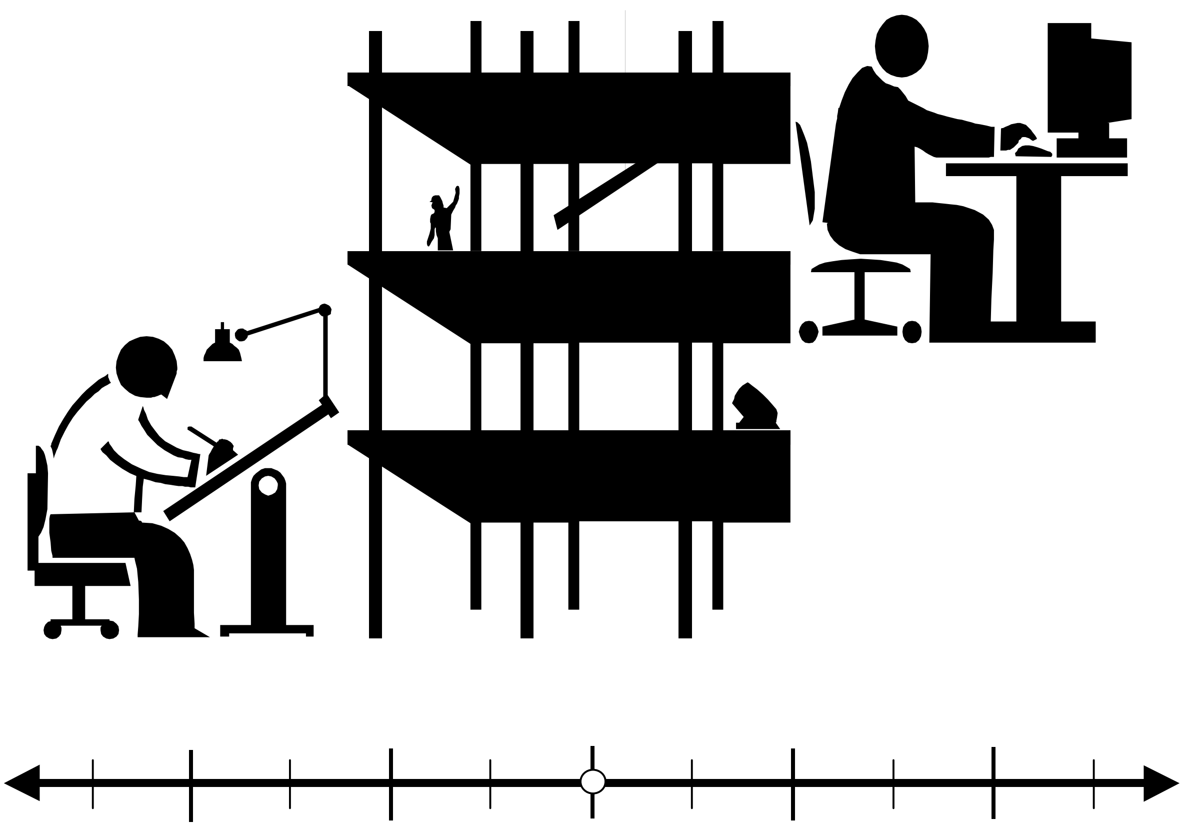
NIST GCR 99-786

U.S. DEPARTMENT OF COMMERCE
Technology Administration
National Institute of Standards and Technology

Office of Applied Economics
Building and Fire Research Laboratory
Gaithersburg, Maryland 20899-8603

Impacts of Design/Information Technology on Project Outcomes

Stephen R. Thomas



NIST GCR 99-786

Impacts of Design/Information Technology on Project Outcomes

Stephen R. Thomas
Construction Industry Institute
3208 Red River Street, Suite 300
Austin, TX 78705-2697

Prepared for
Robert E. Chapman
Office of Applied Economics
Building and Fire Research Laboratory
National Institute of Standards and Technology
Gaithersburg, MD 20899-8603

Under Contract 43NANB813178

January 2000

U.S. DEPARTMENT OF COMMERCE
William M. Daley, Secretary

TECHNOLOGY ADMINSTRATION
Dr. Cheryl L. Shavers, Under Secretary of Commerce for Technology

NATIONAL INSTITUTE OF STANDARDS AND TECHNOLGOY
Raymond G. Kammer, Director

Foreword

The National Institute of Standards and Technology (NIST) is improving its resource allocation process by doing "microstudies" of its research impacts on society. This report, prepared for NIST by the Construction Industry Institute (CII), is a source document for one of a series of microstudies prepared by NIST's Building and Fire Research Laboratory (BFRL). Specifically, this report provides empirical data and anecdotal information useful in estimating the economic impacts of BFRL's FIATECH (fully-integrated and automated project process systems and technologies) major product.

Information and automation technologies are core components of the strategic plans of the U.S. construction industry. The U.S. chemical industry identifies information systems as a key technical discipline in its *Technology Vision 2020* and predicts achieving the smooth flow of information—from concept through design to construction and into plant maintenance and operation—will promote the use of automation and improve economic competitiveness. CII's *1999 Strategic Plan* identifies six major industry trends that will shape the construction industry in the next century. CII identified fully-integrated and automated project processes (FIAPPs) as the most significant trend and predicts it will revolutionize the construction industry. Characteristics of FIAPP products and services include one-time data entry; interoperability with rules-based design, construction, and operation processes; and user friendly input/output techniques.

The FIATECH major product is an interdisciplinary research effort within BFRL—in collaboration with CII, the private sector, other federal agencies, and other laboratories within NIST—to develop key enabling technologies, standard communication protocols, and advanced measurement technologies needed to deliver FIAPP products and services to the construction industry. The goal of BFRL's FIATECH major product is to produce products and services that will result in significant reductions in ***both*** the delivery time of constructed facilities ***and*** the life-cycle costs of those facilities. These products and services are being developed for use by building owners and operators, construction contractors, architects, engineers, and other providers of professional services.

The research described in this report focuses on four key design/information technologies. These technologies are: (1) bar coding; (2) integrated databases; (3) 3D CAD (computer-aided design) systems; and (4) EDI (electronic data interchange). These technologies were selected for evaluation for two reasons. First, they are core components of the FIAPP products and services currently under development. Consequently, understanding how the use of these technologies affects key project outcomes (i.e., cost, schedule, and safety) provides a set of lower-bound estimates of the benefits and cost savings that can be expected from the use of FIAPP products and services once they become available commercially. Second, these technologies are covered as part of CII's annual survey of its membership. The results of the annual survey are compiled by CII and tabulated in its Benchmarking and Metrics database. By using the Benchmarking and Metrics database, CII was able to measure empirically the economic value of using established, as well as new and innovative design/information technologies within the non-residential sectors of the construction industry (i.e., commercial/institutional buildings, industrial facilities, and infrastructure projects).

The research effort described in this report includes: (1) a statistical analysis of a broad cross-section of projects from the CII Benchmarking and Metrics database; (2) a case-by-case analysis of “exemplary” projects selected from the CII Benchmarking and Metrics database; and (3) a synthesis of findings. This three-pronged approach is designed to provide the reader with an understanding of the current use of design/information technologies, how their use affects project outcomes, and how to successfully integrate design/information technologies into the delivery process for construction projects.

