost success are associated with high levels of automation technology usage
3	Higher levels of project cost success are associated with high levels of integration technology usage
4	Higher levels of project cost success are associated with high levels of technology usage for industry-wide high-tech work functions
5	Higher levels of project cost success are associated with high levels of technology usage for industry-wide low-tech work functions
6	Higher levels of project cost success are associated with high levels of technology usage in the front-end phase
7	Higher levels of project cost success are associated with high levels of technology usage in the design phase
8	Higher levels of project cost success are associated with high levels of technology usage in the procurement phase
9	Higher levels of project cost success are associated with high levels of technology usage in the construction management phase
10	Higher levels of project cost success are associated with high levels of technology usage in the construction execution phase
11	Higher levels of project cost success are associated with high levels of technology usage in the startup/operations/maintenance phase
12	Higher levels of project schedule success are associated with high levels of project technology usage
13	Higher levels of project schedule success are associated with high levels of automation technology usage
14	Higher levels of project schedule success are associated with high levels of integration technology usage
15	Higher levels of project schedule success are associated with high levels of technology usage for industry-wide high-tech work functions
16	Higher levels of project schedule success are associated with high levels of technology usage for industry-wide low-tech work functions
17	Higher levels of project schedule success are associated with high levels of technology usage in the front-end phase
18	Higher levels of project schedule success are associated with high levels of technology usage in the design phase
19	Higher levels of project schedule success are associated with high levels of technology usage in the procurement phase
20	Higher levels of project schedule success are associated with high levels of technology usage in the construction management phase
21	Higher levels of project schedule success are associated with high levels of technology usage in the construction execution phase
22	Higher levels of project schedule success are associated with high levels of technology usage in the startup/operations/maintenance phase

general information about the project and final performance of the project in terms of cost and schedule success. Additionally, this section obtains information about key study variables, such as the industry sector and total installed cost of the project. The remainder of the survey assesses the levels of technology applied on the project.

For the purpose of this study, a project's life cycle is structured in six phases: front end (which includes scoping, feasibility, and preliminary design activities), design, procurement, construction management, construction execution, and startup/operations/maintenance. In order to draw a clear distinction between the tasks that involved the processing of information from those that involved direct installation work, the construction phase was split into construction management and construction execution. The reason for the distinction was that indirect work occurs within the information infrastructure while direct work involves robotic devices (Welch 1998). Each phase is comprised of work functions, some of which represent tasks (for possible automation) and some of which represent task-to-task integration links. There are a total of 68 work functions that make up a project. Table 2 shows the distribution of these work functions for each phase.

Study participants were first asked to identify a recent project that they were familiar with for assessment. For the subject project, the survey then asks participants to assess the degree of technology used in executing each work function for that project. The survey offers respondents three optional levels of technology utilization: Level 1, Level 2, or Level 3. In addition, "not applicable" and "don't know" responses were offered as possible responses for each work function assessment. Thus, participants were encouraged to provide honest and informed responses. Each level of technology utilization is defined as follows:

1. Level 1—No electronic tools or only the most common electronic tools are used; for example, information is conveyed verbally or on paper and transmitted via "snail mail," fax, or courier.
2. Level 2—Uncommon electronic tools play key roles in executing the work function, but human workers still dominate. Information is stored primarily in stand-alone electronic formats and is transmitted via isolated electronic media such as disks or as e-mail attachments, etc.
3. Level 3—While human workers still participate, fully or nearly fully automated systems dominate. Information is stored on a networked system accessible by all appropriate participants.

A nationwide survey of technology use levels on capital facility projects was conducted between October 1998 and August 1999. A total of 210 project responses were collected from all sources and by all means, including personal interviews, phone/fax interviews, and mail-in surveys of forms. These responses represented 30 major metropolitan areas in 24 U.S. states. A total of 218 interviews were conducted and some were eliminated because they did not meet the previously established standard for representativeness. Ultimately, 170 survey responses were used in the analysis. The overall yield percentage (i.e., the ratio of interviews conducted to survey responses used) was 78%, with several areas having yield percentages of 100%. In general, participants were enthusiastic to participate in the study.

