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Impacts of Automation and Integration Technologies on Project and Company Performance

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Foreword

Information technologies have transformed many aspects of our daily lives and revolutionized industries in both the manufacturing and service sectors. Within the construction industry, the changes have so far been less radical. However, the use of information technologies offers the potential for revolutionary change in the effectiveness with which construction-related activities are executed and the value they add to construction industry stakeholders. Recent exponential growth in computer, network, and wireless capabilities, coupled with more powerful software applications, have made it possible to apply information technologies in all phases of the building/facility life cycle, creating the potential for streamlining historically fragmented operations.

Computer, automobile, and aircraft manufacturers have taken the lead in improving the integration of design and manufacturing, harnessing automation technology, and in using electronic standards to replace paper for many types of documents. Unfortunately, the construction industry has not yet used information technologies as effectively to integrate its design, construction, and operational processes. There is still widespread use of paper as a medium to capture and exchange information and data among project participants.

Inadequate interoperability increases the cost burden of construction industry stakeholders and results in missed opportunities that could create significant benefits for the construction industry and the public at large. The lack of quantitative measures of the annual cost burden imposed by inadequate interoperability, however, has hampered efforts to promote the use of integration and automation technologies in the construction industry.

To address this need, the Building and Fire Research Laboratory and the Advanced Technology Program at the National Institute of Standards and Technology (NIST) commissioned a study to identify and estimate the efficiency losses in the U.S. capital facilities industry resulting from inadequate interoperability among computer-aided design, engineering, and software systems. That study, published as NIST GCR 04-867, estimated the annual costs of inadequate interoperability for the U.S. capital facilities industry at \$15.8 billion. Approximately 40 % of this annual cost burden, or \$6 billion, was attributed to inefficient business process management costs.

This study, sponsored by NIST and performed by the Construction Industry Institute (CII), focuses on that portion of the annual cost burden due to inefficient business process management functions. The technical basis for the current study stems from how closely the business process management functions used in NIST GCR 04-867 align with CII Benchmarking and Metrics task work functions. This alignment enables an analysis of how key construction industry stakeholders are using automation and integration technologies (A/I Tech) to reduce these inefficiencies at the project and company level.

This study sharpens the NIST GCR 04-867 findings by investigating two independent data sets that contain information on technology use and performance metrics from two critical components of the construction industry: industrial facilities and buildings. First,

data from 139 CII projects are summarized. Performance metrics and indices quantifying the use of project A/I Tech are discussed and the correlations identified between these metrics and indices are used to measure expected benefits. A complementary second data set from 74 Southeastern United States contractors is used to corroborate findings from the CII data. The results of this study establish that more A/I Tech use helps to improve performance. Schedule performance is strongly associated with increased A/I Tech use. Cost performance is weakly correlated with increased A/I Tech use. The study also indicates increasing deployment of A/I Tech among larger firms and projects.

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Abstract

This study, sponsored by the National Institute of Standards and Technology (NIST) and performed by the Construction Industry Institute (CII) evaluates the use of Automation and Integration Technologies (A/I Tech) and their impact on project and company performance in the construction industry. A previous study commissioned by NIST and documented in GCR 04-867, estimated the annual costs of inadequate interoperability in the U.S. capital facilities industry is \$15.8 billion. Approximately 40 percent of this annual cost burden, or \$6 billion, was attributed to inefficient business process management costs. The business process management functions used in NIST GCR 04-867 align with CII Benchmarking & Metrics (BM&M) task work functions enabling an analysis of how key construction industry stakeholders are using automation and integration technologies to reduce these inefficiencies at the project and company level. This study broadens the previous findings by investigating two independent data sets that contain information on technology use and performance metrics from two critical components of the construction industry: industrial facilities and buildings.

The study consists of three tasks. The first presents mappings between the business process management functions used in the previous NIST study and work functions that assess degree of automation and integration technology use in the CII dataset. In the NIST study, a significant portion of the estimated interoperability cost occurs later in the facility life cycle and is attributed to inefficiencies in the business process management functions. While CII task work functions are performed earlier during the project delivery process, they still assess management processes and relating both sets of functions affords a potential opportunity to corroborate findings in the original NIST study with data from the CII dataset. The second task provides descriptive statistics for the two independent datasets used for this study as well as summary statistics for performance outcomes and degree of A/I Tech practice use. The two data sets include project level data from 139 projects contained in the CII BM&M database and company level data for 74 contractors located in the southeastern United States. The third task describes the correlation between technology use and performance and uses these correlations to measure expected benefits.

The results of this study support that more A/I Tech use helps to improve performance. Schedule performance is strongly associated with increased A/I Tech use while cost performance is more weakly correlated with increased A/I Tech use. Given that inadequate interoperability contributes to inefficient business process management functions, it is reasonable to conclude that increased use of A/I Technologies can improve project and company management processes potentially saving the industry billions of dollars annually. The study also provides findings to support increasing deployment of technology among companies surveyed.

Keywords

Automation/Integration Technologies; IT use; interoperability cost; practice use; performance norms; cost benefits; schedule compression; project outcomes; company outcomes; correlation between IT use and performance

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List of Abbreviations

3D	Three Dimensional
A&E	Architects and Engineers
A/I Tech	Automation and Integration Technologies
A Tech	Automation Technologies
CAD/CAM	Computer-Aided Design/Computer-Aided Manufacturing
CAX	Computer-Aided System
CII	Construction Industry Institute
C.T.	Confidentiality Test
DART	Days Away, Restricted, or Transfer case incidence rate
D/IT	Design Information Technology
EDI	Electronic Data Interchange
EMR	Experience Modification Rate
GC	General Contractors
IT	Information Technology
I Tech	Integration Technologies
NIST	National Institute of Standards and Technology
O&M	Operations and Maintenance
OO	Owners and Operators
RFI	Requests For Information
SF	Specialty Fabricators and Suppliers
TRIR	Total Recordable Incidence Rate

1. INTRODUCTION

1.1 Background

In 2004, the National Institute of Standards and Technology (NIST) published GCR 04-867 estimating the efficiency losses in the U.S. capital facilities industry resulting from inadequate interoperability. The estimated cost to all stakeholders is \$15.8 billion per year. Partial impetus for the interoperability cost study stemmed from two earlier NIST studies conducted by the Construction Industry Institute. These studies, GCR 99-786 and GCR 01-821, found that cost and schedule performance improves with increased use of information technologies (IT). While compelling, these earlier studies focused on specific technologies and do not capture the benefits (or lack thereof) of IT use across a range of business functions. These studies are also dated given the rapidly evolving use of IT within the capital facilities industry. As such, it is useful to reassess the impact of IT on performance across a range of project business or work functions.

CII is a unique consortium of owners, contractors, suppliers, and universities formed to improve the capital project delivery process. Its research agenda and activities are the result of a collaborative effort between industry and academic researchers. Through this ongoing collaboration, CII has established a database that supports the benchmarking of construction industry performance and practice use metrics. The data have been systematically collected since 1996 to support CII benchmarking and research efforts. The database includes over 1 450 projects valued at more than \$65 billion from 97 member companies and organizations. In 2002, CII's benchmarking survey was altered to add questions assessing use of automation and integration technologies (A/I Tech) as a measure of IT use. Prior to this a Design and Information Technology (D/I Tech) metric was used to assess the use of four specific technologies.

1.2 Purpose

The purpose of this research was to measure and evaluate the economic value of using information technologies within the construction industry. Specifically, this investigation identified and documented the benefits of using information technologies from actual project and company experiences during the project delivery process.

