ASSOCIATIONS OF TECHNOLOGY USAGE WITH CAPITAL FACILITY PROJECT SUCCESS

JAMES T. O'CONNOR, P.E., PH.D.

LI-REN YANG, PH.D.

CENTER FOR CONSTRUCTION INDUSTRY STUDIES

REPORT NO. 29

THE UNIVERSITY OF TEXAS AT AUSTIN

Associations of Technology Usage with Capital Facility Project Success

by
James T. O'Connor, PE, Ph.D.
and Li-Ren Yang, Ph.D.

A Report to the
Center for Construction Industry Studies
The University of Texas at Austin

Under the Guidance of the
Fully Integrated and Automated Project Processes
Thrust Steering Team

Austin, Texas
June 2003

This page intentionally left blank.

Executive Summary

Technologies and innovations emerge quickly in the business world. Construction firms attempt to improve project performance by adopting technology. However, the advantages gained from technology utilization are still not clear. Uncertain benefits and lack of information on how technology affects overall project performance make some construction firms reluctant to implement technology. Therefore, there is a need for studies that quantify the impacts of technology utilization on overall project success. Quantifying effects on project success will assist companies in deciding whether to use certain technologies. Thus, the primary objective of this study was to determine the degree to which technology application is associated with project success.

The scope of this report includes discussion of findings pertaining to relationships between technology usage and project success on capital facility projects. Findings according to five data class variables are examined: industry sector (i.e., industrial vs. building vs. infrastructure), project size (based on project total installed cost), owner regulation (i.e., public vs. private), initial site (i.e., greenfield vs. expansion vs. renovation), and project typicality (i.e., typical vs. advanced projects).

The data analyzed in this report are representative of the levels of integration/ automation (IA) technologies used on project work functions (WFs) rather than that used organization-wide. An industry-wide survey was used to collect project data from more than 200 capital facility projects on the issue of integration/automation technology usage and project success parameters. Project performance variables analyzed include project cost success, project schedule success, and composite project success.

Some key findings include the following:

- Technology usage for industry-wide high-tech WFs may positively influence project cost success, particular for Building and Public projects.
- For Infrastructure projects, cost-sensitive WF technology usage may contribute to project cost success.
- For Building projects, task automation technology usage may positively influence project cost success. Also, project technology usage may contribute to project schedule success, integration link, task automation, and schedule-sensitive WFs in particular.
- For Private projects, technology usage for industry-wide mid-tech WFs may positively influence project schedule success.
- For Expansion projects, levels of technology usage for schedule-sensitive WFs are positively associated with project' levels of schedule success.
- Technology usage may positively influence both project cost and schedule success, particularly task automation technology usage and for industry-wide high-tech WFs and cost/schedule-sensitive WFs.
- Project schedule success is more closely associated with technology utilization than is project cost success.

Many more salient and detailed findings are contained in this report. Recommendations for further research are included as well.

This page intentionally left blank.

Table of Contents

List of Tables

This page intentionally left blank.

Chapter 1 Introduction

1.1 Study Background and Objectives

Many studies have shown that the construction industry is reluctant to apply new technologies and employs lower levels of technology than other industries. A national-wide survey conducted by the Civil Engineering Research Foundation indicated that the design and construction industry spends only 0.5% of its total revenues on research and development (CERF 1997). In recent years, however, there has been a growing trend towards increased technology utilization levels on Architect/Engineering/Construction (A/E/C) capital facility projects.

According to a 1995 study, four drivers for adoption of new technologies were identified: 1) competitive advantage, 2) external requirements, 3) priority problems - avoid losses from reduced performance, and 4) technological opportunity to improve operations (Mitropoulos and Tatum 1995). Some construction firms adopt emerging technologies in the attempt to reduce the cost and schedule of a project. However, since the benefits of innovation can be rather intangible, this has slowed or prevented the adoption of new technology. In order to understand the benefits, there is a need for quantification of the benefits derived from technology application. Simmons (1994) suggested that methods used to evaluate the impact of technology on performance measures may be the problem in connecting investment in technology to improvements in business performance. Several researchers have investigated the impacts of different technology on project performance. Some of the project performance indicators they examined include cost, schedule, and safety success, which are of course major concerns to project stakeholders. However, there are few studies with quantifiable information on how technologies affect project success. Research on technology utilization at the project, phase levels and their associations with project success should offer tangible evidence of advantages from using different levels of technologies and should provide construction firms with information on whether to adopt certain technologies.

The primary research objective of this study was to quantify the degree to which project success is significantly associated with technology utilization. Descriptive statistics according to data class variables were developed to determine project- and phase-level technology usage. Additionally, hypothesis testing was performed to identify relationships between technology utilization and project success.