In order to obtain a truly representative sample, not only was the geographic mix of projects intentionally diverse, but a diverse mix of participation was sought with respect to sector of industry,

Table 2. Distribution of Work Functions by Phase

Phase	Description	Number of work functions
1	Front end	6
2	Design	14
3	Procurement	12
4	Construction management	15
5	Construction execution	11
6	Startup, operations, & maintenance	10
Total	—	68

J. Constr. Eng. Manage., 2004, 130(3): 322-329

Table 3. Mix of Projects Analyzed

Population characteristic	Classes	Targeted mix (%)	Actual mix (%)	Deviation (+/−)
Industry Sector	Building	60	51.8	−8
Industry Sector	Industrial	20	23.4	+3
Industry Sector	Infrastructure	20	24.8	+5
TIC	<\$5 million	35	33.2	−2
TIC	\$5–20 million	30	29.4	−1
TIC	\$20–50 million	15	15.9	+1
TIC	\$50–100 million	10	11.7	+2
TIC	>\$100 million	10	9.8	0
Company type	Owner	25–40	36.0	0
Company type	GC	25–35	40.3	+5
Company type	A/E	20–30	23.7	0
Project typicality	Typical	90	85.2	−5
Project typicality	Advanced	10	14.9	+5

Note: TIC=total installed cost.

project size, company type, and project typicality. Individuals interested in participating in the study were identified by one of three methods: (1) A search in various online databases, (2) a search from various industry associations, or (3) a listing out of the local phone book. No single method of identifying study participants was dominant. Also, a specified mix of architect, contractor, and owner respondents was targeted (i.e., targeted mix) in order to obtain a representative sample of the industry. In other words, the sample should be proportionally representative of the population in terms of the population characteristics and classes. The targeted mix was established by published industry demographics data to help ensure that the sample sector distribution of projects reflected that of the population. The actual mix refers to the mix of project data obtained during the data collection phase. For example, the actual mix for advanced projects was obtained by calculating the proportion of advanced projects relative to typical projects. The mix of actual responses (i.e., actual mix) according to the population characteristics presented in Table 3 was within 5% of ideal mix as established by industry demographics except for one sub-population, the building sector.

Sampling Issues

Obtaining Representative Sample

Regarding how representative the 68 work functions are of all project types, the research work indicates that, except for Phase 6, the work functions are very representative of the breadth of projects. While Phase 6 (startup/operations/maintenance) work functions assessments include nearly 33% of "N/A" (i.e., not applicable) responses, only two other work functions ("fabricate roof trusses" and "manipulate and hang sheet rock") have such a response at 30% or higher frequency. This indicates that a significant majority of respondents found the work functions applicable to the wide variety of subject projects.

Dealing with Incomplete Data

Researchers attempted to ensure representative response data by establishing a rule regarding upper limits to the number of "don't know" work function assessments allowable for inclusion in data analysis. This helped ensure that sufficient knowledge was obtained about each phase of a project. In addition, a rule was established regarding lower limits to the number of phases (out of the total of six) that must contain sufficient data. This approach helped ensure that sufficient knowledge was obtained about the entire project in order to be truly representative of the actual project.

Technology Usage Metrics

Technology usage metrics analyzed include those at the phase level (phase technology usage), the project level (project technology usage), the task automation level (automation technology usage), the integration link level (integration technology usage), and those for industry-wide high-tech and industry-wide low-tech work functions. These indices were developed for measuring the use of IA technologies in the industry.

Phase Technology Usage

The Phase IA Index is a measure of the level of technologies used in a single phase of projects. In order to determine if the response data associated with a particular project and phase was adequate to be representative, a minimum response rate of 70% of all work functions associated with a phase was established as the criterion for acceptance. The equation for the phase response rate associated with any project and all phases is

$$\begin{aligned}\text{phase response rate} &= (\text{\# of phase work functions with 1/2/3 response}\\ &\quad + \text{\# of ``N/A'' responses for that phase})/\\ &\quad \text{Total \# of phase work functions}\end{aligned} \tag{1}$$