1.3 Scope and Approach

Two datasets are analyzed in this study. One was developed by CII's Benchmarking & Metrics (BM&M) organization and contains detailed performance measures in addition to the A/I Tech metrics. The CII data were reported by owner and contractors for U.S. domestic and international projects between 2002 and 2004. To better ensure that owner and contractor data were comparable in scope, only those projects for which contractors performed both design and construction tasks were included. The final CII dataset included data from 139 projects, 94 from owners and 45 from contractors. The other complementary data set was independently developed under the direction of Dr. William

O'Brien, a faculty member at The University of Texas at Austin. Dr. O'Brien's dataset consists of company level data from 74 contractors in the Southeastern United States and were collected in 2003 while Dr. O'Brien was a faculty member at the University of Florida.

This research consists of four tasks. The first task is mapping business process management functions from the previous NIST sponsored research (GCR 04-867) and CII BM&M A/I Tech task work functions. In the NIST study, a significant portion of the estimated interoperability cost occurs later in the facility life cycle and is attributed to inefficiencies in these business process management functions attributed to a lack of interoperability. While CII task work functions are performed earlier during the project delivery process, they still assess management processes and relating both sets of functions affords a potential opportunity to corroborate findings in the original NIST study with data from the CII dataset. A similar mapping exercise was performed between the GCR 04-867 business process management functions and the O'Brien dataset (hereafter called Southeastern U.S. Contractors dataset). All mappings are presented and discussed in Chapter 2.

The second task describes the contents of the two data sets, including performance measures and CII's A/I Tech metrics and the Southeastern U.S. Contractors IT usage measures. Beyond basic descriptive statistics, this task developed baseline measures of performance and indicators of economic value. For the CII data, industry norms were identified on five key outcomes: cost, schedule, safety, changes, and field rework. For the Southeastern U.S. Contractors dataset, five key outcomes of cost, schedule, safety, profit, and customer satisfaction are detailed. IT usage norms are based on CII's A/I Tech index and the Southeastern U.S. Contractors IT index.

The third task correlates degree of IT use with the various performance measures in each database. For the CII data, IT usage is reported for both automation and integration technologies. Since it is possible that the levels of automation and integration technologies use are different, data analyses with only automation technologies (A Tech) and only integration technologies (I Tech) are performed in addition to a combined A/I Tech index. The Southeastern U.S. Contractors dataset contains more detailed work functions than the CII dataset; however, the assessment of IT use is not segregated into automation and integration. Correlations are presented by quartile analysis in Chapter 4 and statistical analysis of correlations is included in the appendices. Additional A/I Tech indices and correlations were developed based on the mapping work of task one; these analyses are presented in Chapter 4 as well as in the appendices.

The final task of this research was the development of this report, which summarizes and synthesizes the findings from Tasks 1, 2, and 3. Baseline measures of performance are discussed and key measures of economic value are identified.

2. SUMMARY OF TASK 1 - MAPPING

This chapter summarizes the data and methodological approaches of the NIST GCR 04-867 Cost of Inadequate Interoperability in the U.S. Capital Facilities Industry report (Interoperability Report) and the CII BM&M questionnaire concerning use of automation and integration technologies (A/I Tech). In addition, specific mappings are made between Interoperability Report business process management functions and CII A/I Tech task work functions. Mapping between the Interoperability Report functions and the work functions used for the Southeastern U.S. Contractors study are also presented. Although the Interoperability Report and the CII and Southeastern U.S. Contractors datasets vary in approach to data collection and analysis, mapping allows reasonable comparison between findings of IT use and performance.

This chapter consists of four parts. The first summarizes the methodology of the Interoperability Report study and presents the business process management functions used therein. The second presents the CII A/I Tech task work functions and the third describes the IT utilization work functions in the Southeastern U.S. Contractors dataset. The fourth presents mappings between the Interoperability Report business process management functions and the work functions in the CII and Southeastern U.S. Contractors datasets.

2.1 Interoperability Report: Methodology and Business Process Management Functions

The report published by NIST in 2004 (NIST GCR 04-067) estimates \$15.8 billion cost due to poor interoperability were incurred by the U.S. capital facilities industry in 2002. The interoperability costs were estimated using a work process model, estimates of various costs, and total square meters constructed and in service. It should be noted that of the \$15.8 billion, \$6 billion were attributed to inefficient business process management functions relating to the cost of design and construction activities, which are the measured by the CII and Southeastern U.S. Contractors datasets.

2.1.1 Definition of Inadequate Interoperability Costs

In the Interoperability Report, the cost of inadequate interoperability is quantified by comparing current business activities and costs with a hypothetical counterfactual scenario in which electronic data exchange, management, and access are fluid and seamless. The difference between the current and counterfactual scenarios represents the total economic loss associated with inadequate interoperability. For the cost quantification, the inadequate interoperability cost was divided into three categories as follows:

A. Avoidance Costs: Avoidance costs are related to the ex-ante activities stakeholders undertake to prevent or minimize the impact of technical interoperability problems before they occur.

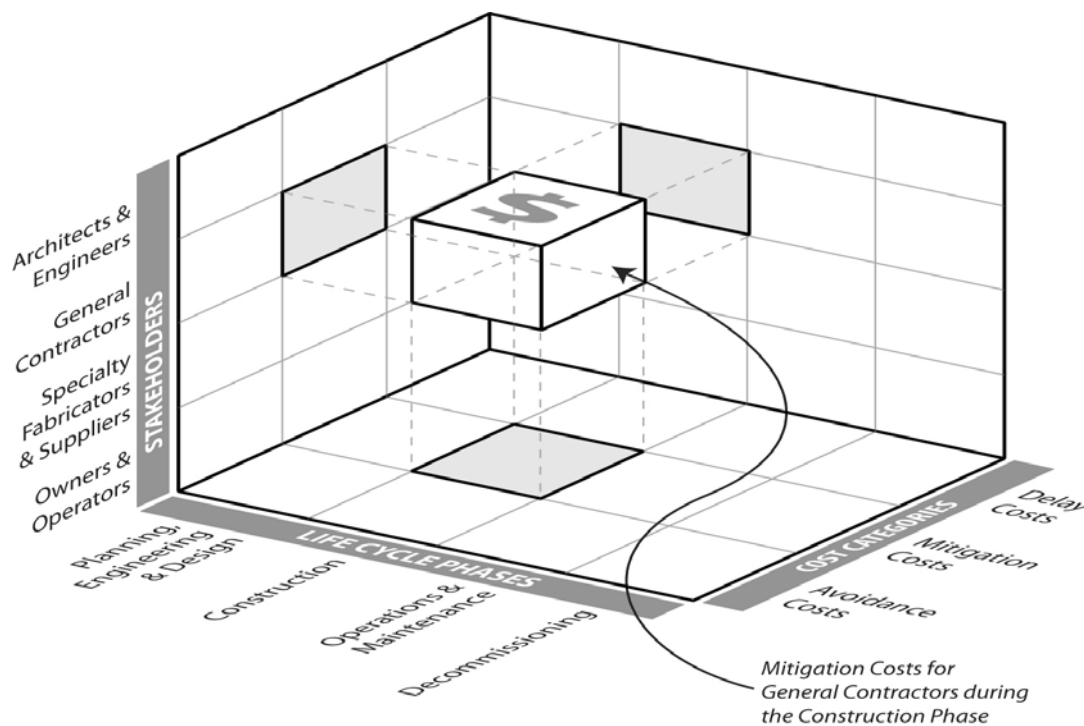
B. Mitigation Costs: Mitigation costs stem from ex-post activities responding to interoperability problems. Most mitigation costs result from electronic or paper files that had to be reentered manually into multiple systems and from searching paper archives. Mitigation costs in this analysis may also stem from redundant construction activities, including scrapped materials costs.