Robert E. Chapman
Office of Applied Economics
Building and Fire Research Laboratory
National Institute of Standards and Technology
Gaithersburg, MD 20899-8603

Abstract

This study sponsored by the National Institute of Standards and Technology (NIST) represents 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. The study was accomplished by the Construction Industry Institute (CII) staff using data from its Benchmarking and Metrics (BM&M) database and feedback from on-site interviews with representatives of select high performing projects.

The CII database reflects the actual project experiences from more than 700 projects from 64 member companies and organizations. Data in the database has been systematically collected during annual data collection cycles since 1996 to support the benchmarking of construction industry performance norms and to measure the degree of practice use. Only US domestic projects were selected for this study and data were segregated by owners and contractors. Contractor data were further screened by selecting only those projects for which contractors performed both design and construction activities.

The study consists of three tasks. The first was a detailed statistical analysis of select projects in the CII database. This analysis produced baseline measures of performance and D/IT use and then established the correlation between these measures to assess the economic value of using the technologies. For the second research task, a set of projects that excelled in the use of D/IT and that scored high on performance measures was identified. These "exemplary" projects provided a basis for further in-depth analyses through on-site interviews with key project representatives. Common characteristics of these projects were summarized via anecdotal information and included in this report as a set of lessons learned. This report, which synthesizes findings of the statistical analyses and on-sight interviews, is the product of the third study task.

The results of this study establish that projects benefit from D/IT use. Both owners and contractors can expect overall project cost savings of approximately 1.4 percent and construction cost savings closer to 4 percent 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 exemplary project interviews provide anecdotal support. According to these interviews, D/IT use contributed to faster shop fabrications resulting in reductions in overall construction time. Additional schedule benefits were reported by those using D/IT for computer modeling, which led to reductions in rework, further shortening required construction time.

Keywords

Design/information technologies; practice use; performance norms; cost benefits; schedule compression; economic value; project outcomes; technology implementation; lessons learned; bar coding; 3D CAD; EDI; integrated database

Table of Contents

List of Tables

List of Figures

1 Introduction

1.1 Background

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. A detailed, authoritative, and readily accessible body of information is needed to enable construction industry stakeholders to make cost-effective investment decisions among established, new, and innovative design/information technologies. The Construction Industry Institute (CII) Benchmarking and Metrics (BM&M) database, which is composed exclusively of actual project execution experiences, provides a valuable basis for the development of this body of information.

CII is a unique consortium of owners, designers, builders, and universities formed to improve the capital project delivery process. Its research is a collaborative effort between industry and academic researchers. Ongoing research at CII has produced a database for benchmarking construction industry performance norms and practice use. The database includes over 700 projects from 64 member companies and organizations. This National Institute of Standards and Technology (NIST) initiative to evaluate the use of design/information technology and relate the degree of use to project performance made use of the CII database. The findings from this data analysis led to the selection of six projects demonstrating significant use of these technologies and superior project performance for more in-depth analyses as a follow-on task of the research.

1.2 Purpose

The purpose of this research was to measure and evaluate the economic value of using established, as well as new and innovative design/information technologies (D/IT) within the construction industry. Specifically, this investigation identified and documented the benefits of using design/information technologies from actual project experiences. A number of projects, which successfully utilized these technologies were selected for follow-on research to develop a series of lessons learned.

1.3 Scope and Approach

This research effort consisted of three tasks specified by NIST. The first was a detailed statistical analysis of a broad cross-section of projects from the CII Benchmarking and Metrics 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 design/information technology practices. Finally, the correlation of design/information technology degree of use with the use of other “best” practices and with each of the five key outcomes was determined and documented.

This statistical analysis, which is segregated by owners and contractors, was performed using data from US domestic projects. Contractor data were used only for those projects on which contractors perform both design and construction tasks. Analyses and chart types, consistent with the standard chart types produced by the CII BM&M Committee were specified by NIST. Table tabulations include descriptive and statistical summaries also specified by NIST. Although the CII database contains data for three versions of its questionnaire, only data from versions 2.0 and 3.0 were included. The version 1.0 questionnaire did not address design/information technology use.

The second research 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 design/information technologies 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 were summarized via anecdotal information and this information was organized into a set of lessons learned.

The final task of this research was the development of this report, which summarizes and synthesizes the findings of Tasks 1 and 2. Baseline measures of performance are discussed and key measures of economic value identified. And finally, the lessons learned from the exemplary projects are presented with discussion concerning their application to future projects.

2 Summary of Task 1 - Statistical Analysis

This section provides a summary of the statistical analyses for the 297 projects meeting the criteria specified by NIST. 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.

2.1 Description of Data Set

The study was restricted to U.S. domestic projects for which data were collected on D/IT use. Owner and contractor data were segregated for analyses and contractor projects were included only if they performed both design and construction tasks. Data were further categorized by industry group, cost, and nature. Four industry groups were recognized: buildings, heavy industrial, infrastructure, and light industrial and three cost categories were used as shown in the charts below. Each project was also classified by nature as add-on, grass roots, or modernization. Breakouts showing the number of owner and contractor projects for each category follow.

