Impacts of Design/Information Technology on Project Outcomes

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Abstract: This paper describes a collaborative effort by industry, government, and academia to evaluate the use of design/information technology (D/IT) and to relate the degree of use to project performance. A detailed statistical analysis of 297 projects in the Construction Industry Institute database is used to produce baseline measures of performance and D/IT use. The relationship between these measures is used to assess the economic value of using the technologies. A set of projects that excelled in the use of D/IT and that scored high on performance measures is then examined. These exemplary projects provide a basis for further in-depth analyses through on-site interviews with key project representatives. The results of this study establish that projects benefit from D/IT use. Both owners and contractors can expect construction cost savings of approximately 4% by increasing the use of D/IT. For owners there is clear evidence of schedule compression as well. Although the statistical analyses do not support schedule compression benefits for contractors, findings from the on-site interviews provide anecdotal support.

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CE Database subject headings: Design; Information technology (IT); Performance; Project management.

Introduction

Although the evolution and deployment of design/information technologies will undoubtedly play an important role in the future of the construction industry, many stakeholders are still unsure of the economic value of using these technologies. Keen (1991) reported that senior managers believe that they would not continue information technology (IT) investment unless firm evidence on performance was established. A detailed, authoritative, and readily accessible body of information is therefore needed to enable construction industry stakeholders to make cost-effective investment decisions among established, new, and innovative design/information technologies (D/IT). Many researchers have emphasized the importance of quantitative measurements of the impact of IT investments (Sethi and King 1994; Simmons 1994; Back and Moreau 2000). Miyatake and Kangari (1993) reported that the lack of information hinders project participants from increasing their IT investment. Lucas and Weill (1993) also documented the need to measure and evaluate the economic value of IT.

The purpose of this paper is to fulfill these needs. Specifically, this paper provides authoritative support for the economic value of using both established as well as new and innovative D/IT within the construction industry. This investigation identifies and documents the benefits of using these technologies from actual project experiences. The Construction Industry Institute (CII) Benchmarking and Metrics (BM&M) database, which is composed exclusively of actual project execution experiences, provided a valuable basis for the development of this body of information. A number of projects, which successfully utilized these technologies, were selected for further in-depth investigation to develop a series of lessons learned.

Background

The study upon which this paper is based was sponsored by National Institute of Standards and Technology (NIST) and carried out in 1999; it consisted of two tasks (Thomas 1999). The first was a detailed statistical analysis of a broad cross section of projects from the CII BM&M database. This analysis produced baseline measures of performance and indicators of economic value. Industry norms were identified on five key outcomes: cost, schedule, safety, changes, and field rework. Norms were also established for the use of D/IT practices. D/IT practice use specifically measures the degree of use of four technologies: integrated database, electronic data interchange (EDI), three-dimensional (3D) computer-aided design (CAD) modeling, and bar coding (CII 1998, 1999; Thomas 1999; CII 2000b). Finally, the relationship between the degree of D/IT use and each of the five key outcomes was determined and documented. This statistical analysis, which was segregated by owners and contractors, was performed using data from U.S. domestic projects. Contractor data

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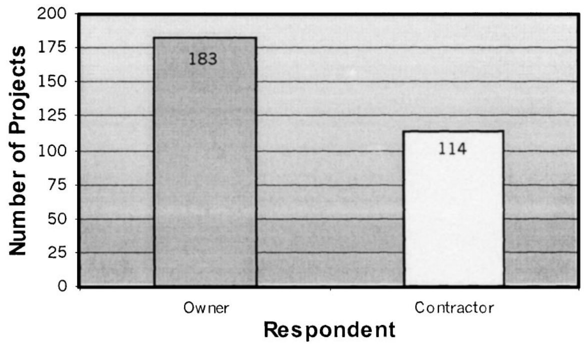

Fig. 1. Data set by respondent

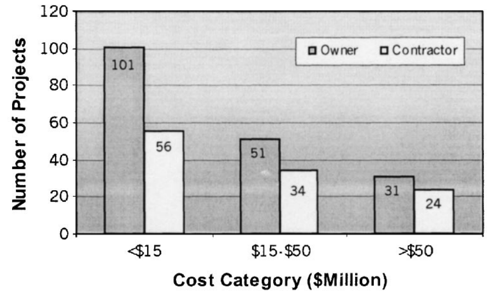

Fig. 3. Dataset by cost category

were used only for those projects on which contractors performed both design and construction tasks. The second task was the identification of a select set of "exemplary" projects for further, in-depth analyses. These projects were identified as exemplary based on their relatively high use of D/IT and high scores on project outcomes. Site visits were conducted with key representatives of each of these projects to identify common characteristics leading to their exemplary performance. These characteristics are summarized via anecdotal information, which are organized into a set of lessons learned. The results of Tasks 1 and 2 helped guide NIST's research efforts focused on early commercialization of construction integration and automation technologies (Chapman 2000).

Data Analysis

This paper examines U.S. domestic projects from versions 2.0 and 3.0 of the CII BM&M database surveyed in 1997 and 1998, respectively. Versions 2.0 and 3.0 included all projects in CII's database at the time of the study that included data on use of D/IT. A total of 297 projects were analyzed. A brief description of the data set is presented followed by tables summarizing average outcomes, degree of D/IT use, and the correlation between use and outcomes.

Description of Data Set

The analyses distinguish between owner and contractor data, as seen in Fig. 1. Data were further categorized by industry group, cost, and nature. As shown in Fig. 2, four industry groups are recognized: buildings, heavy industrial, infrastructure, and light industrial. Fig. 3 shows the three cost categories that were used. Each project was also classified by nature as add-on, grass roots, or modernization, as seen in Fig. 4. The analysis performed was limited in some cases by the distribution of projects in the data set. This was particularly true for infrastructure projects and projects greater than $50 million in cost. If a category contains less than 10 projects or if less than three companies submitted data, no statistical summaries are provided. This is consistent with the CII policy on confidentiality and in such cases the code "C.T." (confidentiality test) was inserted in the tables (CII 1998, 2000b).