C. Delay Costs: Delay costs arise from interoperability problems that delay the completion of a project or the length of time a facility is not in normal operation.

2.1.2 Calculation of the Inadequate Interoperability Cost

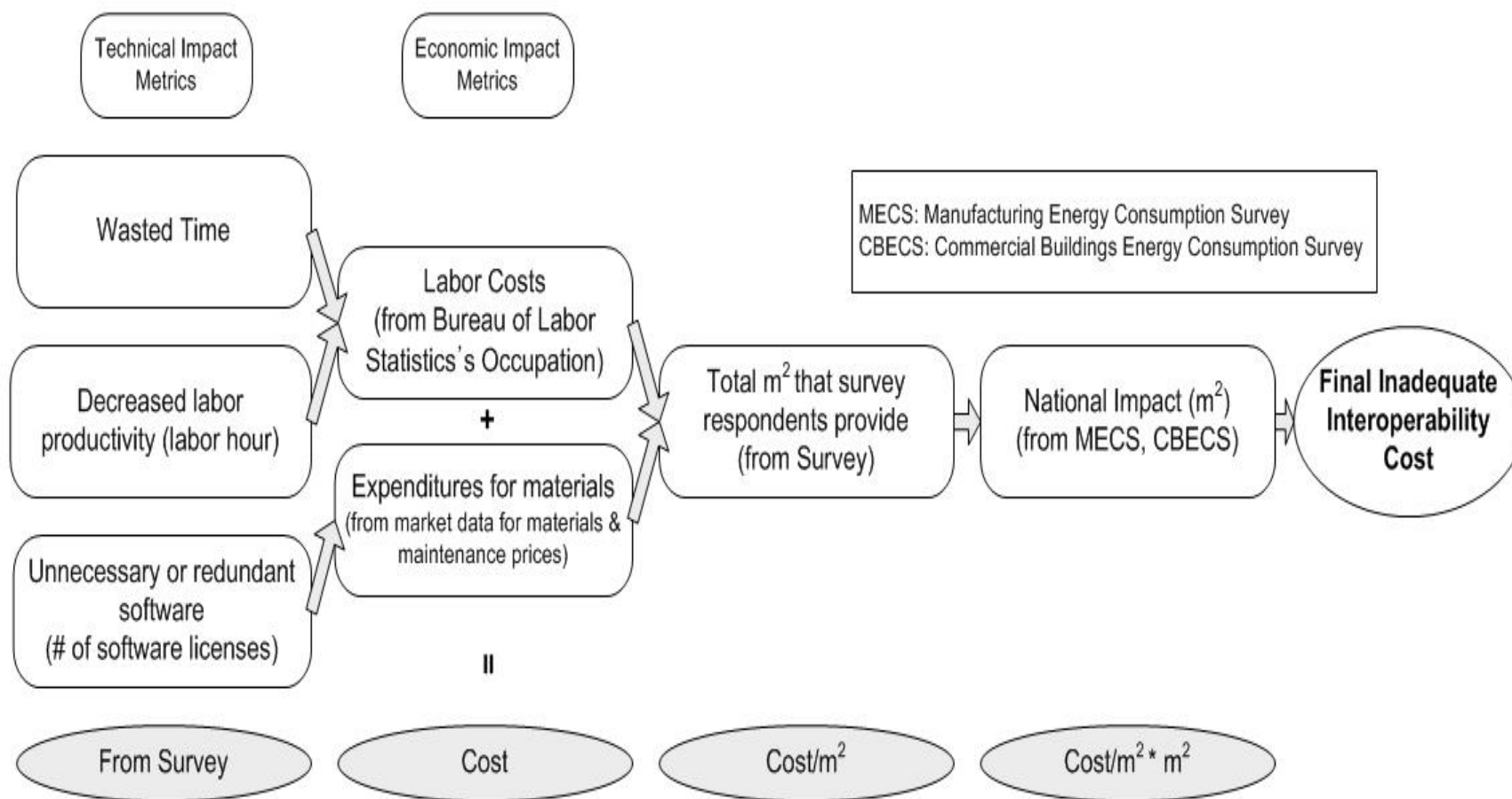
To quantify the cost due to inadequate interoperability, survey instruments were developed for owners and operators (OO), general contractors (GC), specialty fabricators and suppliers (SF), and architects and engineers (A&E). Based on the surveys, costs were categorized according to facility life cycle which includes design and engineering, construction, operations & maintenance (O&M), and decommissioning. Inadequate interoperability costs are categorized in a 3-D framework as shown in Figure 2-1.

Figure 2-1. Representation of Estimation Approach of Interoperability Report



Source: NIST GCR 04-867 page 4-7

Figure 2-2 shows the calculation procedure for determining interoperability costs. Data for technical impact metrics such as wasted time, productivity loss due to inadequate interoperability and unnecessary software systems were obtained through survey instruments. These data were transformed to costs according to economic impact metrics, and then transformed to a cost per square meter (m^2) of facility. National measures of capital facility stock in the U.S. were used to scale the costs to a summary metric.

Figure 2-2. Procedure and Data Sources for Interoperability Report Cost Calculation

2.1.3 Interoperability Report Survey Instruments

In the Interoperability Report, survey instruments were developed for each stakeholder including owners and operators (OO), general contractors (GC), specialty fabricators and suppliers (SF), and architects and engineers (A&E). Table 2-1 summarizes the structure of each survey instrument; there were slight differences based on respondent class, but the basic structure is the same. The OO survey differed the most from the other classes as it surveyed existing facility stock for operations and maintenance costs while other classes focused on design and construction activities. As shown in the table, all types of surveys consist of seven parts. The first two parts contain general information about respondents and their capacity which is needed to calculate the national impact of inadequate interoperability costs. The last five parts cover IT systems and supports, interoperability problems, delay costs, business process systems, and operation and maintenance costs. Questions developed for IT systems and support include existence of redundant IT software, costs for purchasing, educating, and maintaining the software. Questions for interoperability problems cover information reentry caused by use of multiple IT systems (two electronic software or one electronic software and paper-based system). Problems related to requests for information (RFI) are also considered in this part. Delay costs originate from any interoperability costs due to any type of delay. The sixth part of the survey contains the business process management system functions that mapped with CII task work functions in the next part of this report. The last section, “operations and maintenance phases,” is only for OO surveys for facilities management software system and staff.

Table 2-1. Structure of NIST Survey Instruments

No.	Topic	Contents			
		OO	GC	SF	A&E
1	Respondent Identification	General information			
2	Capacity	Capital facilities stock under construction & management	Annual activities		
3	IT Systems & Supports	In design & construction life-cycle phase: - CAD/CAM/CAE (CAx) systems - Interoperability problems (reentry, RFI)	CAD/CAM/CAE (CAx) systems, data translation systems & interoperability research		
4	Interoperability Problems		Before, during, and after construction (reentry and RFI)	Before and after construction (reentry and RFI)	
5	Delay Costs	Interoperability cost due to any types of delay			
6	Business Process Systems	14 functions	14 functions		10 functions
7	Operation & Maintenance Phases	Facilities management software system and staff	N/A		

2.1.4 Business Process Management Functions

Business process management functions are a part of the Interoperability Report survey instruments and provide classes for the quantification of inadequate interoperability costs. There are fourteen business process management functions. Surveys for OO, GC, and SF contained all functions; whereas surveys developed for A&E contain only 10 functions. Each function represents one business process system. For each function, information obtained from the respondents includes existence of software for a specific business process, approximate number of full-time equivalent employees for the system, and percentage labor reduction that can be achieved if the process is fully electronic and interoperable. Table 2-2 shows the functions and stakeholder groups affected by the function. All costs involved with business process management functions are included in avoidance costs.