Figure 2-1. Data Set by Respondent

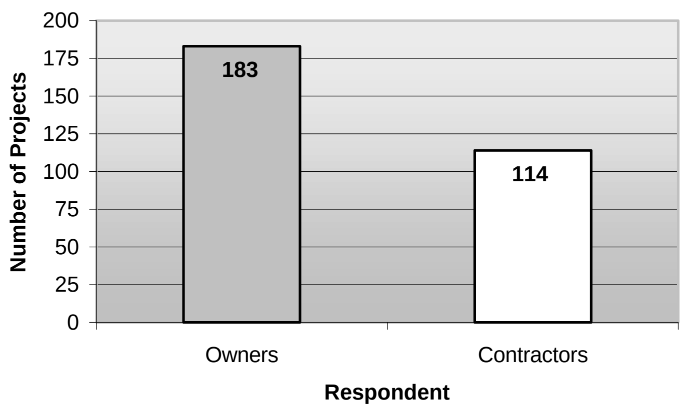


Figure 2-2. Data Set by Industry Group

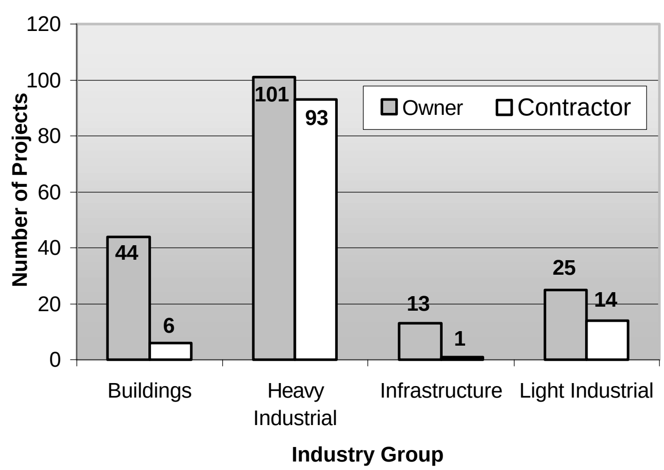


Figure 2-3. Data Set by Cost Category

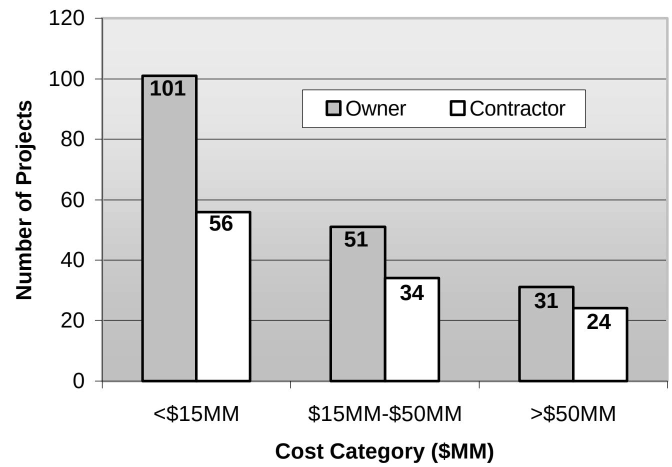
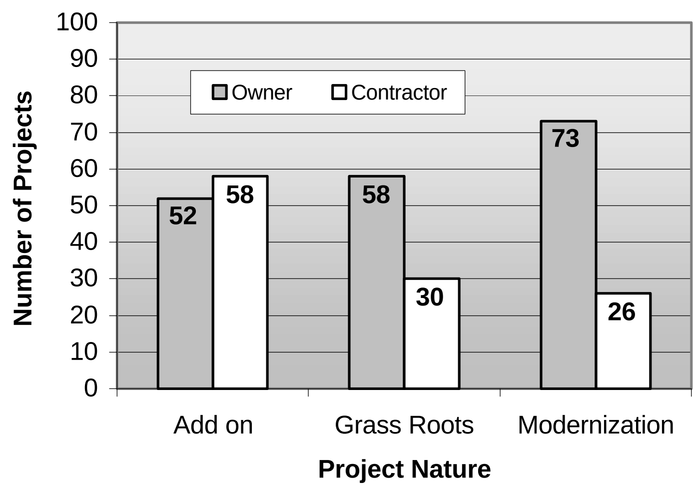


Figure 2-4. Data Set by Project Nature



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. When there were less than 10 projects available in a category or when less than 3 companies submitted the 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.

2.2 Project Outcomes – Owners

Table 2-1 summarizes owner project outcomes for each analysis category. In this summary only mean values are shown. The table reveals a number of important

Table 2-1. Summary of Project Outcomes – Owners

Outcome Metric[1]	All Owners	By Industry Group[n]				By Cost Category			By Project Nature		
		Bldg	H.I.	Infra	L.I.	<$15	$15-$50	>$50	Add	Grass	Modern
Project Cost Growth	-0.026	-0.010	-0.043	0.009*	-0.003	-0.036	-0.013	-0.012	-0.028	-0.023	-0.026
Construction Cost Growth[2]	-0.002	0.030	-0.031	0.029*	0.035	-0.016	0.016	0.010	0.000	0.010	-0.015
Startup Cost Growth[2]	-0.093	C.T.	-0.172	C.T.	0.101*	-0.172	-0.091	0.033*	-0.137*	-0.010	-0.123
Construction Phase Cost Factor[2]	0.580	0.848	0.472	0.617*	0.544	0.605	0.556	0.543	0.521	0.684	0.538
Startup Phase Cost Factor[2]	0.025	C.T.	0.026	C.T.	0.029*	0.024	0.021	0.034*	0.021	0.027	0.027
Actual Overall Project Duration	132	182	111	162*	109	127	137	143	109	155	130
Actual Total Project Duration	96	141	76	114*	87	92	94	112	79	120	88
Construction Phase Duration[2]	58	85	46	72*	49	51	63	74	48	74	52
Startup Phase Duration[2]	7.65	9.93*	5.91	C.T.	13.05*	5.59	8.63	12.37*	7.34	11.50	5.72
Const. Phase Duration Factor[2]	0.446	0.471	0.405	0.558*	0.506	0.402	0.478	0.553	0.463	0.472	0.414
Startup Phase Duration Factor[2]	0.075	0.074*	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*	0.014	0.070	0.007	0.021	0.031	0.067	0.039
Construction Schedule Growth[2]	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[2]	-0.044	-0.065*	-0.047	C.T.	0.039	-0.053	-0.033	-0.042	-0.033	-0.234	0.048
R.I.R.	2.184	1.738*	2.096	C.T.	2.512	1.904	2.379	2.605	1.831	2.500	2.209
L.W.C.I.R.	0.585	1.098*	0.489	C.T.	0.215	0.766	0.395	0.381	0.587	0.730	0.485
Zero Recordables	44.0%	64.3%*	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%*	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*	0.055	0.053	0.054
Change Schedule Factor	0.056	0.057	0.054	C.T.	0.062*	0.051	0.068*	C.T.	0.049*	0.052	0.064
Field Rework Cost Factor	0.054	0.058*	0.046	C.T.	0.070*	0.054	0.065	0.037*	0.048	0.044	0.067
Field Rework Schedule Factor	0.022	C.T.	C.T.	C.T.	C.T.	0.024*	C.T.	C.T.	C.T.	C.T.	C.T.

[1] Metric definitions are provided in Appendix B.
[2] Phase definitions are provided in Appendix C.
* = Statistical warning indicator (less than 20 projects)
C.T. = Data not shown per CII Confidentiality Policy (less than 10 projects or data submitted by less than 3 companies)
n = sample sizes for industry groups after removal of statistical outliers per procedures described in Appendix A
Buildings n = 40
Heavy Industrial n = 93
Infrastructure n = 13
Light Industrial n = 24

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 percent and schedule growth of 4.5 percent. The recordable incident rate (RIR) of 2.184 and lost workday case rate (LWCIR) of 0.585 are well below industry averages for similar projects[1]. A remarkable 44 percent of the projects reported no recordable incidents at all and nearly 78 percent reported no lost workday cases. To assist in analysis of table data, the best performance in each category is shaded. 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 stronger performance 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.

2.3 Project Outcomes – Contractors

Table 2-2 contains the outcome summary for contractor projects. Again, only mean performance values are shown and the best performances for the cost and nature categories are shaded. A majority of the data is from heavy industrial projects as indicated in the footnotes to the table. The lack of data for the other three industry groups results in the frequent display of the confidentiality warning indicator, C.T. While cost performance for contractors is generally worse than that of owners, contractors did report slightly better schedule performance. Safety performance is split with owners reporting lower recordable rates and contractors better lost workday case 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. Little significant contractor data are available except for the heavy industrial group. Similar performance patterns are observed for cost categories and project nature as were observed for the owners. The more expensive projects generally under-performed the others, but the differences are rather small as is the sample size.

[1] OSHA Website, September, 1999.