Project Outcomes: Owners

Table 1 summarizes owner project outcomes for each analysis category. In this summary only mean values are shown. With the exception of the zero recordables and zero lost workdays percentages, lower values indicate better performance. The table reveals a number of important characteristics of these projects. First, the average cost, schedule, and safety performance of these projects is relatively good. Overall, the projects experienced cost growth of −2.6% and schedule growth of 4.5%. The safety metrics, recordable incident rate (RIR) of 2.184, and lost workday case incident rate (LWCIR) of 0.585 are well below industry averages for similar projects (CII 2000a). Forty-four percent (44%) of the projects reported no recordable incidents at all and nearly 78% reported no lost workday cases. Heavy industrial projects generally experienced better cost, schedule, and change performance than the other industry groups, although light industrial projects reported strong schedule growth performance as well. Building projects claimed the best overall safety performance. Within cost categories, the smaller projects reported generally better performance, although the differences are often very small. This finding is of particular interest since larger projects usually report greater use of performance enhancing practices. Other factors are likely contributing to the unexpectedly weak performance of larger projects. These projects are usually more complex, have greater personnel turnover, and are more frequently fast-tracked, all of which contribute to communication and control problems. Another rather surprising finding is the relatively strong performance

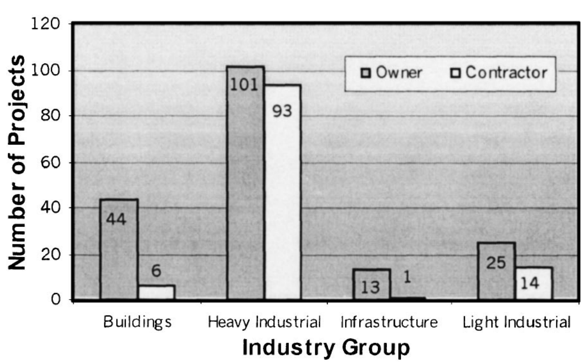

Fig. 2. Data set by industry group

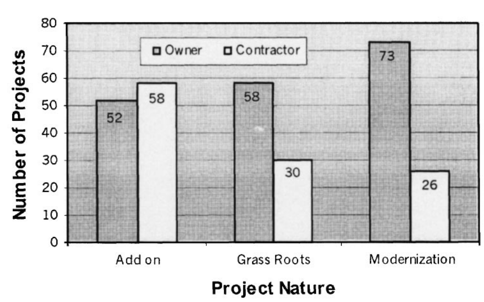

Fig. 4. Data set by project nature

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Table 1. Summary of Project Outcome: Owners

		By industry group				By cost category			By project nature		
Outcome metric	All owners	Building	Heavy industrial	Infrastructure	Light industrial	<$15	$15–$50	>$50	Add	Grass	Modern
Project cost growth	−0.026	−0.010	−0.043	0.009[a]	−0.003	−0.036	−0.013	−0.012	−0.028	−0.023	−0.026
Construction cost growth	−0.002	0.030	−0.031	0.029[a]	0.035	−0.016	0.016	0.010	0.000	0.010	−0.015
Startup cost growth	−0.093	C.T.	−0.172	C.T.	0.101[a]	−0.172	−0.091	0.033[a]	−0.137[a]	−0.010	−0.123
Construction phase cost factor	0.580	0.848	0.472	0.617[a]	0.544	0.605	0.556	0.543	0.521	0.684	0.538
Startup phase cost factor	0.025	C.T.	0.026	C.T.	0.029[b]	0.024	0.021	0.034[a]	0.021	0.027	0.027
Actual overall project duration	132	182	111	162[a]	109	127	137	143	109	155	130
Actual total project duration	96	141	76	114[a]	87	92	94	112	79	120	88
Construction phase duration	58	85	46	72[a]	49	51	63	74	48	74	52
Startup phase duration	7.65	9.93[a]	5.91	C.T.	13.05[a]	5.59	8.63	12.37[a]	7.34	11.50	5.72
Construction phase duration factor	0.446	0.471	0.405	0.558[a]	0.506	0.402	0.478	0.553	0.463	0.472	0.414
Startup phase duration factor	0.075	0.074[a]	0.055	C.T.	0.145	0.055	0.083	0.116	0.074	0.086	0.070
Project schedule growth	0.045	0.067	0.031	0.140[a]	0.014	0.070	0.007	0.021	0.031	0.067	0.039
Construction schedule growth	0.070	0.083	0.067	C.T.	0.026	0.066	0.055	0.107	0.054	0.090	0.066
Startup schedule growth	−0.044	−0.065[a]	−0.047	C.T.	0.039	−0.053	−0.033	−0.042	−0.033	−0.234	0.048
RIR	2.184	1.738[a]	2.096	C.T.	2.512	1.904	2.379	2.605	1.831	2.500	2.209
LWCIR	0.585	1.098[a]	0.489	C.T.	0.215	0.766	0.395	0.381	0.587	0.730	0.485
Zero recordables	44.0%	64.3%[a]	42.5%	C.T.	35.0%	66.1%	33.3%	4.2%	45.5%	27.3%	54.0%
Zero lost workdays	77.6%	81.3%[a]	77.5%	C.T.	76.2%	87.7%	78.8%	51.9%	77.8%	72.2%	81.1%
Change cost factor	0.054	0.066	0.039	C.T.	0.082	0.051	0.061	0.050[a]	0.055	0.053	0.054
Change schedule factor	0.056	0.057	0.054	C.T.	0.062[a]	0.051	0.068[a]	C.T.	0.049[a]	0.052	0.064
Field rework cost factor	0.054	0.058[a]	0.046	C.T.	0.070[a]	0.054	0.065	0.037[a]	0.048	0.044	0.067

Note: C.T.=confidentiality test, data not shown as per Construction Industry Institute confidentiality policy (less than 10 projects or data submitted by less than three companies); RIR=recordable incident rate; and LWCIR=lost workday case incident rate.

[a]Statistical warning indicator (less than 20 projects).

of add-ons and modernization projects versus the grass root projects. Given the complications often associated in the execution of these projects, one might expect grass root projects to show better performance. Grass root projects tend to be larger, however, and are subject to the performance hindering factors previously noted.

Project Outcomes: Contractors

Table 2 contains the outcome summary for contractor projects. Again, only mean performance values are shown. A majority of the data is from heavy industrial projects. The lack of data for the other three industry groups results in the frequent display of the