Table 2-2. Interoperability Report Survey Instruments Business Management Functions

No.	Business Process Management Functions	Impact of Inadequate Interoperability to
A	Accounting	A&E, GC, SF, OO
B	Cost Estimation	A&E, GC, SF, OO
C	Document Management	A&E, GC, SF, OO
D	Enterprise Resource Planning	A&E, GC, SF, OO
E	Facility Planning and Scheduling	A&E, GC, SF, OO
F	Facility Simulation	A&E, GC, SF, OO
G	Information Request Processing	A&E, GC, SF, OO
H	Inspection and Certification	GC, SF, OO
I	Maintenance Planning and Management	GC, SF, OO
J	Materials Management	A&E, GC, SF, OO
K	Procurement	A&E, GC, SF, OO
L	Product Data Management	GC, SF, OO
M	Project Management	A&E, GC, SF, OO
N	Start-up and Commissioning	GC, SF, OO

The Interoperability Report provides limited definitions of each of these functions. Some clarification can be found by matching the job type to the functions as described in Table 2-3 below.

Table 2-3. Business Process Management System Function – Job Classifications

	A&E		GC	SF	OO
	Architects	Engineers			
Accounting	Accountants and Auditors				
Cost Estimation	Cost Estimators				
Document Management	Executive Secretaries and Administrative Assistants				
Enterprise Resource Planning	Management Analysts				
Facility Planning and Scheduling	Civil Engineers				
Facility Simulation	Civil Engineers				
Information Request Processing	Executive Secretaries and Administrative Assistants				
Inspection & Certification	N/A		Civil Engineers		
Maintenance Planning and Management	N/A		Civil Engineers		
Materials Management	Production, Planning, and Expediting Clerks				
Procurement	Purchasing Agents, Except Wholesale, Retail, and Farm Products				
Product Data Management	N/A		Management Analysts		
Project Management	Architects, Except Landscape and Naval	Civil Engineer	Construction Manager		
Start-up & Commissioning	N/A		Civil Engineers		

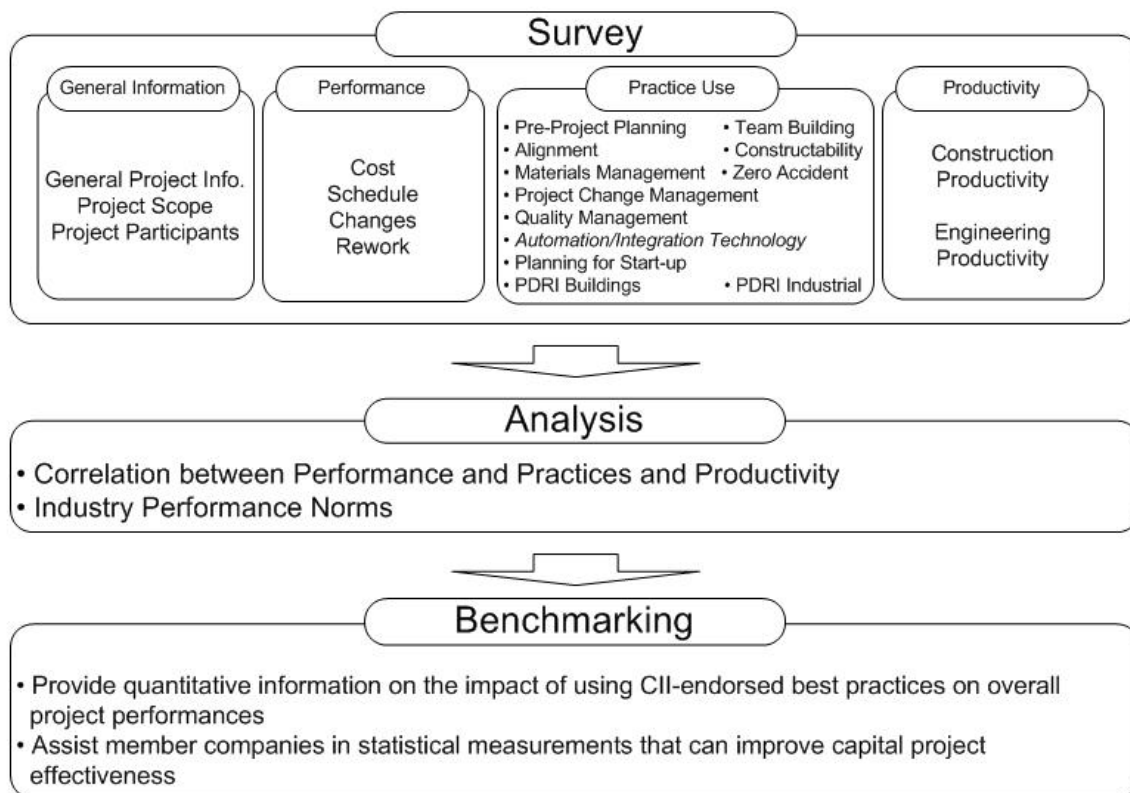
(NIST GCR 04-867, Appendix C)

2.2 CII A/I Tech Task Work Functions

2.2.1 CII Benchmarking & Metrics Program

The CII Benchmarking & Metrics (BM&M) Program was established to provide industry performance norms and to quantify the level of use and value of CII best practices. The goals of the BM&M Program include providing quantitative information to member companies on project performance impacts attributed to using CII best practices as well as assisting member companies with statistical measurements that can improve capital project effectiveness. Figure 2-3 illustrates the process of the CII BM&M Program.

Figure 2-3. CII Benchmarking Process



2.2.2 A/I Tech Task Work Functions

A/I Tech task work functions are project management functions used to assess the level of technology use of automation and integration in the CII survey instrument as shown in Figure 2-3. The CII survey assesses the degree of automation and then integration between each work function. There are a total of 13 functions since the “project management” function is sub-divided into five functions. Task work functions are scored by respondents for both automation and integration. Seven options are available for response. Levels 1 through 5 indicate levels of use and integration with Level 1

indicating little or no automation and integration. Level 5 indicates full automation of functions and full integration of technologies among these functions. Levels 2, 3, and 4 are scaled between levels 1 and 5. “Not applicable” and “unknown” are also options that respondents can select. Table 2-4 shows all 13 CII task work functions used to assess both automation and integration of technology.

Table 2-4. Work Functions for Automation/Integration Technology in CII

No.		CII Work Functions
1		Business Planning & Analysis
2		Conceptual Definition & Design
3		Project (Discipline) Definition & Facility Design
4		Supply Management
5 Project Management	5-1	Coordination System
	5-2	Communications System
	5-3	Cost System
	5-4	Schedule System
	5-5	Quality System
6		Off-Site / Pre-Construction
7		Construction
8		As-Built Documentation
9		Facility Start-Up & Life Cycle Support

2.3 Work Functions Used for the Southeastern U.S. Contractor Dataset

Independent of CII, in 2003 Dr. O’Brien and a Ph.D. student, Mohammad El-Mashaleh, directed a study relating project performance to IT use at the company level (El-Mashaleh, 2003 and El-Mashaleh et al., 2006). Data from 74 contractors in the Southeastern United States were collected by survey. Each respondent was also surveyed for information technology use in four categories: procurement, construction management, construction execution, and start-up. Each category contains multiple work functions. Table 2-5 lists the four categories and 48 work functions used for this study. For each work function which measures the use of IT for that specific function, respondents have five options as responses: three options for indicating the degree of IT use, one option for “don’t know” and one option for “not available.” Based on the responses, an index of IT use was developed to measure the overall IT level of use for the company. Company level performance data were also obtained on five metrics relating to cost, schedule, profit, safety, and customer satisfaction (see definitions in Appendix B, Section B.2).