1.2 Scope Limitations

The analyses of technology usage and relationships with project success are based on a nation-wide survey performed between October 1998 and August 1999. The data collection tool was developed by O'Connor, Welch, and Kumashiro. Technology usage metrics are based on 68 common project work functions, which are defined as identifiable units of work that are commonly performed on a wide variety of capital facility projects. The technology usage analyzed in this study is representative of the levels of technologies commonly utilized on projects. Small projects (< $5 million in total installed cost) were excluded from the analysis.

This report addresses associations between technology usage and project success. Technology usage metrics analyzed include those at the project and phase level. Phase-level technology usage metrics analyzed include technology usage in the Front-End, Design, Procurement, Construction Management, and Construction Execution phases (technology usage in the Operation and Maintenance phase was excluded from the analysis). Project success parameters analyzed include project cost success, project schedule success, and composite project success (a combination of project cost and schedule success).

1.3 Research Hypotheses

Research hypotheses were developed to investigate associations between project performance and technology usage at the project and phase level. Table 1.1 lists the proposed research hypotheses pertaining to associations between project performance and technology usage at the project level. Technology usage metrics analyzed include project technology usage, task automation technology usage, integration links technology usage, and those for industry-wide high-tech, industry-wide mid-tech, industry-wide low-tech, and cost/schedule-sensitive work functions.

The hypotheses listed in Table 1.2 pertain to associations between project performance and technology usage at the phase level. Technology usage metrics analyzed include technology usage in Phase 1 & 2 and Phase 3, 4, & 5. The project performance variables analyzed include project cost performance, project schedule performance, and composite project cost and schedule success.

These hypotheses are presented and analyzed according to five different data class variables: Industry Sector, Total Installed Cost (TIC), Owner Regulation, Initial Site, and Project Typicality. These variables are defined as follows:

1. Industry Sector - Buildings, Industrial, or Infrastructure.
2. Total Installed Cost – Two cost categories are investigated: Medium Size (i.e., $5-50 Million) and Large Size (i.e., >$50 Million).
3. Project Typicality – Respondents were asked to compare the subject project to other company projects relative to overall technology usage. Two optional responses were provided: Typical or Advanced.
4. Owner Regulation – This variable allowed researchers to distinguish Private projects from Public projects.
5. Initial Site – Participants were provided with three options: Greenfield (or new), Renovation, or Expansion.

1.4 Structure of the Report

Chapter 2 presents the research methodology including survey process, methods of analysis, use of statistical tests, and interpretation of these tests. Chapter 3 discusses technology usage metrics. These technology use indices were developed to assess the levels of technology usage on projects. Chapters 4 and 5 address descriptive statistics

Table 1.1: List of Hypotheses for Project-Level Technology Usage

Number	Hypothesis
H1	Levels of project technology usage are positively associated with projects' levels of cost success
H2	Levels of technology usage for task automation WFs are positively associated with projects' levels of cost success
H3	Levels of technology usage for integration link WFs are positively associated with projects' levels of cost success
H4	Levels of technology usage for industry-wide high-tech WFs are positively associated with projects' levels of cost success
H5	Levels of technology usage for industry-wide mid-tech WFs are positively associated with projects' levels of cost success
H6	Levels of technology usage for industry-wide low-tech WFs are positively associated with projects' levels of cost success
H7	Levels of technology usage for cost-sensitive WFs are positively associated with projects' levels of cost success
H8	Levels of project technology usage are positively associated with projects' levels of schedule success
H9	Levels of technology usage for task automation WFs are positively associated with projects' levels of schedule success
H10	Levels of technology usage for integration link WFs are positively associated with projects' levels of schedule success
H11	Levels of technology usage for industry-wide high-tech WFs are positively associated with projects' levels of schedule success
H12	Levels of technology usage for industry-wide mid-tech WFs are positively associated with projects' levels of schedule success
H13	Levels of technology usage for industry-wide low-tech WFs are positively associated with projects' levels of schedule success
H14	Levels of technology usage for schedule-sensitive WFs are positively associated with projects' levels of schedule success
H15	Levels of project technology usage are positively associated with projects' levels of cost & schedule success
H16	Levels of technology usage for task automation WFs are positively associated with projects' levels of cost & schedule success
H17	Levels of technology usage for integration link WFs are positively associated with projects' levels of cost & schedule success
H18	Levels of technology usage for industry-wide high-tech WFs are positively associated with projects' levels of cost & schedule success
H19	Levels of technology usage for industry-wide mid-tech WFs are positively associated with projects' levels of cost & schedule success
H20	Levels of technology usage for industry-wide low-tech WFs are positively associated with projects' levels of cost & schedule success
H21	Levels of technology usage for cost/schedule-sensitive WFs are positively associated with projects' levels of cost & schedule success

and the results of hypothesis testing. Technology usage at different levels and its associated impacts on project cost and schedule success are then discussed. Chapter 6 reiterates key findings and offers recommendations for future research.