Table 2. Summary of Project Outcomes: Contractors

		By industry group				By cost category			By project nature		
Outcome metric	All contractors	Building	Heavy industrial	Infrastructure	Light industrial	<$15	$15–$50	>$50	Add	Grass	Modern
Project budget factor	0.951	C.T.	0.948	C.T.	0.946[a]	0.951	0.956	0.944	0.968	0.943	0.923
Project cost growth	0.041	C.T.	0.036	C.T.	0.048[a]	0.060	0.022	0.029	0.045	0.045	0.029
Construction cost growth	0.043	C.T.	0.041	C.T.	0.037[a]	0.019	0.076	0.037[a]	0.054	0.037	0.029[a]
Project schedule factor	0.969	C.T.	0.976	C.T.	0.939[a]	0.951	0.969	1.009	0.972	0.967	0.966
Construction phase duration	56	C.T.	56	C.T.	53[a]	42	58	76	54	63	50
Project schedule growth	0.025	C.T.	0.023	C.T.	0.019[a]	0.031	0.010	0.033	0.020	0.027	0.030
Construction schedule growth	0.055	C.T.	0.042	C.T.	0.095[a]	0.078	0.037	0.043	0.053	0.084	0.020
RIR	2.203	C.T.	2.073	C.T.	3.274[a]	1.856	2.531	2.223	2.497	1.553[a]	2.319[a]
LWCIR	0.093	C.T.	0.087	C.T.	C.T.	0.000	0.138	0.160[a]	0.080	0.112	0.096[a]
Zero recordables	25.7%	C.T.	24.6%	C.T.	18.2%[a]	20.8%	54.2%	0%	22.2%	26.3%[a]	33.3%[a]
Zero lost workdays	76.9%	C.T.	77.8%	C.T.	C.T.	100%	72.7%	52.6%	80.6%	65.0%	85.7%[a]
Change cost factor	0.084	C.T.	0.072	C.T.	C.T.	0.111	0.057	0.058	0.078	0.095	0.083
Change schedule factor	0.039	C.T.	0.035	C.T.	C.T.	0.037	0.041[a]	C.T.	0.036	0.041[a]	0.040[a]
Field rework cost factor	0.030	C.T.	0.028	C.T.	C.T.	0.035[a]	0.023[a]	0.033[a]	0.035	0.032[a]	C.T.

Note: C.T.=confidentiality test, data not shown as per Construction Industry Institute confidentiality polity (less than 10 projects or data submitted by less than three companies); RIR=recordable incident rate; and LWCIR=lost workday case incident rate.

[a]Statistical warning indicator (less than 20 projects).

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Table 3. Summary of Design/Information Technology (D/IT) Practice Use: Owners

D/IT	All owners	By industry group: Building	Heavy industrial	Infrastructure	Light industrial	By cost category: <$15	$15–$50	>$50	By project nature: Add	Grass	Modern
100%	7.88	6.97	7.88	3.40[a]	3.95	6.97	7.88	5.75	7.88	6.97	5.25
90%	3.64	1.60	4.63	1.88[a]	2.44	2.86	3.95	5.25	3.57	4.63	2.86
75%	1.79	0.73	2.44	1.25[a]	1.79	1.64	1.67	4.31	1.53	2.44	1.79
50%	0.75	0.06	1.10	0.50[a]	0.56	0.75	0.75	0.94	1.02	0.30	0.86
25%	0.00	0.00	0.25	0.00[a]	0.00	0.00	0.00	0.00	0.25	0.00	0.00
10%	0.00	0.00	0.00	0.00[a]	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0%	0.00	0.00	0.00	0.00[a]	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Mean	1.28	0.62	1.71	0.79[a]	0.99	1.10	1.31	1.84	1.36	1.34	1.19
Standard deviation	1.59	1.23	1.75	1.02[a]	1.15	1.27	1.73	2.13	1.56	1.88	1.35
n	183	44	101	13[a]	25	101	51	31	52	58	73

Note: The Appendix describes how the D/IT index is calculated.

[a]Statistical warning indicator (less than 20 projects).

confidentiality warning indicator, C.T. While cost performance for contractors was generally worse than that of owners, contractors did report slightly better schedule performance. Safety performance was split with owners reporting lower recordable rates and contractors lower lost workday rates. When making such comparisons, it is important to keep in mind the differences in the level of involvement between owners and contractors. Owners contribute to project performance throughout all phases; whereas, contractors contribute only for the phase or phases in which they perform work. Nevertheless, similar performance patterns were observed for cost categories and project nature as were observed for the owners. The more expensive projects generally underperformed the others, but the differences are rather small as was the sample size.

Design/Information Technology Practice Use: Owners

Owner mean D/IT practice use statistics are summarized in Table 3. The index specifically measures the degree of use of four technologies: integrated databases, EDI, 3D CAD modeling, and bar coding (CII 1998, 1999, 2000b). D/IT practice use was scored as an index on a 0–10 scale with 0 indicating no use and 10 indicating extensive use. For each technology, the questionnaire collects data on use of the technology for multiple applications and assesses D/IT use as an index score. The method of index calculation is presented in the Appendix. Since only one metric is depicted in the table, the number of observations for each category is provided in the last row. The positive correlation between project size and practice use typically observed throughout the CII database is apparent here as well (CII 1998, 1999, 2000b). Heavy industrial projects are generally larger projects, and as expected, reported higher use of D/IT. An interesting observation is the large number of projects reporting no use of the technologies. Typically, the bottom quartile in each category reported no use.

Design/Information Technology Practice Use: Contractors

On average contractor use of D/IT, as measured by the index in this survey, exceeded that of owners. This finding is consistent with results of the Task 2 analysis of exemplary projects. Meaningful data were only available for heavy industrial projects. As with the owner projects, larger projects made greater use of D/IT practices as indicated by the industry group, cost, and nature categories shown in Table 4. Grass root projects are normally larger than add-on and modernization projects, which likely accounts for their greater practice use.

Table 4. Summary of Design/Information Technology (D/IT) Practice Use: Contractors

D/IT	All contractors	By industry group: Building	Heavy industrial	Infrastructure	Light industrial	By cost category: <$15	$15–$50	>$50	By project nature: Add	Grass	Modern
100%	8.23	C.T.	8.23	C.T.	5.12[a]	4.56	7.03	8.23	7.99	8.23	5.94
90%	4.94	C.T.	5.06	C.T.	4.56[a]	2.50	5.12	7.58	4.56	6.83	4.66
75%	2.88	C.T.	3.31	C.T.	2.31[a]	1.74	3.06	5.18	2.75	3.75	2.15
50%	1.48	C.T.	1.67	C.T.	1.30[a]	0.69	1.84	3.80	1.38	2.04	1.36
25%	0.56	C.T.	0.66	C.T.	0.65[a]	0.00	1.19	1.52	0.37	0.64	0.41
10%	0.00	C.T.	0.00	C.T.	0.00[a]	0.00	0.00	1.16	0.00	0.12	0.00
0%	0.00	C.T.	0.00	C.T.	0.00[a]	0.00	0.00	0.24	0.00	0.00	0.00
Mean	2.01	C.T.	2.19	C.T.	1.68[a]	1.04	2.35	3.78	1.88	2.56	1.65
Standard deviation	1.99	C.T.	2.05	C.T.	1.56[a]	1.11	1.85	2.41	1.92	2.32	1.62
n	114	6	93	1	14[a]	56	34	24	58	30	26

Note: C.T.=confidentiality test, data not shown per CII confidentiality policy (less than 10 projects or data submitted by less than three companies). The Appendix describes how D/IT Index is calculated.

[a]Statistical warning indicator (less than 20 projects).