Table 2-5. Southeastern U.S. Contractors Work Functions

<i>Phase</i>	<i>No.</i>	<i>Work Function</i>
Procurement	1	Determine the lead time required to order equipment and materials
	2	Conduct a quantity survey of drawings
	3	Link quantity survey data to the cost estimating process
	4	Link supplier cost quotes to the cost estimating process
	5	Refine the preliminary budget estimate
	6	Develop the milestone schedule
	7	Develop and transmit requests for proposal to suppliers and subs
	8	Prepare and submit shop drawings
	9	Acquire and review shop drawings; send response
	10	Compile quotes from suppliers and subs into a bid or proposal package
	11	Monitor the progress of fabricators
	12	Plan the transportation routes of large items from the fabricator to the job site
Construction Management	13	Develop the construction schedule
	14	Track field work progress and labor cost code charges
	15	Maintain a daily job diary
	16	Update the current cost forecast
	17	Keep all project team members up to data on construction progress
	18	Track the inventory of materials on site
	19	Link field material managers to suppliers
	20	Develop short-term work schedules based on labor, equipment, and material availability
	21	Work crews submit and receive answers to Requests for Information
	22	Builders provide feedback about the effects of design changes, made by owners or A/E, on cost and schedule
	23	Communicate design changes to field personnel
	24	Communicate status of change orders to field
	25	Update as-built drawings
	26	Contractors submit requests for payment
	27	Transfer funds from owner's account to contractor
Construction Execution	28	Evaluate subsurface conditions
	29	Carry out earth work and grading
	30	Construct rebar charges
	31	Weld pipes
	32	Select the appropriate crane for heavy lifts
	33	Provide an elevated work platform
	34	Fabricate roof trusses
	35	Manipulate and hang sheet rock
	36	Acquire and record laboratory test information
	37	Finish concrete surfaces
	38	Apply paint or coatings
Maintenance and Start-up	39	Conduct pre-operations testing
	40	Train facility operators (e.g. simulation, software)
	41	Use as-built information in personnel training
	42	Track and analyze the maintenance history of important equipment
	43	Develop maintenance plans from maintenance history data
	44	Monitor & assess equipment operators
	45	Facility operators request maintenance or modifications
	46	Update as-built drawings in response to facility modifications
	47	Monitor/track/control facility energy usage
	48	Monitor environmental impact of facility operations (e.g. air/water/quality)

A review of the CII task work functions in Table 2-4 and the Southeastern U.S. Contractors work functions in Table 2-5 reveals very different levels of definition. CII functions are generally defined at a very high level of project planning and execution, whereas, the functions from the Southeastern U.S. Contractors dataset are defined at much lower levels within project management and execution phases. These different levels of definition appear to affect the respondents' ability to assess the level of IT use for that function as will be shown in Chapter 3.

The NIST Interoperability Report business process management functions in Table 2-2 were identified as capital facility industry functions impacted by inadequate interoperability. These functions are defined at a higher level similar to the CII functions. In some cases CII functions are defined at an even higher level such as "Business Planning and Analysis" or "Conceptual Planning & Design" versus the Interoperability Report functions of "Facility Planning and Scheduling." In other cases such as the Interoperability Report function of "Project Management," CII divides this function into five separate project management systems of "Coordination System," "Communication System," "Cost System," "Schedule System," and "Quality System." Both sets of functions have considerable overlap suggesting an opportunity for mapping one to the other.

2.4 Mapping

2.4.1 Mapping of the Interoperability Report Business Process Management Work Functions and the CII A/I Tech Work Functions

This section describes the mapping process between the Interoperability Report business process management work functions and the CII A/I Tech task work functions. Both the NIST Interoperability Report and the CII A/I Tech metrics provide insight into the level of interoperability in the US capital facilities industry. However, there are substantial differences in methodology. As described above, the Interoperability Report focuses on estimating the cost of inadequate interoperability via specific time and cost metrics for each responding firm. These metrics are then scaled by the size of the national capital facilities stock. In contrast, CII's A/I Tech metrics simply assess the level of automation of the particular function and integration across all functions which can be correlated with performance metrics such as cost, schedule, and safety. While CII A/I Tech metrics support the cost and schedule benefits of automation and integration during project delivery, mappings can be made between the NIST Interoperability Report business process management functions and CII A/I Tech task work functions to narrow the analysis and focus our understanding of the benefits and costs of automation and integration technologies on capital project delivery.

2.4.2 Mapping Detail

Mapping the Interoperability Report business process management functions and the CII A/I Tech functions was performed as a group exercise by Drs. Thomas and O'Brien, CII post doctoral researcher Dr. L. Liang, and Ph.D. graduate research assistant Y. Kang. Three levels of association were selected for the mapping: closely related, somewhat related, and not related. Table 2-6 documents the mapping, showing assessment of association for closely related and somewhat related functions. Note that each CII A/I Tech task work function may be mapped to more than one Interoperability Report business process management function and also that multiple A/I Tech work functions may map to a single business process management function. While CII collects data for automation and integration separately, the research team did not determine any case where the metrics have separate mappings. Hence Table 2-6 reports just one mapping for both automation and integration metrics.

Table 2-6. Relation between NIST Business functions and CII Work Functions

NIST Business Process Management Functions		Mapped CII Work Functions		CII Work Functions
No.	Business Functions	Closely related	Somewhat related	
A	Accounting		1, 5-3	1. Business Planning & Analysis
B	Cost Estimation	2, 5-3	1	2. Conceptual Definition & Design
C	Document Management	5-1, 5-2, 8	5-5, 7	3. Project Definition & Facility Design
D	Enterprise Resource Planning		1	4. Supply Management
E	Facility Planning and Scheduling	5-4	2, 3, 5-3, 6	5. Project Management
F	Facility Simulation		1	5-1. Coordination System
G	Information Request Processing	5-1, 5-2		5-2. Communication System
H	Inspection and Certification	5-5	6, 7, 9	5-3. Cost System
I	Maintenance Planning and Management	9		5-4. Schedule System
J	Materials Management	4	6	5-5. Quality System
K	Procurement	3, 4, 5-3, 5-4, 6		6. Off-Site / Pre-Construction
L	Product Data Management	5-1, 5-2, 7, 8	4, 5-3, 5-4, 5-5	7. Construction
M	Project Management	5-3, 5-4, 5-5, 7	4, 6, 8, 5-1, 5-2	8. As-Built Documentation
N	Start-up and Commissioning	9	5-4, 5-5, 8	9. Facility Start-Up & Life Cycle Support

While Table 2-6 summarizes the mappings, the following text provides a brief discussion about the mappings between the Business Process Functions (designated by their letter and name in Table 2-6) and A/I Technology work functions (designated by their number and name placed within quotation marks). In most cases the mappings are self explanatory, but additional discussion is provided where appropriate.

A. Accounting

The Accounting function was too specific compared with CII work functions making it difficult to find any CII functions that map closely. However, Accounting would be included in the “5-3 Cost System” and likely in “1 Business Planning & Analysis” producing somewhat related mappings.