If a particular phase of a project did not meet the 70% rate criterion, then no phase index was computed for that phase. For any given work function, the assessed level of technology on the 1-2-3 scale was established as the work function score. The raw Phase IA index was then computed to equally weight all work function scores

$$\begin{aligned}\text{phase IA index (raw)} &= \text{sum of phase work function scores}/\\ &\quad (\text{total \# of phase work functions}\\ &\quad - \text{\# of phase ``N/A'' responses}\\ &\quad - \text{\# of phase ``don't know'' responses})\end{aligned} \tag{2}$$

To translate the raw index to a more familiar 0–10 score, the Phase IA index was computed in the following way:

$$\text{phase IA index} = (\text{raw phase IA index} - 1)*5 \tag{3}$$

Project Technology Usage

The Project IA index is defined as the average amount of integration and automation across several phases of a project. For the purpose of this study, a project's life cycle is structured in six phases. In establishing phase weight values, all weights were assumed to be uniform for simplicity and so as to not bias results. The survey was designed to include tasks that were thought to have substantial impact on projects. If indeed there is an association between technology usage and project success, one would

J. Constr. Eng. Manage., 2004, 130(3): 322-329

expect this association to be evident even with the application of uniform weights (Kumashiro 1999). Uniform weights were applied to phase weights on an initial basis. However, subsequent analyses could involve the application of nonuniform weights.

In order to compute a Project IA index, it was established that a project had to have at least three of six phase indices (each of which met the 70% rule). In addition, at least two of the phase indices had to pertain to either the design, construction management, or construction execution phases. This criterion was developed to ensure that Project IA index values adequately reflected project design and construction-related activities, which are of primary interest to the researchers.

Once these criteria were met, the index was computed as follows:

$$\begin{aligned}&\text{project IA index}\\&\quad=\text{sum of phase IA index scores/}\\&\qquad\#\text{ of phases with a computed index}\end{aligned}\tag{4}$$

Automation and Integration Technology Usage

The project task index is a measure of the level of technology used in task automation work functions of a project. The project link index is a measure of the level of technology used in integration link work functions. As stated previously, two types of work functions are included in the survey assessment form: TA work functions and task-to-task integration (or IL) work functions. Task automation refers to the technology level used in automating a work function (i.e., the use of a computerized tool to manipulate data or produce a product). Task-to-task integration link refers to the level of technology used in exchanging information between tasks (i.e., the sharing of information between project participants or melding of information sourced from separate systems).

Before project-level task and link indices can be computed, indices must be computed first at the phase level. Raw phase task indices and raw phase link indices are the computed averages of 1-2-3 scale responses associated with each of the respective task automation and integration link work function assessments in a single phase. Unlike the Phase IA indices, no response rate restrictions were applied in computing the phase task index and phase link index. The formulas for computation of the raw phase task index and phase link index are as follows:

$$\begin{aligned}&\text{phase task index (raw)}\\&\quad=\text{sum of all task automation work function scores/}\\&\qquad\text{total }\#\text{ of task automation work functions assessed}\\&\qquad\text{in that phase}\end{aligned}\tag{5}$$

$$\begin{aligned}&\text{phase link index (raw)}\\&\quad=\text{sum of all integration link work function scores/}\\&\qquad\text{total }\#\text{ of integration link work functions assessed}\\&\qquad\text{in that phase}\end{aligned}\tag{6}$$

Raw index values were then converted to a 0–10 score in a similar manner as before with the Phase IA index values. The project task index and project link index were then calculated as follows:

$$\begin{aligned}&\text{project task index}\\&\quad=\text{sum of phase task index values/}\\&\qquad\text{total }\#\text{ of phases with task indices}\end{aligned}\tag{7}$$

$$\begin{aligned}&\text{project link index}\\&\quad=\text{sum of phase link index values/}\\&\qquad\text{total }\#\text{ of phases with link indices}\end{aligned}\tag{8}$$

Technology Usage for Industry-Wide High-Tech Work Functions

The Industry-Wide High-Tech WF index is a measure of overall progress in automating the industry-wide high-tech work functions. Ranging from 6.70 to 5.29 in IA index value, the highest levels of technology usage pertain to the following ten work functions:

- Develop a milestone schedule from the scope of work;
- Use conceptual design work as a basis for detailed design work;
- Generate facility floor plans;
- Design the fluid transport system and related drawings;
- Design the structural system and related drawing;
- Design the electrical system and related drawings;
- Design the HVAC system and prepare related drawings;
- Prepare project specifications;
- Update the current cost forecast; and
- Monitor/track/control facility energy usage.