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Table 5. Relationship between Design/Information Technology Practice Use and Project Outcomes: Owners

	Design information use Low use↔High use					
	Investment stage		Benefit stage			
Outcome metric	4th	3rd	2nd	1st	Δ[1] No use to greatest benefit	Δ[2] Avg. invest. stage to greatest benefit
Project cost growth	_−0.020_	−0.020	_−0.034_	−0.028	0.014	0.014
Construction cost growth	_−0.008_	**0.065**	−0.010	_−0.047_	0.039	0.076
Startup cost growth	_−0.073_*	C.T.	_−0.100_*	−0.088	0.027	0.027
Construction phase cost factor	_0.644_	0.661	0.533	_0.491_	0.153	0.162
Startup phase cost factor	0.018*	0.017*	0.032	0.029	—	—
Actual overall project duration	_145_	138	126	_120_	25	21.5
Actual total project duration	_107_	**109**	90	_80_	27	28
Construction phase duration	_65_	64	53	_50_	15	14.5
Startup phase duration	_8.19_	**12.53***	_4.00_	8.57	4.19	6.36
Const. phase duration factor	_0.445_	**0.490**	0.431	_0.428_	0.017	0.040
Startup phase duration factor	_0.080_	**0.101***	_0.049_	0.085	0.031	0.042
Project schedule growth	_0.055_	**0.088**	_0.026_	0.030	0.029	0.046
Construction schedule growth	_0.089_	**0.099**	_0.035_	0.069	0.054	0.059
Startup schedule growth	_−0.039_	−0.063*	−0.001	_−0.076_	0.037	0.025
RIR	_3.015_	2.081	2.444	_1.439_	1.576	1.109
LWCIR	_0.529_	**1.017**	0.653	_0.238_	0.291	0.535
Zero recordables	53.8%	48.1%	39.3%	37.1%	—	—
Zero lost workdays	_80.0%_	69.0%	72.4%	_86.5%_	6.5%	12%
Change cost factor	0.051	0.044	0.056	0.064	—	—
Change schedule factor	_0.052_	0.048*	_0.049_*	0.081*	0.003	0.001
Field rework cost factor	_0.060_*	0.043*	_0.052_	0.059	0.008	—
Field rework schedule factor	C.T.	C.T.	C.T.	C.T.		

Note: C.T.=confidentiality test, data not shown as per Construction Industry Institute confidentiality policy (less than 10 projects or data submitted by less than three companies); RIR=recordable incident rate; LWCIR=lost workday case incident rate; *=statistical warning indicator (less than 20 projects); Δ[1]=maximum potential improvement from no use (4th quartile); Δ[2]=maximum potential improvement from average of investment stage (4th and 3rd quartiles); and bold indicates performance penalty for learning curve effect.

Relationship between Design/Information Technology Practice Use and Project Outcomes

The relationship between D/IT practice use and project outcomes for owner projects is presented in Table 5. The mean value for each outcome metric is provided for each quartile of D/IT practice use. Definitions for the outcome metrics and project phases can be found in the previous CII publications (CII 1998, 1999; Thomas 1999; CII 2000b). As D/IT use advances from 4th quartile (low use) to 1st quartile (high use), the outcome values would be expected to decrease reflecting improved performance with increased practice use. As a general rule, this is the observed case. In many instances, however, improvements in performance are not consistent with increases in practice use. Frequently, a decrease in performance is observed as companies initiate use of new technologies as shown in Fig. 5. This decrease in performance when moving from the 4th to 3rd quartile of D/IT use suggests a performance penalty associated with a learning curve for new technologies. Fourth quartile usage normally indicates no use as noted above in Tables 3 and 4. As projects advance beyond 3rd quartile usage, significant performance gains are experienced in the 2nd and 1st quartiles. The 4th and 3rd quartiles may be considered the investment stage where companies invest in new technologies and the 2nd and 1st quartiles the benefit stage where companies gain the benefits from use of the technologies.

Italics is used in Table 5 to illustrate the quartile of the investment stage with no use of the technologies (4th quartile) and the quartile in the benefit stage with the best performance. The difference in performance for these quartiles is shown in the first delta (Δ) column illustrating the greatest benefit expected from use of the technologies. The pattern of shading in the benefit stage is mixed, indicating that it may be possible to gain most of the benefits of these technologies when the project reaches the 2nd quartile of D/IT implementation. The bold values in the 3rd quar-

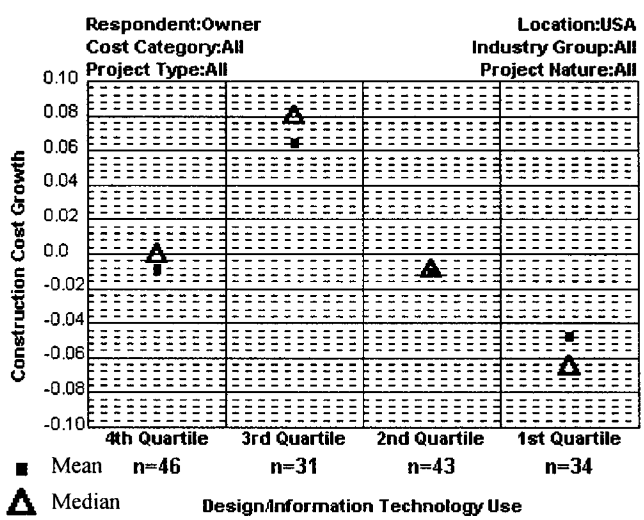

Fig. 5. Example design/information technology practice use versus construction cost growth: owners

Table 6. Relationship between Design/Information Technology Practice Use and Project Outcomes: Contractors

	Design/information use Low use↔High use					
	Investment stage		Benefit stage			
Outcome metric	4th	3rd	2nd	1st	Δ^1 No use to greatest benefit	Δ^2 Avg. invest. stage to greatest benefit
Project budget factor	_0.960_	0.953	_0.944_	0.946	0.016	0.013
Project cost growth	_0.040_	**0.099**	0.027	_0.010_	0.030	0.060
Construction cost growth	_0.054_	0.032*	0.080	_0.007_	0.047	0.036
Project schedule factor	0.964	0.954	0.979	0.979	—	—
Construction phase duration	46	48*	55	70	—	—
Project schedule growth	_0.040_	0.017	_0.016_	0.026	0.024	0.013
Construction schedule growth	_0.100_*	0.033*	0.066	_0.026_	0.074	0.041
RIR	_2.957_*	1.820*	2.291*	_1.829_	1.128	0.560
LWCIR	0.000*	0.077*	0.137*	0.163	—	—
Zero recordables	44.4%*	37.5%*	15.4%*	8.7%	—	—
Zero lost workdays	100%*	88.2%*	72.7%*	50.0%	—	—
Change cost factor	_0.076_	**0.137**	0.075	_0.045_	0.031	0.062
Change schedule factor	_0.028_*	**0.052***	_0.027_*	C.T.	0.001	0.013
Field rework cost factor	C.T.	C.T.	0.026*	0.024*	—	—
Field rework schedule factor	C.T.	C.T.	C.T.	C.T.	—	—

Note: C.T.=confidentiality test, data not shown as per Construction Industry Institute confidentiality polity (less than 10 projects or data submitted by less than three companies); RIR=recordable incident rate; LWCIR=lost workday case incident rate; *=statistical warning indicator (less than 20 projects); Δ^1=maximum potential improvement from no use (4th quartile); Δ^2=maximum potential improvement from average of investment stage (4th and 3rd quartiles); and bold indicates performance penalty for learning curve effect.

tile indicate those cases where the learning curve effect was observed. Since there is frequently a penalty for initial use of the technologies, a second delta column has been added illustrating the benefit obtained when moving from an average of the investment quartiles to the greatest benefit in the benefit stage. This is perhaps a more reasonable expectation of benefits to be achieved by use of these technologies.