B. Cost Estimation

Several CII work functions map to Cost Estimation. Both “2 Conceptual Definition & Design” and “5-3 Cost System” are closely related to Cost Estimation and “1 Business Planning & Analysis” is also related, but to a lesser degree. Cost estimates are routinely required when a project is in “2 Conceptual Definition & Design” and “1 Business Planning & Analysis” require early cost estimates to support economic analyses.

C. Document Management

A number of CII work functions map to the Document Management function. “5-1 Coordination” and “5-2 Communication Systems” depend on documentation and “8 As-Built Documentation” clearly requires good document management producing closely related assessments. The “5-5 Quality System” requires documentation management too and “7 Construction” cannot be performed without documentation management. Although the mapping team identified only these two functions as somewhat related, clearly most CII functions have to have some degree document management.

D. Enterprise Resource Planning

There is no specific CII work function which can be directly linked to Enterprise Resource Planning; however, “1 Business Planning & Analysis” was thought to have some connection producing a somewhat related assessment.

E. Facility Planning and Scheduling

Given the high level of definition of CII work functions, it is not surprising that a number of these functions map to Facility Planning and Scheduling. “5-4 Schedule System” is closely related. “2 Conceptual Definition & Design,” “3 Project Definition & Facility Design,” “5-3 Cost System,” and “6 Off-Site / Pre-Construction” were thought to be at least somewhat related.

F. Facility Simulation

No CII function was assessed as closely related to the Facility Simulation function. However, since facility simulation is often used during “2 Conceptual Definition & Design,” this CII function was rated as somewhat related.

G. Information Request Processing

This function proved somewhat problematic for mapping since many of the CII functions require processing of information, but do not necessarily process information requests. “5-1 Coordination” and “5-2 Communication Systems” are essential for Information Request Processing and were therefore assessed as closely related.

H. Inspection and Certification

“5-5 Quality System” clearly links to Inspection and Certification warranting a closely related rating and “6 Off-Site and Pre-Construction,” “7 Construction,” and “9 Facility Start-up & Life Cycle Support” were deemed to be somewhat related.

I. Maintenance Planning and Management

This business process function received one closely related CII function map, “9 Facility Start-Up & Life Cycle Support.” While a number of other CII functions were discussed, none of these functions were mapped even at the somewhat related level.

J. Materials Management

The CII function “4 Supply Management” directly relates to this business process management function and is assessed as closely related. “6 Off-Site and Pre-Construction” requires good materials management and also received an assessment, but at the somewhat related level.

K. Procurement

This business process work function received several CII function mappings which are expected given the early life cycle nature of many of the CII functions. Procurement commences following definition and authorization and continues up to start-up and commissioning. “3 Project Definition & Facility Design,” “4 Supply Management,” “5-3 Cost System,” “5-4 Schedule System,” and “6 Off-Site / Pre-Construction” all mapped as closely related.

L. Product Data Management

Data management is very broad concept and as would be expected, many CII functions mapped well with it. All CII functions within “5 Project Management” mapped to some degree with “5-1 Coordination System” and “5-2 Cost System” mapping as closely related. The other Project Management functions as well as “4 Supply Management” mapped as somewhat related. Two other CII functions: “7 Construction” and “8 As-built Documentation” also mapped closely related since they rely heavily on data management.

M. Project Management

As would be expected given the level of definition of CII functions, the business process management function Project Management received the largest number of CII function mappings. All CII “5 Project Management” functions mapped with “5-3 Cost System,” “5-4 Schedule System,” and “5-5 Quality System” mapping as closely related and “5-1 Coordination System” and “5-2 Communication System” mapping as somewhat related. The latter two CII project management functions are less understood, likely contributing to their weaker mappings. Other CII functions mapped include “7 Construction” as closely related and “4 Supply Management,” “6 Off-Site / Pre-Construction,” and “8 As-built Documentation” mapping as somewhat related.

N. Start-up and Commissioning

As would be expected this function mapped closely related with the CII function “9 Facility Start-up & Life Cycle Support.” Other CII functions that mapped somewhat related include “5-4 Schedule System,” “5-5 Quality System,” and “8 As-built Documentation.” It is possible to argue that these “somewhat related” CII metrics could be classified as closely related.

2.4.3 Mapping of Interoperability Report Business Process System Functions and Southeastern U.S. Contractors Work Functions

The dataset developed from contractors in the Southeastern U.S. is similar in structure to the CII dataset, containing both performance measures and work function assessments of IT use. The IT work functions used in this dataset are grouped into four categories, two of which map directly to the Interoperability Report business process management functions. These function categories are Procurement and Construction Management. As shown in Table 2-5, 12 work functions are categorized in the Procurement group and each of these work functions can be mapped as closely related to the Interoperability Report Procurement business process function as shown in Table 2-7.

For the Interoperability Report Project Management function, two mappings are provided. The first directly maps all the Southeastern U.S. Contractors Construction Management work functions (numbers 13 through 27) into the Project Management I grouping. The second mapping examines individual Southeastern U.S. Contractors Construction Management work functions excluding some from the Construction Management grouping and including a few from the Construction Execution grouping. The reasoning behind the second grouping is that the Interoperability Report Project Management function may be focused on integration technologies, therefore the second Project Management mapping focuses on work functions that are closely related to integration. Table 2-7 lists these mappings as Project Management II.

Table 2-7. Mapping of Interoperability Report Business Process Management Functions and Southeastern U.S. Contractors Work Functions

NIST Business Functions		Work functions from the contractor firm database	
		No. ¹	Task
Procurement		1	Determine the lead time required to order equipment and materials
		2	Conduct a quantity survey of drawings
		3	Link quantity survey data to the cost estimating process
		4	Link supplier cost quotes to the cost estimating process
		5	Refine the preliminary budget estimate
		6	Develop the milestone schedule
		7	Develop and transmit requests for proposal to suppliers and subs
		8	Prepare and submit shop drawings
		9	Acquire and review shop drawings; send response
		10	Compile quotes from suppliers and subs into a bid or proposal package
		11	Monitor the progress of fabricators
		12	Plan the transportation routes of large items from the fabricator to the job site
Project Management	I	13	Develop the construction schedule
		14	Track field work progress and labor cost code charges
		15	Maintain a daily job diary
		16	Update the current cost forecast
		17	Keep all project team members up to data on construction progress
		18	Track the inventory of materials on site
		19	Link field material managers to suppliers
		20	Develop short-term work schedules based on labor, equipment, and material availability
		21	Work crews submit and receive answers to Requests for Information
		22	Builders provide feedback about the effects of design changes, made by owners or A/E, on cost and schedule
		23	Communicate design changes to field personnel
		24	Communicate status of change orders to field
	II ²	25	Update as-built drawings
		26	Contractors submit requests for payment
		27	Transfer funds from owner's account to contractor
		14	Track field work progress and labor cost code charges
		15	Maintain a daily job diary
		17	Keep all project team members up to data on construction progress
		18	Track the inventory of materials on site
		19	Link field material managers to suppliers
		20	Develop short-term work schedules based on labor, equipment, and material availability
		21	Work crews submit and receive answers to Requests for Information
		22	Builders provide feedback about the effects of design changes, made by owners or A/E, on cost and schedule
		23	Communicate design changes to field personnel
		24	Communicate status of change orders to field
		25	Update as-built drawings
		28	Evaluate subsurface conditions
		36	Acquire and record laboratory test information

¹ Work function numbers are identical to the numbers in Table 2-5

² Mapping focused on integration technology

Observations from the mapping exercise conclude that many of the mappings are very subjective and are dependent on the “group think” that the team developed during the process. While the purpose of the mapping exercise was to relate work functions between the various datasets in an effort to identify potential similarities in findings across the datasets, the practicality of this exercise became questionable. The primary benefit obtained through the mappings was identification of closely and somewhat related CII work functions facilitating development of special “mapped” A/I Tech indices which could be checked for improved correlations with project outcomes. The correlations between A/I Tech and outcomes are discussed in detail in Chapter 4, however, the “mapped” A/I Tech indices correlations were dropped from the analysis since they produced results similar to the broader A/I Tech indices. Although the mapped indices produced slightly more significant correlations for one index, the mappings were actually quite subjective and eliminated nearly half of the A/I Tech work functions from the analysis.