Table 2-2. Summary of Project Outcomes – Contractors

Outcome Metric[1]	All Contractors	By Industry Group[n]				By Cost Category			By Project Nature		
		Bldg	H.I.	Infra	L.I.	<$15	$15-$50	>$50	Add	Grass	Modern
Project Budget Factor	0.951	C.T.	0.948	C.T.	0.946*	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*	0.060	0.022	0.029	0.045	0.045	0.029
Construction Cost Growth[2]	0.043	C.T.	0.041	C.T.	0.037*	0.019	0.076	0.037*	0.054	0.037	0.029*
Project Schedule Factor	0.969	C.T.	0.976	C.T.	0.939*	0.951	0.969	1.009	0.972	0.967	0.966
Construction Phase Duration[2]	56	C.T.	56	C.T.	53*	42	58	76	54	63	50
Project Schedule Growth	0.025	C.T.	0.023	C.T.	0.019*	0.031	0.010	0.033	0.020	0.027	0.030
Construction Schedule Growth[2]	0.055	C.T.	0.042	C.T.	0.095*	0.078	0.037	0.043	0.053	0.084	0.020
R.I.R.	2.203	C.T.	2.073	C.T.	3.274*	1.856	2.531	2.223	2.497	1.553*	2.319*
L.W.C.I.R.	0.093	C.T.	0.087	C.T.	C.T.	0.000	0.138	0.160*	0.080	0.112	0.096*
Zero Recordables	25.7%	C.T.	24.6%	C.T.	18.2%*	20.8%	54.2%	0%	22.2%	26.3%*	33.3%*
Zero Lost Workdays	76.9%	C.T.	77.8%	C.T.	C.T.	100%	72.7%	52.6%*	80.6%	65.0%	85.7%*
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*	C.T.	0.036	0.041*	0.040*
Field Rework Cost Factor	0.030	C.T.	0.028	C.T.	C.T.	0.035*	0.023*	0.033*	0.035	0.032*	C.T.
Field Rework Schedule Factor	0.035*	C.T.	C.T.	C.T.	C.T.	C.T.	C.T.	C.T.	C.T.	C.T.	C.T.

[1] Metric definitions are provided in Appendix B.
[2] Phase definitions are provided in Appendix C.
* = Statistical warning indicator (less than 20 projects)
C.T. = Data not shown per CII Confidentiality Policy (less than 10 projects or data submitted by less than 3 companies)
n = sample sizes for industry groups after removal of statistical outliers per procedures described in Appendix A
Buildings n = 5
Heavy Industrial n = 85
Infrastructure n = 1
Light Industrial n = 12

2.4 Degree of Design/Information Technology (D/IT) Practice Use – Owners

Owner mean D/IT practice use statistics are summarized in Table 2-3. D/IT practice use is scored as an index on a 0 to 10 scale with 0 indicating no use and 10 indicating extensive use. Since only one metric is depicted in the table, the number of observations for each category is conveniently 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[2]. Heavy industrial projects are generally the largest projects within their categories, and as expected, report higher use of D/IT. Shaded cells again indicate highest use within the category. 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. The index specifically measures the degree of use of four technologies: integrated databases, electronic data interchange (EDI), 3D CAD modeling, and bar coding. Since all projects would be expected to report some use, the low scores are likely due to interpretation and survey issues which will be further discussed later in this report.

Table 2-3. Summary of D/IT Practice Use – Owners

	All Owners	By Industry Group				By Cost Category			By Project Nature		
		Bldg	H.I.	Infra	L.I.	<$15	$15-$50	>$50	Add	Grass	Modern
100%	7.88	6.97	7.88	3.40*	3.95	6.97	7.88	5.75	7.88	6.97	5.25
90%	3.64	1.60	4.63	1.88*	2.44	2.86	3.95	5.25	3.57	4.63	2.86
75%	1.79	0.73	2.44	1.25*	1.79	1.64	1.67	4.31	1.53	2.44	1.79
50%	0.75	0.06	1.10	0.50*	0.56	0.75	0.75	0.94	1.02	0.30	0.86
25%	0.00	0.00	0.25	0.00*	0.00	0.00	0.00	0.00	0.25	0.00	0.00
10%	0.00	0.00	0.00	0.00*	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0%	0.00	0.00	0.00	0.00*	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Mean	1.28	0.62	1.71	0.79*	0.99	1.10	1.31	1.84	1.36	1.34	1.19
S.D.	1.59	1.23	1.75	1.02*	1.15	1.27	1.73	2.13	1.56	1.88	1.35
n	183	44	101	13*	25	101	51	31	52	58	73

* = Statistical warning indicator (less than 20 projects)
Note: Appendix D describes how D/IT Index is calculated

2.5 Degree of Design/Information Technology (D/IT) Practice Use – Contractors

On average contractor use of D/IT, as measured by the index in this survey, exceeds that of owners. This finding is consistent with results of the Task 2 analysis of exemplary projects to be presented in Section 3. As with the owner projects, meaningful data are only available for heavy industrial projects. Here also, larger projects make greater use of D/IT practices as indicated by the industry group, cost and nature categories shown in Table 2-4. Grass root projects are normally larger than add-on and modernization projects, which likely accounts for their greater practice use.

[2] CII, Benchmarking & Metrics Data Report, 1999, Austin, Texas.

Table 2-4. Summary of D/IT Practice Use – Contractors

	All Contractors	By Industry Group				By Cost Category			By Project Nature		
		Bldg	H.I.	Infra	L.I.	<$15	$15-$50	>$50	Add	Grass	Modern
100%	8.23	C.T.	8.23	C.T.	5.12*	4.56	7.03	8.23	7.99	8.23	5.94
90%	4.94	C.T.	5.06	C.T.	4.56*	2.50	5.12	7.58	4.56	6.83	4.66
75%	2.88	C.T.	3.31	C.T.	2.31*	1.74	3.06	5.18	2.75	3.75	2.15
50%	1.48	C.T.	1.67	C.T.	1.30*	0.69	1.84	3.80	1.38	2.04	1.36
25%	0.56	C.T.	0.66	C.T.	0.65*	0.00	1.19	1.52	0.37	0.64	0.41
10%	0.00	C.T.	0.00	C.T.	0.00*	0.00	0.00	1.16	0.00	0.12	0.00
0%	0.00	C.T.	0.00	C.T.	0.00*	0.00	0.00	0.24	0.00	0.00	0.00
Mean	2.01	C.T.	2.19	C.T.	1.68*	1.04	2.35	3.78	1.88	2.56	1.65
S.D.	1.99	C.T.	2.05	C.T.	1.56*	1.11	1.85	2.41	1.92	2.32	1.62
n	114	6	93	1	14*	56	34	24	58	30	26

* = Statistical warning indicator (less than 20 projects)
C.T. = Data not shown per CII Confidentiality Policy (less than 10 projects or data submitted by less than 3 companies)
Note: Appendix D describes how D/IT Index is calculated

2.6 Correlation of D/IT Practice Use with Project Outcomes

The correlation summary for D/IT practice use and project outcomes for owner projects is presented in Table 2-5 below. 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 are provided in Appendix B and C. 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 Figure 2-5. 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 in Section 2.4 above. 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.