Table 1.2: List of Hypotheses for Phase-Level Technology Usage

Number	Hypothesis
H22	Levels of technology usage in Phase 1 & 2 are positively associated with projects' levels of cost success
H23	Levels of technology usage in Phase 3, 4 & 5 are positively associated with projects' levels of cost success
H34	Levels of technology usage in Phase 1 & 2 are positively associated with projects' levels of schedule success
H25	Levels of technology usage in Phase 3, 4 & 5 are positively associated with projects' levels of schedule success
H26	Levels of technology usage in Phase 1 & 2 are positively associated with projects' levels of cost & schedule success
H27	Levels of technology usage in Phase 3, 4 & 5 are positively associated with projects' levels of cost & schedule success

Chapter 2 Research Methodology

This chapter presents the research methodology used to measure the impacts of technology usage on project success. The purpose of these analyses is to determine the relationships between project success and technology usage at the project and phase level. The survey process, methods of analysis, and use of statistical tests are discussed here.

2.1 Survey Process

A nation-wide survey of technology use levels on capital facility projects was conducted to assess the level of use of integration/automation (IA) technologies on projects and the impact of IA technologies on project outcomes. A data collection tool was developed to collect project-based data through interviews. Responses were collected from 30 major metropolitan areas in 24 different U.S. states. Steps were taken to help ensure that computed IA indices are representative of the levels of IA technology used on projects.

The data collection tool measured the degree of technology usage on capital facility projects and their impacts on project performance. The survey was composed of two sections: project/company information and degree of technology use for work functions. The first section of the survey obtains information concerning the project, project type, and final performance of the project in terms of cost and schedule success. The second section assesses level of technology used in executing the project. It addressed 68 work functions covering six project phases: Front End (Phase 1), Design (Phase 2), Procurement (Phase 3), Construction Management (Phase 4), Construction Execution (Phase 5), and Operations & Maintenance (Phase 6). The 68 work functions were divided into two categories: task automation work functions and integration link work functions. The concepts of an automation task and an integration link are defined as follows:

- Automation task - a discrete task for which automation can reduce the amount of human effort required to accomplish the task's objectives
- Integration link - the means by which information is conducted from one discrete task to the next

Participants were asked to evaluate the degree of technology use for each task on the subject project. In assessing the degree of technology used in executing each work function, respondents could choose from three levels: Level 1, Level 2, or Level 3. "Not Applicable" and "Don't Know" responses were also offered as possible responses. Each level of technology utilization was defined as follows:

- Level 1- No electronic tools are used to complete the work function. Information is conveyed verbally or in paper form and transmitted via "snail mail", fax, or courier.

- Level 2- Some electronic tools are used in completing the work function. A machine assists a human in completing the work function. Information is stored in a stand-alone electronic format and transmitted via isolated electronic media like disks or e-mail.
- Level 3- Fully automated systems are used in completing the work function. A human assists the machine in doing the work. Information is stored on a fully networked system where all participants can access and share information easily, e.g. network systems.

2.2 Building Sector Success vs. Industrial Sector Success

Design-Bid-Build (DDB) has been widely used for commercial and most infrastructure projects. Under the Design-Bid-Build approach, project success is measured in terms of cost and schedule performance in the construction phase. For industrial projects, engineering-procurement-construction (EPC) is the most common project delivery method. When compared to building and infrastructure projects, industrial project success is measured by cost and schedule performance across the whole EPC process.

2.3 Use of Statistical Tests

An independent-samples *t* test was conducted to determine whether the data provide evidence for significant differences in performance outcomes being associated with differences in technology usage. The rationale for a *t* test on the difference between the means of two independent groups is based on two assumptions: normal distribution in each population and equal variances for populations. The independent-samples *t* tests were used to evaluate the difference between the means of the two independent groups. The null hypothesis was that the IA index mean for projects with success equals the IA index mean for projects with failure. The alternative hypothesis stated that the means of the two independent groups are not equal. The independent-samples *t* test could not be performed when the assumptions underlying this test were violated. Therefore, a nonparametric alternative called a Mann-Whitney *U* test was also performed to further evaluate the research hypotheses. The Mann-Whitney *U* tests were used to evaluate whether the medians differ significantly between two independent groups. Unlike the independent-samples *t* test, the Mann-Whitney *U* test only assumes that the populations are identical. The decision about which test should be used is based on whether the assumptions underlining the test are satisfied. The significance level for statistical tests (α) was set equal to 0.10. Also, Bonferroni's correction was used to control the experiment-wise Type I error rate.