3. SUMMARY OF TASK 2 – DESCRIPTIVE STATISTICS

This chapter provides the descriptive statistics for both CII and the Southeastern U.S. Contractors datasets. The datasets are complementary; the CII dataset contains project information from both contractors and owners that are among the larger firms in the capital facilities industry. The Southeastern U.S. Contractors dataset provides company level data among a range of small and midsize contractors drawn primarily from the Southeastern United States.

3.1 CII Data

3.1.1 Data Description

CII data for Automation/Integration technology are drawn from versions 7 and 8 of the CII Benchmarking and Metrics questionnaire, and represent 139 projects reported over the period 2002-2004. Data are categorized by location (Figure 3-1), industry group (Figure 3-2), cost (Figure 3-3), and project nature (Figure 3-4). Each figure shows the number of projects for both owner and contractor respondents.

Note that in some figures the sample size is smaller than the total number of projects since all respondents do not answer all questions. There are some statistical outliers and confidentiality issues with small samples. As such, certain data are excluded from analysis following the decision rules provided in Appendix A. Hence some of the analyses presented in the following sections do not draw from all 139 projects. Where appropriate in the tables, small samples or data suppression for confidentiality are noted.

Figure 3-1. CII Data Set by Respondent Type and Location

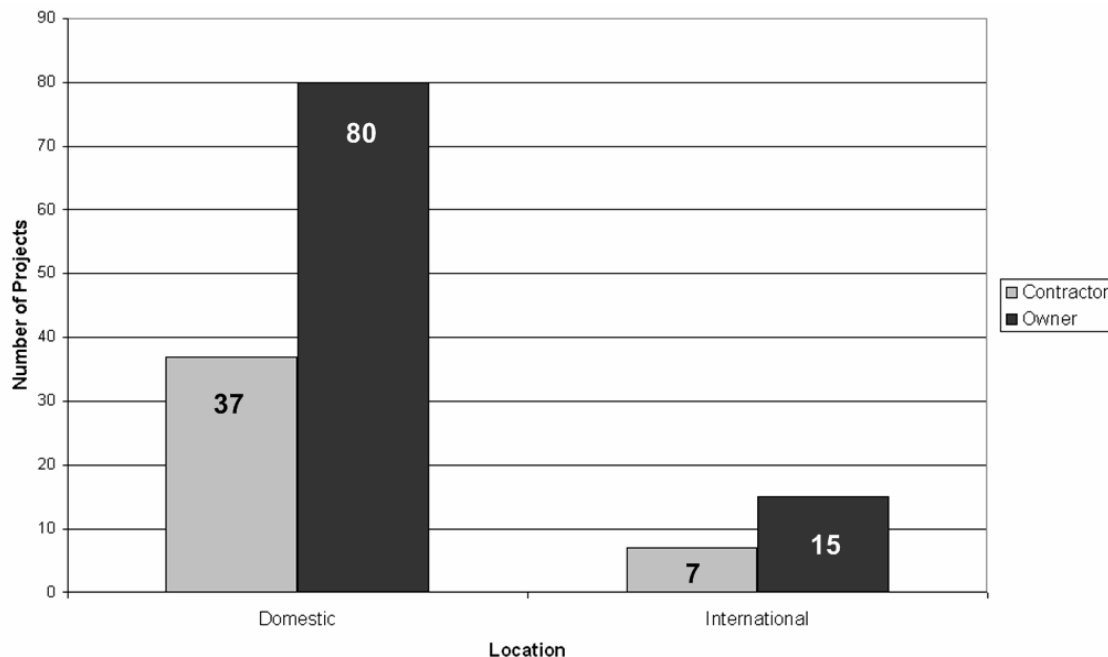


Figure 3-2. CII Data Set by Industry Group

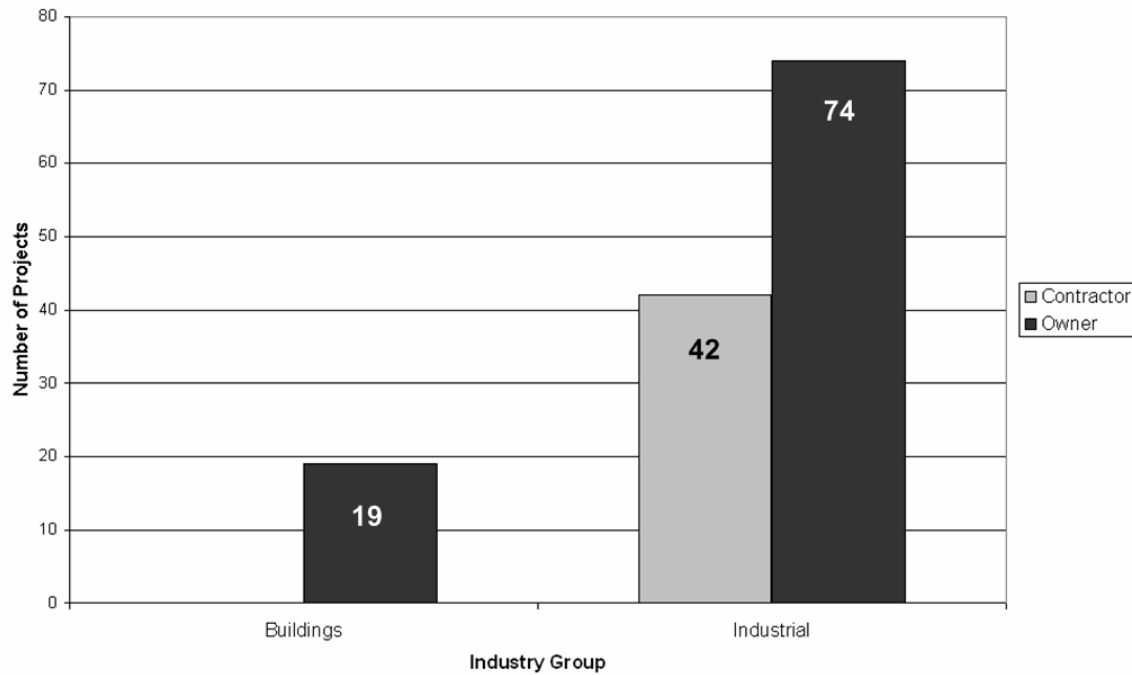


Figure 3-3. CII Data Set by Cost of Project

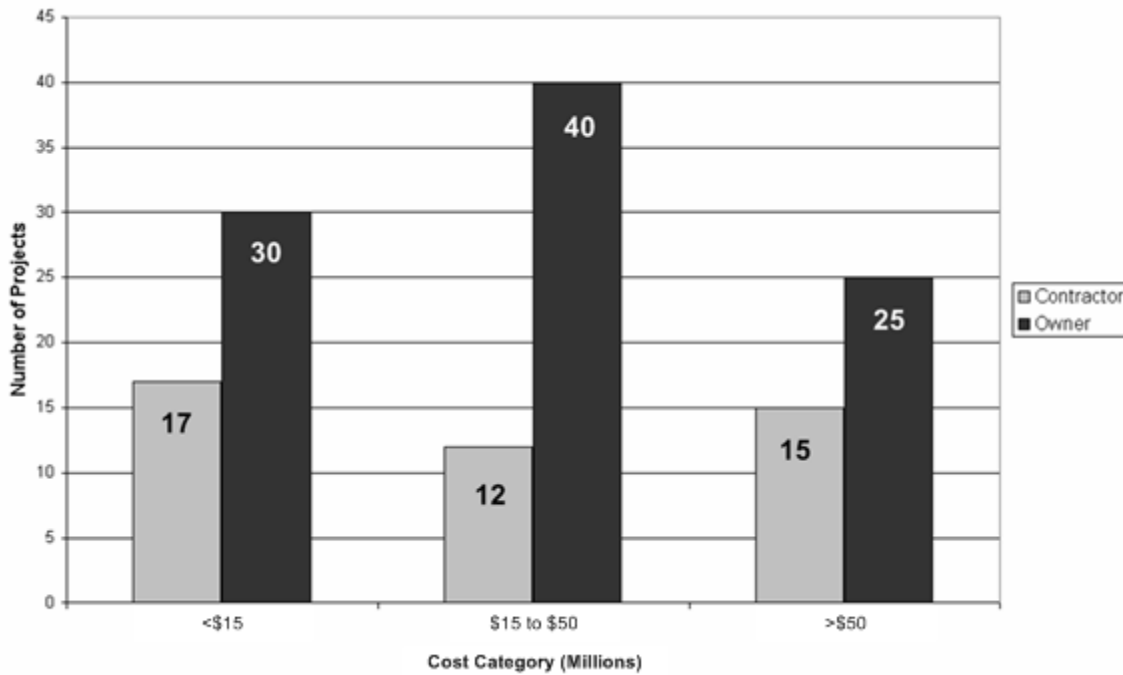
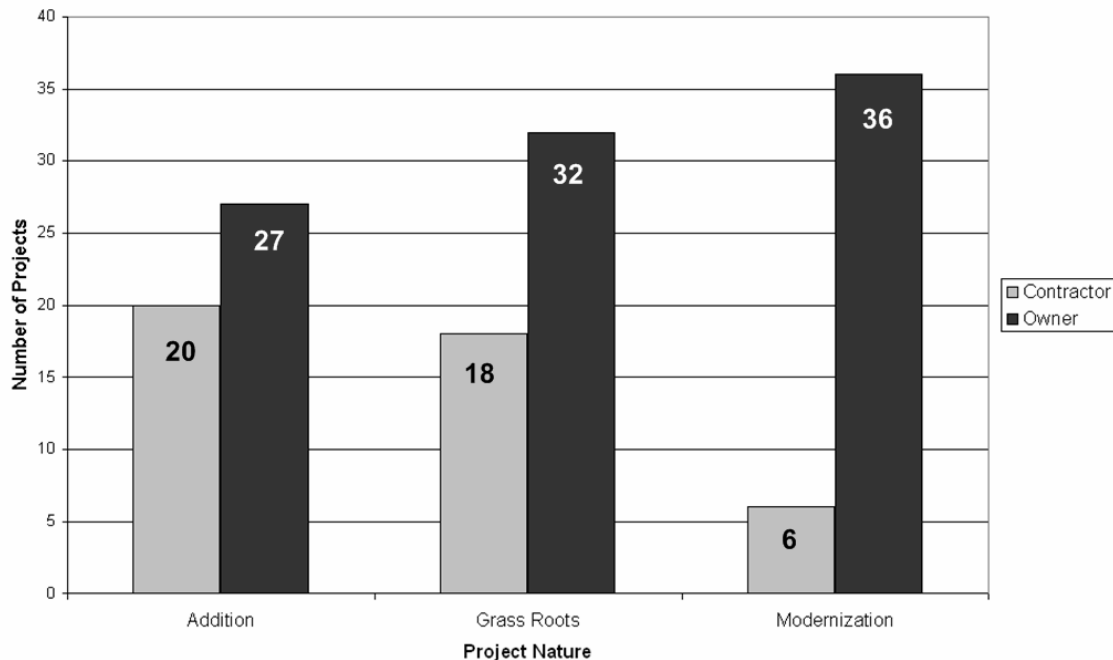


Figure 3-4. CII Data Set by Project Nature



3.1.2 Performance Outcomes – CII Owners

Table 3-1 summarizes owner project performance for each comparison category. The definitions of all metrics are summarized in Appendix B, Section B.1. The shading of cells indicates better performance within the category and values marked with asterisks indicate small samples in accordance with definitions provided in Appendix A. Findings from these small samples should be interpreted with caution. For cases where the data sample is very small (10 or fewer) or the data are provided by less than 3 companies, the data are suppressed and a confidentiality warning indicator (C.T.) is shown. Overall, the owner projects reported very good cost growth of -0.1 %; however, schedule growth at 11.4 % indicates an opportunity for improvement.