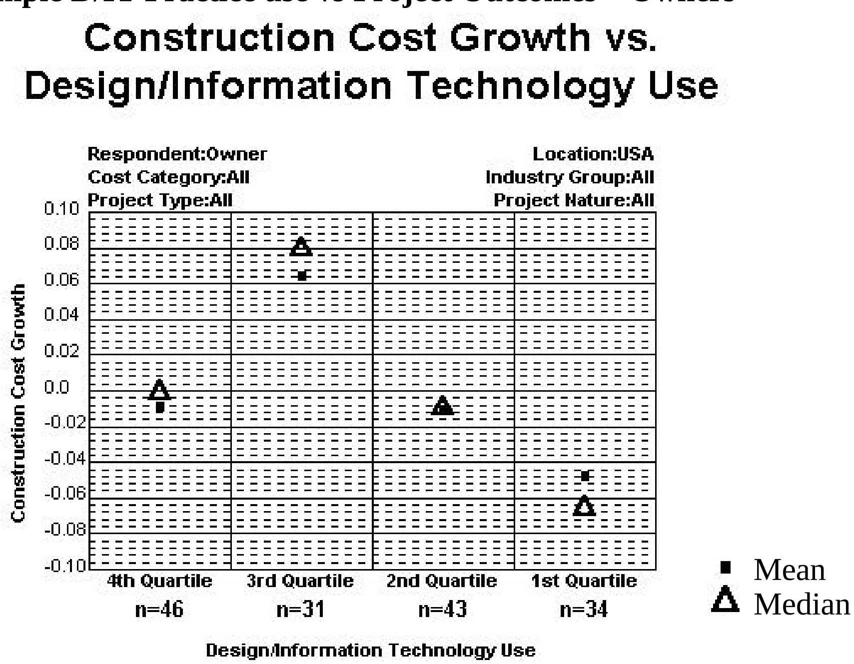
Shading is used in Table 2-5 to illustrate the quartile of the investment stage with no use of the technologies (4th quartile) and the quartile in the benefit stage with the best performance. The difference in performance for these quartiles shows in the first delta (Δ) column illustrating the greatest 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 bolded values in the 3rd quartile 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

Table 2-5. Correlation of D/IT Practice Use with Project Outcomes – Owners

Outcome Metric[1]	Design/Information Use: Low use ⟵⟶ High use — Investment stage 4th	Investment stage 3rd	Benefit stage 2nd	Benefit stage 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[2]	-0.008	**0.065**	-0.010	-0.047	0.039	0.076
Startup Cost Growth[2]	-0.073*	C.T.	-0.100*	-0.088	0.027	0.027
Construction Phase Cost Factor[2]	0.644	0.661	0.533	0.491	0.153	0.162
Startup Phase Cost Factor[2]	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[2]	65	64	53	50	15	14.5
Startup Phase Duration[2]	8.19	**12.53***	4.00	8.57	4.19	6.36
Const. Phase Duration Factor[2]	0.445	**0.490**	0.431	0.428	0.017	0.040
Startup Phase Duration Factor[2]	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[2]	0.089	**0.099**	0.035	0.069	0.054	0.059
Startup Schedule Growth[2]	-0.039	-0.063*	-0.001	-0.076	0.037	0.025
R.I.R.	3.015	2.081	2.444	1.439	1.576	1.109
L.W.C.I.R.	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.		

[1] Metric definitions are provided in Appendix B.
[2] Phase definitions are provided in Appendix C.
* = Statistical warning indicator (less than 20 projects)
C.T. = Data not shown per CII Confidentiality Policy (less than 10 projects or data submitted by less than 3 companies)
Δ^1 = Maximum potential improvement from no use (4th quartile)
Δ^2 = Maximum potential improvement from average of investment stage (4th & 3rd quartiles)
Bold indicates performance penalty for learning curve effect

Figure 2-5. Example D/IT Practice use vs Project Outcomes – Owners



benefit stage. This is perhaps a more reasonable expectation of benefits to be achieved by use of these technologies.

Table 2-6 summarizes the correlation of D/IT use and performance outcomes for contractors in a manner similar to that of owners in Table 2-5. The specific outcome metrics for contractors are different in many cases from those of the owners. Again, the definitions of the metrics and phases are provided in Appendix B and C. Table 2-6 also reveals the learning curve effect previously noted for owners; this is illustrated in Figure 2-6 for contractors. This effect, although present, is not as pronounced as it was for owners.

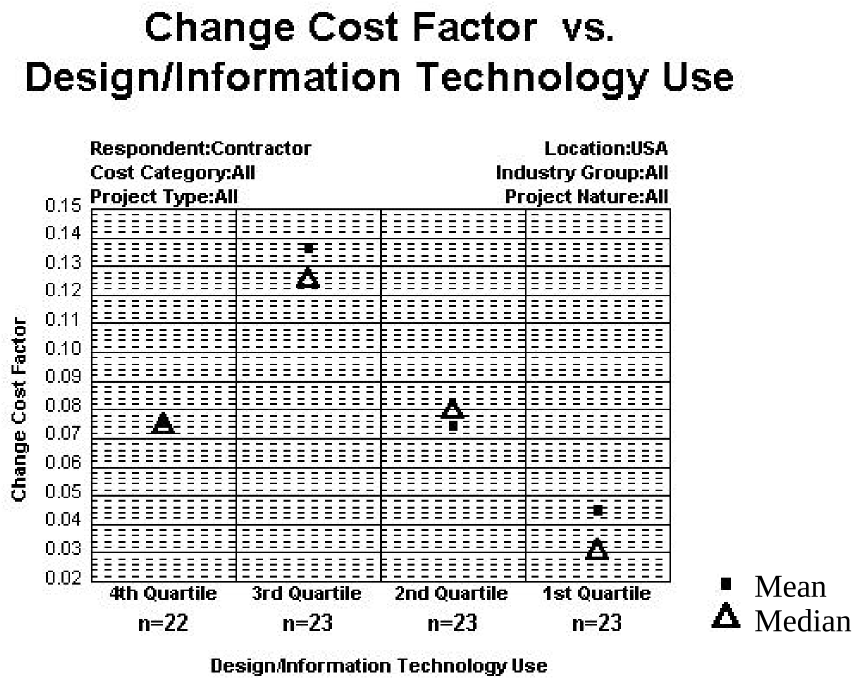
Table 2-6. Correlation of D/IT Practice Use with Project Outcomes – Contractors

Outcome Metric[1]	Design/Information Use (Low use ⟵ ⟶ High use)				Δ^1 No use to Greatest Benefit	Δ^2 Avg. Invest. Stage to Greatest Benefit
	Investment stage		Benefit stage			
	4th	3rd	2nd	1st		
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[2]	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[2]	46	48*	55	70	-	-
Project Schedule Growth	0.040	0.017	0.016	0.026	0.024	0.013
Construction Schedule Growth[2]	0.100*	0.033*	0.066	0.026	0.074	0.041
R.I.R.	2.957*	1.820*	2.291*	1.829	1.128	0.560
L.W.C.I.R.	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.	-	-

[1] Metric definitions are provided in Appendix B.
[2] Phase definitions are provided in Appendix C.
* = Statistical warning indicator (less than 20 projects)
C.T. = Data not shown per CII Confidentiality Policy (less than 10 projects or data submitted by less than 3 companies)
Δ^1 = Maximum potential improvement from no use (4th quartile)
Δ^2 = Maximum potential improvement from average of investment stage (4th & 3rd quartiles)
Bold indicates performance penalty for learning curve effect

A number of differences are apparent for owners and contractors from analysis of Tables 2-5 and 2-6. Table 2-5 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 2-5. Contractor data in Table 2-6, 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 outcome improvements experienced by owners with increased D/IT use also appear to elude contractors. These observations will be discussed in more detail in Section 4.