Table 6 summarizes the relationship between D/IT use and performance outcomes for contractors. The specific outcome metrics for contractors are different in many cases from those of the owners. Table 6 also reveals the learning curve effect previously noted for owners; this is illustrated in Fig. 6 for contractors. This effect, although present, is not as pronounced as it was for owners.

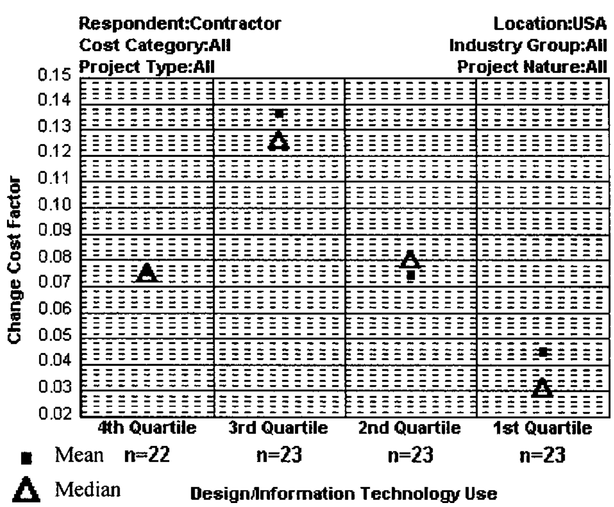

Fig. 6. Example design/information technology practice use versus change cost factor: contractors

A number of differences are apparent for owners and contractors from the analysis of Tables 5 and 6. Table 5 clearly indicates a reduction in construction and project duration with an increase in D/IT use. This is perhaps the most consistent observation in Table 5. Contractor data in Table 6, however, reveal the opposite for construction durations; here duration increases without fail with D/IT use. Overall and total project duration outcomes for contractors are not provided since their participation is limited to the phases of their contract. Safety and rework improvements experienced by owners with increased D/IT use also appear to elude contractors.

Exemplary Projects Analysis

Task 2 first required a definition of ‘‘exemplary projects’’ to permit selection of these projects and further analyses. After careful study of the Task 1 results, it was decided that these projects should be rated in the top quartile for use of D/IT and have demonstrated above-average cost, schedule, safety, change order, and rework performance. Examination of the data indicated that none of the top quartile projects in D/IT use had above-average performance for all five performance metrics. Projects ultimately selected, however, achieved above average ratings in at least three of the five outcomes (Spencer 1999).

As stated earlier, the CII survey for D/IT use evaluates the degree of use of four major technologies: bar coding, integrated databases, 3D CAD, and electronic data interchange (EDI). To be selected as an exemplary project, projects had to score high on the D/IT index and demonstrate a broad use of the technologies.

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Table 7. Summary of Design/Information Technology (D/IT) Use and Performance Outcomes for Exemplary Projects

Outcome metric	O1	O2	O3	CII owner average	C1	C2	C3	CII contractor average
Cost growth (%)	−15.7*	−18.8*	−5.5	−4.3	−8.5*	−11.1*	1.4	3.6
Schedule growth (%)	−9.0*	−7.2	−8.8*	3.1	−46.4*	3	0	2.3
Recordable incident rate	0.80	1.45	0.73	2.1	0.9	1.74	0.34*	2.07
Total field rework factor	0.025	0.02	0.006*	0.046	0.012*	0.047	0.041	0.028
Change cost factor	NA	0.002*	NA	0.039	NA	−0.063*	0.028	0.072
D/IT Use (0–10 scale)	*5.24**	*2.44**	*5.38**	*1.7*	*4.3**	*4.55**	*5.3**	*2.19*
Integrated database	X	N	X		X	X	X	
EDI	X	X	X		X	X	X	
3D CAD	X	X	X		X	X	X	
Bar code	X	S	N		X	X	X	

Note: CII=Construction Industry Institute; *=top quartile performance; NA=not available. Assessed degree of technology use: X=regular use; S=some use (1 or 2 applications); N=no reported use; EDI=electronic data interchange; and 3D CAD=three-dimensional computer-aided design.

Broad use was defined as use of at least three of the four technologies surveyed.

Ultimately, 11 projects with high D/IT index scores, broad D/IT use, and above-average performance were identified for further analysis. Although the objective was to select only five such projects, letters were sent to all 11 projects with the expectation that members of some project teams would no longer be available to participate in the study. To ensure the final sample was representative and yet homogeneous, a mix of owner and contractor projects from the same industry group was considered the optimal combination of projects. Six projects responded, agreeing to participate in the study. In a most fortunate situation, three of the projects were from owners and three from contractors and all were chemical projects from the heavy industrial group. Table 7 summarizes both performance outcomes and D/IT use for the projects selected. Owner projects are designated O1–O3 and contractor projects C1–C3. Table 8 provides descriptive data for these six exemplary projects.

After exemplary projects were selected, a letter was sent to the project manager or other designated project representative as a read-ahead to prepare the representative for an on-site interview. The objectives of the interview were identified and a telephone call was scheduled with each project representative to discuss the interview objectives and permit adequate preparation. Objectives established for the on-site interviews were to determine (Spencer 1999):

- How the technologies were used;
- In which phases of the project the technologies were used;
- If the technologies are still used by the companies;
- If use of the technologies has increased or decreased;
- Drivers for use of the technology;
- How the technology contributed to the project success; and
- Perceived benefits of using the technologies and any time or cost savings.

The interviews sought to obtain specific information concerning benefits and adverse impacts of using the technologies not identifiable through the CII questionnaire, which served as the basis for Task 1. Results of these interviews are summarized for each technology as reported uses, likely future uses, and lessons learned.