A raw index was computed to equally weight all associated work function scores and then was converted to a 0–10 score

$$\begin{aligned}&\text{industry-wide high-tech WF index (raw)}\\&\quad=\text{sum of all high-tech work function scores/}\\&\qquad\text{total }\#\text{ of high-tech work functions assessed}\\&\qquad\text{on that project}\end{aligned}\tag{9}$$

Technology Usage for Industry-Wide Low-Tech Work Functions

The industry-wide low-tech WF index is a measure of overall progress in automating the industry-wide low-tech work functions. Ranging from 1.43 to 2.28 in IA index value, the lowest levels of technology usage pertain to the following ten work functions:

- Get field input on construction methods and sequencing;
- Monitor fabricator progress;
- Plan transportation routes;
- Maintain a daily job diary;
- Link field material managers to suppliers;
- Communicate design changes to field personnel;
- Communicate status of change orders to field;
- Fabricate rebar cages;
- Manipulate/hang sheet rock; and
- Apply paint/coatings.

J. Constr. Eng. Manage., 2004, 130(3): 322-329

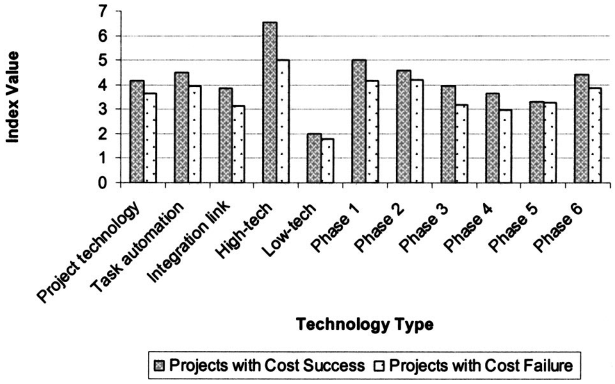

Fig. 1. Levels of technology usage versus cost performance for all projects

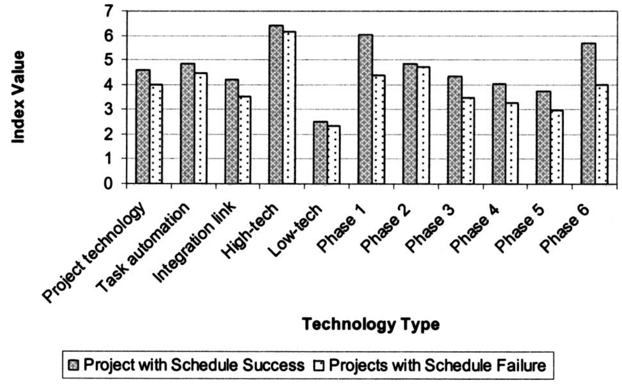

Fig. 2. Levels of technology usage versus schedule performance for all projects

A raw index was computed to equally weight all associated work function scores and then was converted to a 0–10 score

$$\text{industry-wide low-tech WF index (raw)} = \text{sum of all low-tech work function scores/ total \# of low-tech work functions assessed on that project} \quad (10)$$

Hypothesis Testing

An independent-samples t test was conducted to determine whether these data provide evidence for a significant difference in technology usage between projects with success and failure. The null hypothesis was that the IA index mean for projects with success equals the IA index mean for projects with failure. The alternative hypothesis stated that the means of the two independent groups are not equal. The independent-samples t test could not be performed when the assumptions underlying this test were violated. Therefore, a nonparametric alternative, called a Mann–Whitney U test, was also used to further evaluate the research hypotheses. The significance level for statistical tests was set equal to 0.10. Also, Bonferroni's correction was used to control experiment-wise type I error rate.

The decision about which test should be used is based on whether the assumptions underlying the test are met. Green et al. (2000) proposed the following guidelines for selection between a Mann–Whitney U test and an independent-samples t test:

- If the normality assumption is satisfied, an independent-samples t test is preferred;
- If the population distributions are symmetrical and flat, either a Mann–Whitney U test or an independent-samples t test could be used; and
- If the distributions are systematical but with thicker tails than a normal distribution, a Mann–Whitney U test should be used.