Figure 2-6. Example D/IT Practice Use vs Project Outcomes – Contractors



3 Summary of Task 2 – Exemplary Projects Analysis

This section summarizes the Task 2 effort in which a select group of exemplary projects were identified for in-depth analysis to determine common characteristics leading to the development of a series of lessons learned. The Task 1 statistical analyses enabled the identification of a small set of projects that excelled in both performance as measured by the outcomes and in use of design and information technologies as measured by the D/IT index. On-site interviews were then conducted with representatives of each project team to collect additional data on use of specific technologies and to document benefits attributed to this use. These findings are summarized in this section as lessons learned and recommendations for future use.

3.1 Task 2 Methodology

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 3 of the 5 outcomes.

The CII survey for D/IT use evaluates the degree of use of 4 major technologies: bar coding, integrated databases, 3D CAD, and electronic data interchange (EDI). 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 Appendix D. 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. Broad use was defined as use of at least 3 of the 4 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 5 such projects, letters were sent to all eleven 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, 3 of the projects were from owners and 3 from contractors and all were chemical projects from the heavy industrial group. Table 3-1 below summarizes both performance outcomes and D/IT use for the projects selected. Owner projects are designated O1-O3 and contractor projects C1-C3. Table 3-2 provides descriptive data for these 6 exemplary projects.

Table 3-1. Summary of D/IT Use and Performance Outcomes for Selected Projects

Outcome Metric	O1	O2	O3	CII Owner Avg.	C1	C2	C3	CII Contractor Avg.
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 to 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	

* 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

Table 3-2. Descriptive Data for Exemplary Projects

Project	Type	Nature	Cost ($MM)	Perform. Period	Const. Dur.	Location
O1	Chem. Process	Grass Roots	56.6	9/93-4/96	12	Texas
O2	Chem. Process	Grass Roots	66.4	3/95-2/97	13	Texas
O3	Chem. Process	Grass Roots	137.0	5/95-10/97	12	Texas
C1	Chem. Process	Grass Roots	41.6	10/94-3/96	12	Texas
C2	Chem. Process	Addition	173.6	9/95-5/98	21	Miss.
C3	Chem. Process	Addition	156.4	11/94-5/97	16	Texas

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:

- 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
- 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.

3.2 Task 2 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, meaning routine use, and limited, meaning current use on an isolated or less frequent basis.

3.2.1 Bar Coding

Each respondent was asked about the role of bar coding and its perceived impacts on their project. As listed in Table 3-3, 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. Better methods of affixing codes and ensuring readability after painting, etc., are essential to expanded use.

Table 3-3. Bar Coding Use & Lessons Learned

BAR CODING	**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 materials coding • Job progress reporting/tracking
	Lessons Learned
	• Cost not justified for tracking pipe spool ($/piece) • Time card abuse by employees

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 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.

3.2.2 Integrated Database

Table 3-4 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 use 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.

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.

Table 3-4. Integrated Database Use & Lessons Learned

INTEGRATED DATABASE	**Standard Use - Current**
	• For conceptual to final design phase by owners & contractors • Material tracking within the organization • Internal productivity reports, actual vs budget
	Limited Use - Current
	• During construction by owners & contractors • International design "links"
	Likely Expanded Use
	• More international design • Owner/contractor links as security are improved
	Lessons Learned
	• Software compatibility problems were experienced • Provided time & dollar savings for owners & contractors – for one international project, lower labor/operating costs made use feasible • Compatible capabilities by both owner & contractor are key to expanded use

3.2.3 3D CAD

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 3-5 below.

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 in 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 percent in electrical materials alone. Another contractor attributed savings of $5 million on a $230 million project from having fully adopted 3D CAD. This was not the project for which he was being interviewed, however.

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.

Table 3-5. 3D CAD Use & Lessons Learned

3D CAD	**Standard Use - Current**
	• Visualization • Interference checking • Layout • Material take-off • Fabrication drawings
	Limited Use - Current
	• Color coding design checks • Equipment feasibility/safety/time & cost studies • Piping • Structural • Electrical – conduits & cable trays, lighting • Concrete • Clearance zones for personnel & 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.

3.2.4 Electronic Data Interchange

Use of Electronic Data Interchange (EDI) has become standard practice, at least for the projects included in this survey. See Table 3-6 below. Some confusion exists, however, as to 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.

Table 3-6. EDI Use & Lessons Learned

EDI	**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 & 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 & systems are compatible

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 another case, a contractor reported savings of several hundred thousand dollars credited to EDI use.

3.2.5 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 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.

Table 3-7. Other Technologies Identified

O T H E R	Technology
	• Computer aided engineering (CAE) • Photogrammetry is being used for modernizations & addition type projects

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 2-3 and 2-4. Second, the size of the project is the single most important characteristic in determining the degree of D/IT use. This too was 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.