Findings

On-site interviews provided the following findings concerning the use of bar coding, integrated databases, 3D CAD, and EDI. For each technology, findings are summarized for current use, likely future use, and lessons learned. Current use is categorized as standard (routine) use and limited (isolated or less frequent) use.

Bar Coding

Each respondent was asked about the role of bar coding and its perceived impacts on their project. As listed in Table 9, standard current use includes employee badging for access control and timekeeping as well as material tracking. For these exemplary projects, the principal items tracked with the technology were structural steel and piping spools. Only one project reported use of the bar codes after the materials were received on site. In this case bar codes were scanned after the item was installed as a means of tracking progress. Some use of bar coding was also reported for tool control and inventory of small parts bins.

Bar coding use is likely to continue for present applications and expand for bill of materials tracking and progress reporting. Durability is an issue identified for bar code use. The handling, transport, and installation of materials often lead to damaged or missing codes.

Lessons learned in the use of bar coding indicate that at times, use of the technology may not be cost effective. Items requiring finishing, such as galvanizing or painting, present a problem since

Table 8. Descriptive Data for Exemplary Projects

Project	Type	Nature	Cost ($million)	Performance period	Construction duration	Location
O1	Chemical process	Grass roots	56.6	9/93–4/96	12	Texas
O2	Chemical process	Grass roots	66.4	3/95–2/97	13	Texas
O3	Chemical process	Grass roots	137.0	5/95–10/97	12	Texas
C1	Chemical process	Grass roots	41.6	10/94–3/96	12	Texas
C2	Chemical process	Addition	173.6	9/95–5/98	21	Mississippi
C3	Chemical process	Addition	156.4	11/94–5/97	16	Texas

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Table 9. Bar Coding Use and Lessons Learned

Type	Description
Standard use—current	• Employee badging • Time sheets—job coding, payroll • Material receipt/tracking
Limited use—current	• Inventory control • Tool control • Job progress reporting
Likely expanded use	• Bill of material coding • Job progress reporting/tracking
Lessons learned	• Cost not justified for tracking pipe spool ($/piece) • Time card abuse by employees

tags must be removed and reapplied throughout the process. Employee badging, the most common reported use of the technology, provided opportunities for abuse. In some instances employees were reported to have used the badges of absent employees to falsely report hours worked.

Integrated Database

Table 10 summarizes interview findings on the use of integrated databases. The most common reported use for integrated databases involved planning and design efforts. Although other applications of the technology such as material tracking and productivity reporting were frequently reported, these often were not recognized as uses of integrated databases. Application of the technology to support international design efforts is becoming increasingly popular and will likely contribute to significant future use of the technology.

Table 10. Integrated Database Use and Lessons Learned

Type	Description
Standard use—current	• For conceptual to final design phase by owners and contractors • Material tracking within the organization • Internal productivity reports, actual versus budget
Limit use—current	• During construction by owners and contractors • International design ‘‘links’’
Likely expanded use	• More international design • Owner/contractor links as security is improved
Lessons learned	• Software compatibility problems were experienced • Provided time and dollar savings for owners and contractors—for one international project, lower labor/operating costs made use feasible • Compatible capabilities by both owner and contractor are key to expanded use

Table 11. Three-Dimensional Computer-Aided Design (3D CAD) Use and Lessons Learned

Type	Description
Standard use—current	• Visualization • Interference checking • Layout • Material take-off • Fabrication drawings
Limited use—current	• Color coding design checks • Equipment feasibility/safety/time and cost studies • Piping • Structural • Electrical—conduits and cable trays, lighting • Concrete • Clearance zones for personnel and equipment • Equipment—pumps, tanks, etc.
Likely expanded use	• More components being added to design • Increased integration with engineering analysis software • For virtually all designs regardless of size/cost
Lessons learned	• Biggest savings result from reduced rework—one project reported rework was reduced by a factor of 10; use of 3D CAD to conduct interference checking reduced rework • Cycle time was reduced by more concurrent work as a result of faster shop fabrications resulting from downloads to suppliers • Eliminates need for plastic models • Cost savings were realized from precise material take-offs; one company reported a 30% savings in electrical material costs from elimination of restocking charges and leftovers • Familiarity with various software packages is essential • All components (essentially) must be in model to achieve accurate virtual lift analysis • Time savings result from use of virtual lifts—one projected attributed a 3 month savings to the virtual lift of a reactor; use of virtual crane lifts resulted in smoother field operations and reduced equipment standby time • Facilitates maintenance of as-built drawings for future expansions • Supports the need for as-built drawings simplifying modernizations • Design time is significantly reduced—time was reduced by 40% in one case reported • One PM indicated use was standard on all projects over $500,000 • Some design reviews are still performed on hard copy as it is often easier to visualize • One respondent reported total savings attributed to use of 3D CAD of approximately $5 million on a $230 million project

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Table 12. Electronic Data Interchange (EDI) Use and Lessons Learned

Type	Description
Standard use—current	• Electronic funds transfer • Purchase orders • Material releases
Limited use—current	• Transferring design specifications • Supplier alliances • Inspection reports to vendors
Likely expanded use	• Drawings and specifications transfer for bids • More alliances if contractors can overcome owner fears
Lessons learned	• EDI supports successful alliances with suppliers • Use promotes design efficiency: less over design, more likely to get exact product needed, material take-offs can be done by supplier, only exact inventory is paid for • Cost savings of several hundred thousand dollars was reported by one company due to use • Some companies are working towards 100% use of electronic specifications • System compatibility problems were experienced by some • Technology is commonly used when both parties have the capability and systems are compatible

Use of integrated databases presents important opportunities for cost savings and schedule compression. This is particularly true of international efforts where it is possible to maintain near continuous work for design activities by taking advantage of time zone differences. Compatibility problems due to differing computer systems and frequent software upgrades, however, can present many problems. Similar compatibility issues were noted for EDI and 3D CAD. Finally, to take greater advantage of the technology and have fully integrated databases, EDI and 3D CAD systems need to be integrated into the systems.

Three-Dimensional Computer-Aided Design

3D CAD was by far the most recognized application for D/IT for the exemplary projects studied. Project participants interviewed were more familiar with the applications of this technology than any of the others. Standard and more limited uses of the 3D CAD are summarized in Table 11. Most of the interview discussions centered on benefits of 3D CAD use. Due to the reduction in costs associated with the technology, companies are finding it feasible to include smaller elements of design in their models. As models become more comprehensive, both cost and schedule benefits increase. Reductions in rework were recognized as the biggest time and money savers. In one case, a company reported that rework was reduced by a factor of 10. The savings are often achieved through an improved ability to perform interference checking. All interviewed personnel reported that interference checking significantly reduced rework. Another recognized benefit of the technology relates to as-built drawings. Since there are relatively more add-on and modernization projects within the U.S., as-built drawings become increasingly important.