Analysis Results for Project Cost Success

Project cost success analyses focused on determining if a statistically significant difference exists between projects with cost success and failure in terms of their technology usage. Fig. 1 presents the levels of technology usage by project cost performance. The largest difference in levels of technology usage between projects with cost success and failure is associated with industry-wide high-tech work functions. Table 4 shows the results of the independent-samples t tests and indicates that technology usage for the high-tech work functions may contribute significantly to project cost success. The other technology usage did not produce statistically significant results. When the data were subdivided into their various categories, only some of the project types con-

Table 4. Impact of Technology Usage on Cost Success for All Projects

		Projects with cost success			Projects with cost failure						
Hypothesis number	Technology usage	Number	Index mean	Standard deviation	Number	Index mean	Standard deviation	Mean difference	t statistic	Significance (two-tailed)	Eta square
1	Project	24	4.16	1.73	14	3.66	2.00	0.50	—	—	—
2	Automation	25	4.48	1.68	16	3.93	2.03	0.55	—	—	—
3	Integration	25	3.85	2.01	16	3.12	2.31	0.73	—	—	—
4	High-tech	25	6.52	2.14	16	5.01	2.06	1.51	2.23	0.032	0.11
5	Low-tech	25	1.99	1.56	15	1.80	1.68	0.19	—	—	—
6	Phase 1	20	5.02	1.86	13	4.17	2.79	0.85	—	—	—
7	Phase 2	18	4.60	2.19	11	4.21	2.65	0.39	—	—	—
8	Phase 3	24	3.96	2.57	15	3.18	2.25	0.78	—	—	—
9	Phase 4	24	3.66	2.03	14	2.96	2.29	0.70	—	—	—
10	Phase 5	21	3.29	1.44	11	3.27	1.25	0.02	—	—	—
11	Phase 6	14	4.42	3.03	12	3.84	2.60	0.58	—	—	—

J. Constr. Eng. Manage., 2004, 130(3): 322-329

Table 5. Impact of Technology Usage on Schedule Success for All Projects

Hypothesis number	Technology usage	Projects with schedule success: Number	Index mean	Standard deviation	Projects with schedule failure: Number	Index mean	Standard deviation	Mean difference	t statistic	Significance (two-tailed)	Eta square
12	Project	18	4.60	1.85	19	3.98	1.75	0.62	—	—	—
13	Automation	18	4.84	1.99	21	4.47	1.77	0.37	—	—	—
14	Integration	18	4.20	2.04	21	3.53	2.31	0.67	—	—	—
15	High-tech	18	6.41	2.51	21	6.14	2.16	0.27	—	—	—
16	Low-tech	18	2.51	1.92	21	2.35	2.15	0.16	—	—	—
17	Phase 1	14	6.01	1.98	20	4.38	2.15	1.63	2.25	0.031	0.14
18	Phase 2	12	4.82	2.15	16	4.70	2.36	0.12	—	—	—
19	Phase 3	18	4.33	2.72	18	3.48	2.27	0.85	—	—	—
20	Phase 4	18	4.02	2.52	20	3.27	2.17	0.75	—	—	—
21	Phase 5	17	3.75	1.82	17	2.95	1.47	0.80	—	—	—
22	Phase 6	11	5.69	3.11	16	4.00	3.03	1.69	1.41	0.170	0.07

tained adequate sample sizes for analysis. However, the data did not produce statistically significant results when analyzed according to the five data class variables.

Analysis Results for Project Schedule Success

The focus of the project schedule success analyses was to determine if a statistically significant difference exists in levels of technology usage for different project schedule outcomes. Fig. 2 presents the levels of technology usage by project schedule performance. The largest differences in levels of technology usage between projects with schedule success and failure are associated with Phases 1 and 6. Table 5 presents the results of the independent-samples t tests. The test results indicate that technology usage in the front-end phase may contribute significantly to project schedule success. The other technology usage did not produce statistically significant results. When the data were subdivided into categories, only some of the project types contained sufficient sample sizes for analysis. Tables 6 and 7 show the results of the statistical tests by project type. The test results indicate that building projects achieve greater schedule success with increased technology usage, particularly integration, Phase 1 (front end), and phase 6 (startup/operations/maintenance) technology usage. The analyses also suggest that levels of technology usage are positively associated with expansion projects' levels of schedule success. In addition, technology usage in the front-end and construction execution phases may contribute to the schedule success of medium-sized projects. The data do not show statistically significant results for the other project types.