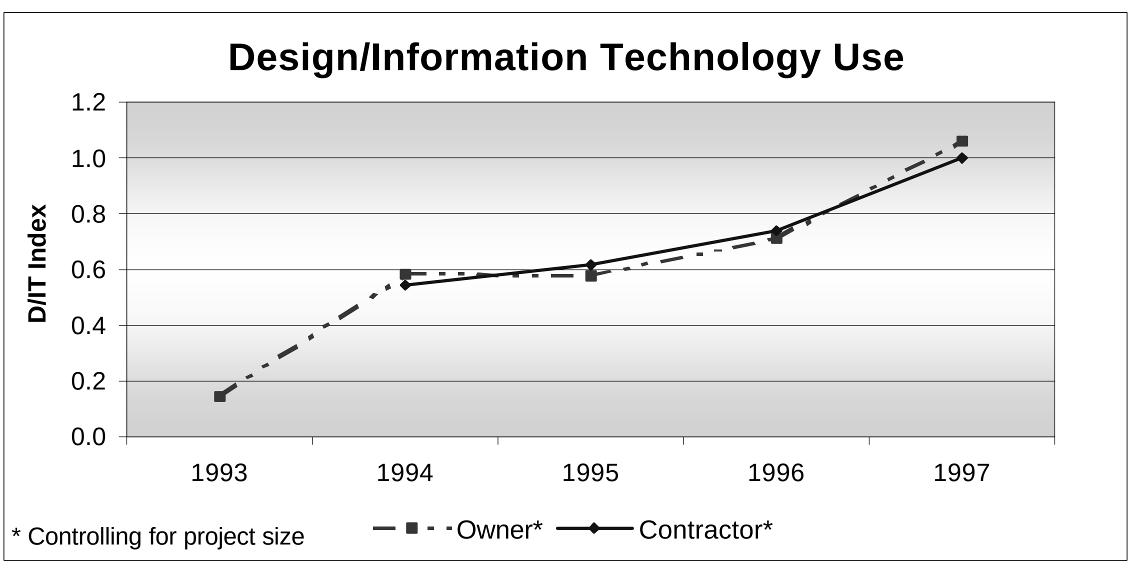
4 Synthesis of Task 1 & Task 2 Findings

4.1 Implementation of D/IT

Use of the surveyed technologies is likely greater than the Task 1 statistical analyses indicates. The large number of projects reporting no use, essentially 25 percent of each industry group, is probably indicative of sampling errors. Many of these technologies are relatively new and the on-site interviews revealed a number misconceptions concerning them. For instance, in more than one interview, the project representative demonstrated a lack of understanding of integrated databases. Although most companies use integrated databases, they often fail to identify their application as such. Also, the CII survey instrument places the questions on use of D/IT near the end of the 23-page questionnaire. Each technology survey contained a lead-in question such as “Was an integrated database utilized on this project?” The structure of the questionnaire created an unintended short cut to finishing the survey for those respondents that were unsure of the question being asked, since answering “no” to the leading question permitted them to skip that set of questions. A glossary was provided with the questionnaire, however, there is no way of knowing how often it was used.

The Task 2 interviews indicate 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. Figure 4-1 below 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 size project to control for the impact of declining project sizes throughout the analysis period. This step is warranted in light of the obvious correlation between project size and D/IT use apparent in Tables 2-3 and 2-4.

Figure 4-1. D/IT Use



Task 2 findings clearly indicate that the single most important factor in the degree of use of D/IT is the project size. This confirms results of the statistical analyses. The >$50 million cost category reported more use than the smaller project categories for both owners and contractors, as shown in Tables 2-3 and 2-4. Since the cost of these technologies is decreasing significantly each year, the trend shown in Figure 4-1 is likely to continue. Also contributing to increased practice use are changes in the team members executing the projects. As new members join the project team, many of whom have been raised with a greater appreciation for technology use, resistance to adoption of these technologies is decreasing.

Figure 4-1 also helps to clarify the relative degree of practice use for both owners and contractors. An examination of practice use data in Tables 2-3 and 2-4 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. Figure 4-1 was prepared while controlling for a consistent decline in project size from 1993 through 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, Figure 4-1 reflects the degree of use per dollar of project cost standardized for a sample $10 million project. In this manner the impact of decreasing project size is controlled while assessing the trend in D/IT use. The technique also controls for the greater average size of contractor projects, $50 million versus $40 million 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 2-5 and 2-6 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.

4.2 Relationship Between D/IT Use and Outcomes

Data summarized in Tables 2-5 and 2-6 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. Thus, strong evidence is available to support improved cost performance from use of D/IT.

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 2-3 and 2-4). Table 2-5, however, reveals that those projects using the technologies most 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 2-6). 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 undoubtedly obtain quantifiable safety benefits, whereas for contractors the impact is less obvious. The relatively small contractor sample for safety data apparent in Table 2-2 may be affecting 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 2-5 and 2-6 renders the sample impractical for rework analysis.

5 Conclusions and Recommendations

This study produced some significant and interesting 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 likely is related to their larger role in the project.

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.

Use of the various technologies tends to overlap. Although not specifically addressed in this study, there is probably a synergistic advantage of using multiple technologies. This perhaps should be evaluated in future studies.

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 perhaps reflects 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 the concerns for the risks. 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.

Finally, the composition of the CII database must be considered when interpreting these findings. The majority of the projects statistically analyzed and all of the projects surveyed during on-site visits were from the heavy industrial group. CII continues to expand the representation of the other industry groups and, therefore, a reasonable number of projects in the other industry groups should soon be available for analyses. If one includes international projects and version 4 data, which have been received and are undergoing preliminary screening, then the number of projects available for analysis for each of the industry groups increases to a meaningful number. Table 5-1 depicts the total number of projects currently in the CII database by industry group. Further studies should be undertaken to assess the benefits of D/IT use for the other industry groups.

Table 5-1. Distribution of Current CII Database by Industry Group

		Building	Heavy Industrial	Infrastructure	Light Industrial
Owner	Domestic	48	136	13	28
	International	48	87	12	2
Contractor	Domestic	16	190	26	24
	International	3	64	3	9

Appendix A – Removal of Statistical Outliers

Prior to performing the Task 1 statistical analyses, all outcome metrics values calculated were screened to remove statistical outliers. This step was incorporated to remove values so extreme that their inclusion would likely distort the statistical summaries produced. The technique used to identify statistical outliers was the same used to define outliers in most statistical texts. This is also the same definition used for outlier commonly used in the preparation of box and whisker plots. All values exceeding the 75^{th} percentile value +1.5 times the inter-quartile range or those less than the 25^{th} percentile value - 1.5 times the inter-quartile range were excluded.

Appendix B – Metric Definitions

Performance Metric Formulas and Definitions

Performance Metric Category: COST

Metric: *Project Cost Growth*	**Formulas:** $\frac{\text{Actual Total Project Cost - Initial Predicted Project Cost}}{\text{Initial Predicted Project Cost}}$
Metric: *Project Budget Factor* *(Contractor data only)*	**Formula:** $\frac{\text{Actual Total Project Cost}}{\text{Initial Predicted Project Cost +Approved Changes}}$
Metric: *Phase Cost Factor* *(Owner data only)*	**Formula:** $\frac{\text{Actual Phase Cost}}{\text{Actual Total Project Cost}}$
Metric: *Phase Cost Growth* *(Owner data only)*	**Formula:** $\frac{\text{Actual Phase Cost – Initial Predicted Phase Cost}}{\text{Initial Predicted Phase Cost}}$

Definition of Terms

Actual Total Project Cost:

- Industrial sector owners - Total installed cost at turnover, excluding land costs.
- Building sector owners – Total cost of design and construction to prepare the facility for occupancy.
- Contractors – Total cost of the final scope of work.

Initial Predicted Project Cost:

- Owners – Budget at the start of detail design.
- Contractors – Cost estimate used as the basis of contract award.

Actual Phase Cost:

- All costs associated with the project phase in question.
- See the Project Phase Table in Appendix C for phase definitions.

Initial Predicted Phase Cost:

- Budget at the start of detail design.
- See the Project Phase Table in Appendix C for phase definitions.

Approved Changes

- Estimated cost of owner-authorized changes.

Performance Metric Category: SCHEDULE

Metric: ***Project Schedule Growth***	**Formula:** Actual Total Proj. Duration - Initial Predicted Proj. Duration Initial Predicted Proj. Duration
Metric: ***Project Schedule Factor*** *(Contractor data only)*	**Formula:** Actual Total Project Duration Initial Predicted Project Duration + Approved Changes
Metric: ***Phase Duration Factor*** *(Owner data only)*	**Formula:** Actual Phase Duration Actual Overall Project Duration
Metric: ***Total Project Duration***	Actual Total Project Duration (weeks)
Metric: ***Construction Phase Duration***	Actual Construction Phase Duration (weeks)

Definition of Terms

Actual Total Project Duration:

- Owners – Duration from beginning of detail design to turnover to user.
- Contractors - Total duration for the final scope of work from mobilization to completion.