Other lessons learned from the interviews show that accurate material take-offs generated from 3D CAD drawings result in procurement and inventory savings. One project reported savings of 30% in electrical materials alone. Contractors with the ability to work with different programs have a competitive advantage. This is because owners frequently require contractors to use or be compatible with their existing software system. A final lesson learned concerns assembly or component fabrications. The ability to take portions of the model and electronically send them to fabricators saves time and money. After the shop generates isometric drawings and corresponding materials lists, these files can be electronically transmitted back to the designer for review.

Electronic Data Interchange

Table 12 describes standard use and lessons learned from electronic data interchange (EDI) use. EDI has become standard practice among the exemplary projects studied. Some confusion exists, however, on the definition of EDI. Although all of the exemplary projects reported use for fund transfers and purchase orders, those interviewed lacked specific information concerning the technology. In at least one case, the project representative considered e-mail to be EDI. An interesting application of EDI reported by two respondents involved contractor/supplier alliances. These projects reported EDI use in support of the alliances where the contractor used the technology to transmit design details directly to the supplier, enabling time savings and greater accuracy in the selection of components. In one case, EDI was used to provide timely inspection results to suppliers.

As with most of the other technologies surveyed, compatibility remains an issue for expanded EDI use. One user reported frequent software upgrades to be a problem. For more widespread use, alliance members need to standardize on compatible systems. Despite these obstacles, substantial savings are being achieved through use of EDI. In one case, a contractor reported savings of several hundred thousand dollars credited to EDI use.

Other Technologies

An additional benefit realized from the on-site visits was the opportunity to obtain first-hand information on other applications of the four technologies not identified through the CII questionnaire and information on other technologies being used. Noteworthy here is the application of photogrammetry to further enhance the benefits of 3D CAD systems. With this technology, photographs of system components are incorporated into 3D CAD drawings, reducing preparation time and improving accuracy. Another technology being used, but not included in the survey, is computer-aided engineering (CAE), whereby systems are designed with the aid of computer systems, not merely drawn.

A number of conclusions can be made from the Task 2 interviews. In general, contractors lead owners in the implementation of these technologies. Although there was no direct inquiry made to support this finding, this conclusion from the field interviews is supported by results of the statistical analyses summarized in Tables 3 and 4. Second, the size of the project is the single most important characteristic in determining the degree of D/IT use. This conclusion was also confirmed by the statistical analyses. While benefits were realized from the use of all technologies surveyed, 3D CAD was perceived as providing the most significant impact on project outcomes. Anecdotal information gathered supports improvements in schedule compression, cost savings, and safety performance due to use of these technologies. Finally, a lack of system compatibility, standardization, and user friendliness were most often cited as barriers to further implementation of these and other technologies.

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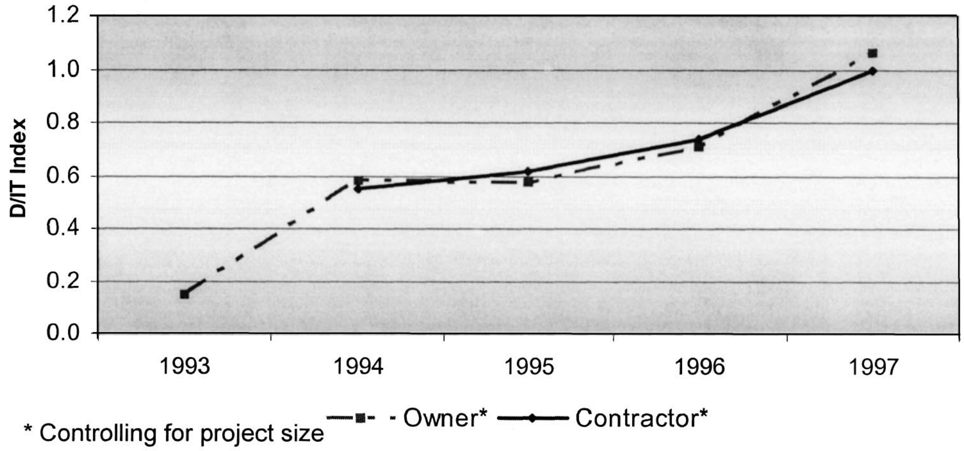

Fig. 7. Design/information technology (D/IT) use

Synthesis of Findings

Implementation of Design/Information Technology

The Task 2 interviews revealed continued or expanded use of the four technologies surveyed. Only one case indicated that the cost of using the technology was not justified. The expanded use finding is consistent with trend analyses performed by analyzing D/IT use by year for the same data set used in Task 1. Fig. 7 clearly indicates for both owners and contractors that use of these technologies has increased with time. To prepare this chart, the degree of D/IT use was assessed for each project and then standardized for a common sized project to control the impact of declining project sizes throughout the analysis period. Fig. 7 was prepared while controlling for a consistent decline in project size from 1993 to 1997, the performance period of the projects in the analyses. Since project size is the most important factor in determining the degree of D/IT use, Fig. 7 reflects the degree of use per dollar of project cost standardized for a $10 million project. In this manner the impact of decreasing project size is controlled while assessing the trend in D/IT use. This step is warranted in light of the obvious correlation between project size and D/IT use apparent in Tables 3 and 4.

Task 2 findings confirm that the single most important factor in the degree of use of D/IT is the project size. This is consistent with results of the statistical analyses. In all but one case, the >$50 million cost category reported more use than the smaller project categories for both owners and contractors, as shown in Tables 3 and 4. Since the cost of these technologies is decreasing significantly each year, the trend shown in Fig. 7 is likely to continue. Also contributing to increased practice use are changes in project team members. As new members join the project team, many of whom are more familiar with information technology, resistance to adoption of these technologies is decreasing.

Fig. 7 also helps to clarify the relative degree of practice use for both owners and contractors. An examination of practice use data in Tables 3 and 4 would indicate contractors are ahead of owners in implementing D/IT. Not only mean, but most percentile values for D/IT use for contractors exceed those of owners. Results in these tables are consistent with findings from the on-site interviews. During these interviews, contractors appeared to report greater use than owners. The key to the apparent discrepancy lies in the size of the projects. The average size of contractor projects, $50 million, exceeds the $40 million average for owners in the CII database.

Another question of interest is "Who reaps the greater benefit for implementing these technologies?" A comparison of owner and contractor data on potential performance gains from increased use of these technologies shown in Tables 5 and 6 provides a means of answering the question. Comparing the delta for owners and contractors indicates that contractors would appear to benefit more in cost savings, whereas owners gain most in safety. The results for schedule, changes, and rework are mixed.