2.4 Methods of Analysis and Meaning of Tests

The statistical tests evaluate the differences between levels of technology usage of two independent groups. These analyses include three categories: 1) projects with cost success vs. projects with cost failure, 2) projects with schedule success vs. projects with schedule failure, 3) composite project success vs. composite project failure. The methodology associated with these analyses is presented here.

Projects with Cost Success vs. Projects with Cost Failure

Project cost success is defined to have occurred when the total installed cost was significantly *under* or essentially the *same* as authorized budget (i.e. under or on budget). Project cost failure occurs when the total installed cost was significantly *over* authorized budget (i.e. over budget). Since both under-budget and on-budget represent project cost success, steps were taken to merge randomly sampled on-budget data with under-budget data. These analyses focus on determining if there is a difference between projects with cost success and failure in terms of their technology usage. Significant test results indicate that projects with cost success, on average, employ higher levels of technologies than projects with cost failure. In other words, levels of technology usage are positively associated with projects' levels of cost success.

Projects with Schedule Success vs. Projects with Schedule Failure

Project schedule success is defined to have occurred when the actual project completion date was significantly *earlier* than or essentially the *same* as planned (i.e. ahead of or on schedule). Project schedule failure occurs when the actual project completion date was significantly *later* than planned (i.e. behind schedule). Randomly sampled on-schedule data were merged with ahead-of-schedule data to represent project schedule success group. These analyses focus on determining if there is a difference between projects with schedule success and failure in terms of their technology usage. Significant test results indicate that projects with schedule success, on average, employ higher levels of technologies than projects with schedule failure. In other words, levels of technology usage are positively associated with projects' levels of schedule success.

Composite Project Success vs. Composite Project Failure

Composite project success is defined to have occurred when the projects were completed on budget (including under budget) and on schedule (including ahead of schedule). Composite project failure occurs when the projects were over budget and/or behind schedule. These analyses focus on determining if there is a difference between projects with cost and schedule success and failure in terms of their technology usage. Significant test results suggest that levels of technology usage are positively associated with projects' levels of cost and schedule success.

This page intentionally left blank.

Chapter 3 Development of Technology Usage Metrics

Technology usage metrics analyzed include those at the phase level, at the project level, at the task automation level, at the integration link level, and those for cost/schedule-sensitive, industry-wide high-tech, industry-wide mid-tech, and industry-wide low-tech work functions. These indices were developed to measure the use of Integration and Automation technologies in the construction industry. The technology use index values were compared with project success values to determine the relationships between technology usage and projects success.

3.1 Phase Technology Usage

Phase 1 & 2 technology usage is a measure of the level of technologies used in the Front-End and Design phases of sampled projects, which are information-intensive phases. Indices were developed to represent mean responses for the various work function assessments in the Front-End and Design phases of projects. Phase 3, 4 & 5 technology usage is a measure of the level of technologies used in the procurement and on-site phases of a project. This index represents the mean of responses associated with the work function assessments in the Procurement, Construction Management, and Construction Execution phases.

For any given work function, the assessed level of technology on the 1-2-3 scale was established as the Work Function Score. The raw Phase IA Index was then computed to equally weight all Work Function Scores:

Phase 1 & 2 IA Index (raw)
= (Sum of Work Function Scores in phase 1 and 2) / (Total # of WFs in phase 1 and 2 - # of "N/A" responses - # of "Don't Know" responses)

Phase 3, 4 & 5 IA Index (raw)
= (Sum of Work Function Scores in phase 3, 4 and 5) / (Total # of WFs in phase 3, 4 and 5 - # of "N/A" responses - # of "Don't Know" responses)

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

Phase IA Index = (raw Phase IA Index – 1) * 5

3.2 Project Technology Usage

Project IA indices are derived from mean responses associated with all the work function technology assessments on a project. Project IA Index was computed as follows:

Project IA Index (raw)
= (Sum of Work Function Scores for a project) / (Total # of WFs on that project - # of "N/A" responses - # of "Don't Know" responses)

The index values were converted to a 0–10 score in a similar way as used for the Phase IA Index values.