Analysis by industry group is limited by the small building sample of only 19 projects. Since some phase data are not reported by all building projects, some data suppression is required. Generally, industrial projects reported better cost and schedule performance than building projects as indicated by lower numbers on the project cost and schedule growth metrics which measure growth from target budgets and schedules. These findings are consistent with most CII benchmarking results which indicate that larger and more complex heavy industrial projects typically report better performance. Alternative project assessment of cost and schedule performance is provided by the “Delta” metrics which measure performance as absolute deviation from targets. By this measure, buildings actually outperformed industrial projects by a slight margin (lower numbers are better for all performance metrics); however, these findings lack statistical significance. Of

particular interest is the seemingly better safety performance of the building projects compared to the industrial projects. This observation is not consistent with that of larger datasets of the CII benchmarking database nor findings reported in CII's annual Safety Report which is based on more than one billion work-hours. The small sample for building projects used in this dataset may not be representative of the broader industry.

By cost category, surprisingly, design cost growth was the only performance metric on which larger projects (those costing over \$50 million) demonstrated superior performance compared to midsize and smaller projects. This is unusual since CII data routinely show that larger projects tend to employ performance enhancing practices to a greater degree than smaller projects. Overall, midsize projects (costs ranging between \$15 million and \$50 million) showed the best performance in project cost growth, project budget factor, and project schedule growth. Smaller projects (those costing less than \$15 million) showed the best performance for phase level cost and schedule metrics. Smaller projects also were the best in safety performance based on the large percentage of small projects that report no recordable incidents. While the better safety performance of the smaller projects can be explained, the relatively poor cost and schedule performance of the larger projects suggests that again, the dataset may not be representative of data typically found in the CII BM&M Program.

By project nature, owner modernization projects exhibited the best overall cost performance as indicated by the cost growth metrics, which as noted above illustrates exceptional characteristics of the dataset. They also reported better safety performance than others. Grass roots projects having less impacts from interferences and interface complexities do report more predictable cost and schedule performance according to the delta metrics. Additions, despite many of the issues common to modernization projects, actually reported better performance on a few schedule and change metrics. It is possible that other factors are influencing the somewhat surprising results seen by project nature. Recognizing the complexities caused by additions and modernizations, owners may be requiring performance enhancing procedure to include more sophisticated IT systems. Some evidence of this will be discussed later in this chapter when technology use is presented.