Actual Overall Project Duration:

- Unlike Actual Total Duration, Actual Overall Duration also includes time consumed for the Pre-Project Planning Phase.

Actual Phase Duration:

- Actual total duration of the project phase in question. See the Project Phase Table in Appendix C for phase definitions.

Initial Predicted Project Duration:

- Owners - Duration prediction upon which the authorization to proceed with detail design is based.
- Contractors - The contractor's duration estimate at the time of contract award.

Approved Changes

- Estimated duration of owner-authorized changes.

Performance Metric Category: SAFETY

Metric: ***Recordable Incident Rate (RIR)***	**Formula:** $\frac{\text{Total Number of Recordable Cases} \times 200{,}000}{\text{Total Site Work-Hours}}$
Metric: ***Lost Workday Case Incident Rate (LWCIR)***	**Formula:** $\frac{\text{Total Number of Lost Workday Cases} \times 200{,}000}{\text{Total Site Work-Hours}}$

Definition of Terms

- Recordable Cases: All work-related deaths and illnesses, and those work-related injuries which result in: loss of consciousness, restriction of work or motion, transfer to another job, or require medical treatment beyond first aid.
- Lost Workday Cases: Cases which involve days away from work or days of restricted work activity, or both.

Performance Metric Category: CHANGES

Metric: ***Change Cost Factor***	**Formula:** $\frac{\text{Total Cost of Changes}}{\text{Actual Total Project Cost}}$

Definition of Terms

Total Cost of Changes:

- Total cost impact of scope and project development changes.

Actual Total Project Cost:

- Industrial Sector Owners – Total installed cost at turnover, excluding land costs.
- Building Sector Owners – Total cost of design and construction to prepare the facility for occupancy.
- Contractors – Total cost of the final scope of work.

Performance Metric Category: REWORK

Metric: ***Total Field Rework Factor***	**Formula:** $\frac{\text{Total Direct Cost of Field Rework}}{\text{Actual Construction Phase Cost}}$

Definition of Terms

- Total Direct Cost of Field Rework: Total direct cost of field rework regardless of initiating cause.
- Actual Construction Phase Cost: All costs associated with the construction phase. See the Project Phase Table in Appendix C for construction phase definition.

Appendix C – Project Phase Definitions

Project Phase Table

Project Phase	**Start/Stop**	Typical Activities & Products	Typical Cost Elements
Pre-Project Planning Typical Participants: • Owner personnel • Planning Consultants • Constructability Consultant • Alliance / Partner	**Start: Defined Business Need that requires facilities** **Stop: Total Project Budget Authorized**	• Options Analysis • Life-cycle Cost Analysis • Project Execution Plan • Appropriation Submittal Pkg • P&IDs and Site Layout • Project Scoping • Procurement Plan • Arch. Rendering	• Owner Planning team personnel expenses • Consultant fees & expenses • Environmental Permitting costs • Project Manager / Construction Manager fees • Licensor Costs
Detail Design Typical Participants: • Owner personnel • Design Contractor • Constructability Expert • Alliance / Partner	**Start: Design Basis** **Stop: Release of all approved drawings and specs for construction (or last package for fast-track)**	• Drawing & spec preparation • Bill of material preparation • Procurement Status • Sequence of operations • Technical Review • Definitive Cost Estimate	• Owner project management personnel • Designer fees • Project Manager / Construction Manager fees
Demolition / Abatement (see note below) Typical Participants: • Owner personnel • General Contractor • Demolition Contractor • Remediation / Abatement Contractor	**Start: Mobilization for demolition** **Stop: Completion of demolition**	• Remove existing facility or portion of facility to allow construction or renovation to proceed • Perform cleanup or abatement / remediation	• Owner project management personnel • Project Manager / Construction Manager fees • General Contractor and/or Demolition specialist charges • Abatement / remediation contractor charges

Note: The demolition / abatement phase should be reported when the demolition / abatement work is a separate schedule activity (potentially paralleling the design and procurement phases) in preparation for new construction. Do not use the demolition / abatement phase if the work is integral with modernization or addition activities.

Project Phase Table (Cont.)

Project Phase	**Start/Stop**	Typical Activities & Products	Typical Cost Elements
Procurement Typical Participants: • Owner personnel • Design Contractor • Alliance / Partner	**Start: Procurement Plan for Engineered Equipment** **Stop: All engineered equipment has been delivered to site**	• Supplier Qualification • Supplier Inquiries • Bid Analysis • Purchasing • Engineered Equipment • Transportation • Supplier QA/QC	• Owner project management personnel • Project/Construction Manager fees • Procurement & Expediting personnel • Engineered Equipment • Transportation • Shop QA/QC
Construction Typical Participants: • Owner personnel • Design Contractor (Inspection) • Construction Contractor and its subcontractors	**Start: Beginning of continuous substantial construction activity** **Stop: *Mechanical Completion***	• Set up trailers • Site preparation • Procurement of bulks • Issue Subcontracts • Construction plan for Methods/Sequencing • Build Facility & Install Engineered Equipment • Complete Punchlist • Demobilize construction equipment	• Owner project management personnel • Project Manager / Construction Manager fees • Building permits • Inspection QA/QC • Construction labor, equipment & supplies • Bulk materials • Construction equipment • Contractor management personnel • Warranties
Start-up / Commissioning Note: Not usually applicable to infrastructure or building projects Typical Participants: • Owner personnel • Design Contractor • Construction Contractor • Training Consultant • Equipment Suppliers	**Start: *Mechanical Completion*** **Stop: Custody transfer to user/operator (steady state operation)**	• Testing Systems • Training Operators • Documenting Results • Introduce Feedstocks and obtain first Product • Hand-off to user/operator • Operating System • Functional Facility • Warranty Work	• Owner project management personnel • Project Manager / Construction Manager fees • Consultant fees & expenses • Operator training expenses • Wasted feedstocks • Supplier fees

Appendix D – Calculation of D/IT Use Index

	Use Levels						
	Extensive Use				No Use		
Integrated Database Applications Used	1	2	3	4	5	N/A	***Score***
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

	Use Levels						
	Extensive Use				No Use		
EDI Applications Used	1	2	3	4	5	N/A	***Score***
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

	Use Levels						
	Extensive Use				No Use		
3D CAD Modeling Applications Used	1	2	3	4	5	N/A	***Score***
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

	Use Levels						
	Extensive Use				No Use		
Bar Coding Applications Used	1	2	3	4	5	N/A	***Score***
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 Þ Divide total by 4 to scale to 1-10 point range	
Design/Information Technology Practice Use Index	**1.44**

Appendix E – References

Construction Industry Institute (CII). (1999). Benchmarking and Metrics Data Report for 1998. The Construction Industry Institute, Austin, Texas.

Occupational Safety and Health Administration (OSHA). (1999) Web Site, *http://www.osha.gov/oshstats/bls/const7.html*, September, 1999.