Impacts of Design/Information Technology Use on Outcomes

Data summarized in Tables 5 and 6 clearly indicate a relationship between increased use of these technologies and better project performance. Anecdotal information from the on-site interviews provided several examples where use of 3D CAD and EDI resulted in savings from several hundred thousand dollars to $5 million (Spencer 1999). Thus strong evidence is available to support improved cost performance from use of D/IT (Thomas 1999; Lee 2001).

There is equally strong evidence to indicate that use of these technologies also contributes to schedule compression. Larger projects would logically be expected to report longer durations. Larger projects also make greater use of D/IT as previously noted (reference Tables 3 and 4). Table 5, however, reveals that projects using those technologies have shorter average durations. This table shows consistent reductions in both overall project and construction durations with increased use of D/IT. There clearly must be some schedule compression involved that results in reduced durations as project sizes increase. Of particular interest, however, is that this trend is not observed for contractor projects (Table 6). The compression apparent for owners may be related to their broader role in the project and benefits gained from use of D/IT throughout all phases. Contractor data, however, are for those contractors performing both design and construct functions.

Impacts on safety performance are also mixed. Owners obtain quantifiable safety benefits, whereas for contractors the impact is less obvious. The relatively small contractor sample for safety data apparent in Table 2 may affect these findings. Finally, during the on-site visits, significant benefits were reported in reduced rework. The statistical analyses, however, fail to confirm this benefit to the larger data sample. The relative lack of rework data indicated by Tables 5 and 6 renders the sample impractical for rework analysis.

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Conclusion

This study produced some significant findings. First, the use of D/IT and project performance is positively correlated. Projects reporting greater use of the technologies usually report much better performance. Both owners and contractors continue to increase the use of the technologies and both realize meaningful benefits. Owners, however, appear to obtain a broader range of benefits. This result is likely related to their larger role in the project. Second, project size is the single most important factor for determining the degree of use for these technologies on most projects. Fortunately, as the cost of implementing these technologies continues to fall, it is likely that there will be increased use on smaller projects.

Third, there is a risk for companies as they begin implementing D/IT on their projects. A pronounced learning curve effect is noticeable in many cases, resulting in performance penalties, which may reflect the costs and schedule impacts as team members experiment with the technologies. The rewards for those that achieve higher degrees of implementation, however, more than offset these risks. Finally, most benefits of use will be realized by moving to the top half as scored by the CII D/IT index. It is not necessary to become a 1st quartile user, as overall performance differences between the 1st and 2nd quartiles are not significant.

Acknowledgment

The study upon which this paper is based was sponsored by the National Institute of Standards and Technology (NIST) under Contract No. 43NANB813178.

Appendix: Calculation of Design/Information Technology Use Index

	Use levels						
	Extensive use			No use			
	1	2	3	4	5	N/A	*Score*
Integrated database applications used							
Facility planning	1.00	0.75	0.50	0.25	*0.00*	—	0.00
Design/engineering	1.00	*0.75*	0.50	0.25	0.00	—	0.75
3D CAD model	1.00	0.75	*0.50*	0.25	0.00	—	0.50
Procurement/suppliers	1.00	0.75	0.50	0.25	*0.00*	—	0.00
Material management	1.00	0.75	0.50	0.25	*0.00*	—	0.00
Construction operations/project controls	1.00	0.75	0.50	0.25	*0.00*	—	0.00
Facility operations	1.00	0.75	0.50	0.25	*0.00*	—	0.00
Administrative/accounting	1.00	0.75	0.50	0.25	*0.00*	—	0.00
EDI applications used							
Purchase orders	1.00	0.75	0.50	0.25	*0.00*	—	0.00
Material releases	1.00	0.75	0.50	0.25	*0.00*	—	0.00
Design specifications	1.00	0.75	0.50	0.25	*0.00*	—	0.00
Inspection reports	1.00	0.75	0.50	0.25	*0.00*	—	0.00
Fund transfers	*1.00*	0.75	0.50	0.25	*0.00*	—	1.00
3D CAD modeling applications used							
Define/communicate project scope	1.00	0.75	0.50	0.25	*0.00*	—	0.00
Perform plant walk-throughs (replacing plastic models)	1.00	0.75	0.50	0.25	*0.00*	—	0.00
Perform plant operability/maintainability analyses	1.00	0.75	0.50	0.25	*0.00*	—	0.00
Perform constructability reviews with design team	1.00	0.75	*0.50*	0.25	0.00	—	0.50
Use as reference during project/coordination meetings	1.00	0.75	0.50	*0.25*	0.00	—	0.25
Work breakdown and estimating	1.00	0.75	0.50	0.25	*0.00*	—	0.00
Plan rigging or crane operations	1.00	*0.75*	0.50	0.25	0.00	—	0.75
Check installation clearances/access	1.00	*0.75*	0.50	0.25	0.00	—	0.75
Plan and sequence construction activities	1.00	0.75	*0.50*	0.25	0.00	—	0.50
Construction simulation/visualization	1.00	0.75	0.50	*0.25*	0.00	—	0.25
Survey control and construction layout	1.00	0.75	0.50	0.25	*0.00*	—	0.00
Material management, tracking, scheduling	1.00	0.75	0.50	0.25	*0.00*	—	0.00
Exchange information with suppliers/fabricators	1.00	0.75	0.50	0.25	*0.00*	—	0.00
Track construction progress	1.00	0.75	0.50	0.25	*0.00*	—	0.00
Visualize project details or design changes	1.00	0.75	*0.50*	0.25	0.00	—	0.50
Record "as-built" conditions	1.00	0.75	0.50	0.25	*0.00*	—	0.00
Train construction personnel	1.00	0.75	0.50	0.25	*0.00*	—	0.00
Safety assessment/training	1.00	0.75	0.50	0.25	*0.00*	—	0.00
Plan temporary structures (formwork, scaffolding, etc.)	1.00	0.75	0.50	0.25	*0.00*	—	0.00
Operation/maintenance training	1.00	0.75	0.50	0.25	*0.00*	—	0.00
Turn-over design documents to the project owner	1.00	0.75	0.50	0.25	*0.00*	—	0.00
Startup planning	1.00	0.75	0.50	0.25	*0.00*	—	0.00

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Bar coding applications used							
Document control	1.00	0.75	0.50	0.25	*0.00*	—	0.00
Materials management	1.00	0.75	0.50	0.25	*0.00*	—	0.00
Equipment maintenance	1.00	0.75	0.50	0.25	*0.00*	—	0.00
Small tool/consumable material control	1.00	0.75	0.50	0.25	*0.00*	—	0.00
Payroll/timekeeping	1.00	0.75	0.50	0.25	*0.00*	—	0.00
TOTAL							5.75
40 questions, maximum score of 40⇒divide total by 4 to scale to 1–10 point range							
Design/information technology practice use index							1.44

Note: 3D CAD=three-dimensional computer-aided design; and EDI=electronic data interchange.

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