Conclusions

The purpose of this study was to quantify whether project success is impacted by use of technologies. This was accomplished by an industry-wide survey and analysis of more than 200 capital facility projects. Data were analyzed using appropriate statistical analysis techniques. The analyses suggest that several technologies make a significant contribution to a project's cost and schedule success, particularly for certain types of projects. Findings from this study are helpful to companies in deciding whether to adopt certain technologies.

Specific key findings are recapped as follows:

1. Project stakeholders usually decide among trade-offs in choosing whether to improve project cost or schedule performance. However, impacts of technology utilization on

Table 6. Results of t-Test by Project Type

Project type	Technology usage	Projects with schedule success: Number	Index mean	Standard deviation	Projects with schedule failure: Number	Index mean	Standard deviation	Mean difference	t statistic	Significance (two-tailed)	Eta square
Building	Project	6	5.36	1.46	7	3.02	0.51	2.34	3.98	0.002	0.59
Building	Integration	6	5.33	2.18	9	2.38	1.47	2.95	3.15	0.008	0.43
Building	Phase 6	5	7.29	2.71	6	3.37	2.52	3.92	2.48	0.035	0.41
Expansion	Project	5	4.56	0.38	8	3.36	0.68	1.20	3.55	0.005	0.53
Medium	Phase 1	10	6.20	1.55	16	4.28	2.37	1.92	2.27	0.032	0.18
Medium	Phase 5	12	4.14	1.78	13	2.93	1.32	1.21	1.94	0.064	0.14

Table 7. Results of Mann–Whitney U Test by Project Type

Project type	Technology usage	Projects with schedule success: Number	Mean rank	Sum of ranks	Projects with schedule failure: Number	Mean rank	Sum of ranks	z value	Significance (two-tailed)
Building	Phase 1	5	10.90	54.50	9	5.61	50.50	−2.30	0.019

J. Constr. Eng. Manage., 2004, 130(3): 322-329

project performance parameters can be different. The test results indicate that the schedule success-technology relationship is stronger than that for cost.
2. Higher levels of project cost success are associated with high levels of technology usage for industry-wide high-tech work functions.
3. Higher levels of project schedule success are particularly associated with high levels of technology utilization for building, medium-sized, and expansion projects.
4. Higher levels of project schedule success are associated with high levels of technology usage in the front-end phase, particularly for building and medium-sized projects.
5. For building projects, higher levels of project schedule success are associated with high levels of technology usage, particularly integration and phase 6 (startup/operations/maintenance) technology usage.
6. For medium-sized projects, higher levels of project schedule success are associated with high levels of technology usage in the construction execution phase.
7. For expansion projects, higher levels of project schedule success are associated with high levels of project technology usage.

Recommendations

Data sample size limited the analyses possible. Many statistical tests were not conducted due to small sample size, particularly for advanced and renovation projects. A larger number of project assessments should be involved in future similar data collection efforts to increase the reliability of the statistical tests. This could also lead to greater insights into the associations between technology usage and project success.

Other recommendations for future research are presented as follows:
1. For building projects, technologies contribute significantly to project schedule success. It would be worthwhile to investigate Building projects and their unique characteristics in further exploring determinants of project schedule success.
2. Consideration should be given to expanding the survey resolution for technology usage from three optional responses to four (i.e., none or only very common electronic tools, a few specialized electronic tools, several specialized electronic tools, and integrated electronic tools).
3. An objective for future study is to determine how the uses of IA technologies are changing over time. The data collection efforts discussed in this paper occurred between October 1998 and August 1999. In order to analyze changes over time, it is recommended that the study be repeated in the 2003–2004 timeframe.

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J. Constr. Eng. Manage., 2004, 130(3): 322-329