3.3 Automation and Integration Technology Usage

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

Project Task Automation Indices are the means of responses associated with the task automation work function measurements on a project. Similarly, Project Integration Link Indices are the means of responses associated with the integration link work function measurements on a project. Raw indices were computed by equally weighting all associated Work Function Scores and then converting to a 0–10 score:

Project Task Index (raw) = (Sum of all task automation Work Function Scores) / (Total # of task automation work functions assessed on that project)

Phase Link Index (raw) = (Sum of all integration link Work Function Scores) / (Total # of integration link work functions assessed on that project)

3.4 Technology Usage for Industry-Wide High-Tech WFs

The Industry-Wide High-Tech WF Index is a measure of technology usage among WFs with generally high usage levels. The sample-wide mean levels of technology usage for the 68 work functions range from 1.43 to 6.70. Table 3.1 presents the work function-level descriptive statistics for the industry-wide high-tech work functions. Ranging from 4.97 to 6.70 in IA Index value, the highest levels of technology usage pertain to the following 15 work functions:

- 104: Estimate a budget from the scope of work
- 105: Prepare milestone schedule
- 204: Detailed design from conceptual design
- 205: Prepare floor plans
- 206: Design fluid systems
- 207: Design structural systems

- 208: Design electrical systems
- 209: Design HVAC systems
- 212: Prepare specifications
- 214: Track design progress
- 306: Develop the milestone schedule
- 401: Develop the construction schedule
- 402: Tract field work progress & labor cost code charges
- 404: Update cost forecast
- 609: Monitor facility energy consumption

Table 3.1: Industry-Wide High-Tech WFs Descriptive Statistics

ID	Work Function	N	Mean	Std. Dev.	Rank
2.05	Prepare floor plans	135	6.70	3.18	1
2.08	Design electrical systems	133	6.58	3.10	2
2.07	Design structural systems	140	6.39	3.12	3
2.06	Design fluid systems	104	6.39	3.15	4
2.09	Design HVAC systems	117	6.28	3.23	5
2.04	Detailed design from conceptual design	144	5.94	3.74	6
6.09	Monitor facility energy consumption	84	5.83	3.94	7
1.05	Prepare milestone schedule	185	5.62	2.86	8
2.12	Prepare specifications	150	5.40	3.04	9
4.04	Update cost forecast	173	5.29	3.13	10
1.04	Estimate a budget from the scope of work	182	5.27	3.14	11
3.06	Develop the milestone schedule	185	5.24	2.96	12
4.02	Tract field work progress& labor cost code charges	173	5.17	3.18	13
4.01	Develop the construction schedule	182	5.14	2.90	14
2.14	Track design progress	150	4.97	3.50	15

Project-based raw indices were computed by equally weighting all associated Work Function Scores:

Industry-Wide High-Tech WF Index (raw)
= (Sum of all industry-wide high-tech Work Function Scores for a project) / (Total # of industry-wide high-tech work functions assessed on that project)

To translate the raw index to a 0-10 point score, the project indices were computed in the following way:

Industry-Wide High-Tech WF Index
= (raw Industry-Wide High-Tech WF Index – 1) * 5

3.5 Technology Usage for Industry-Wide Mid-Tech WFs

The Industry-Wide Mid-Tech WF Index is a measure of technology utilization among industry-wide mid-tech WFs. Table 3.2 presents the work function-level descriptive statistics for the industry-wide mid-tech work functions. Ranging from 3.39 to 4.21 in IA Index value, the middle levels of technology usage pertain to the following 15 work functions:

- 201: Access supplier product information
- 203: Analyze construction methods
- 304: Link supplier quotes to cost estimate
- 307: Transmit requests for proposal to suppliers and subs
- 308: Prepare & submit shop drawings
- 310: Compile quotes into bid
- 405: Communication construction progress
- 408: Develop short-term work schedules
- 413: Update as-built drawings
- 501: Evaluate subsurface conditions
- 509: Acquire & record laboratory test information
- 604: Track equipment maintenance history
- 605: Develop equipment maintenance plans
- 602: Train facility operators
- 608: Update as-built drawing

Table 3.2: Industry-Wide Mid-Tech WFs Descriptive Statistics

ID	Work Function	N	Mean	Std. Dev.	Rank
6.05	Develop equipment maintenance plans	95	4.21	3.37	28
6.04	Track equipment maintenance history	99	4.14	3.57	29
5.01	Evaluate subsurface conditions	140	4.07	2.79	30
6.08	Update as-built drawings	119	3.99	3.29	31
4.05	Communication construction progress	185	3.95	3.39	32
3.07	Transmit requests for proposal to suppliers and subs	169	3.73	3.23	33
2.01	Access supplier product information	138	3.70	3.54	34
6.02	Train facility operators	114	3.68	3.33	35
4.08	Develop short-term work schedules	170	3.68	3.38	36
3.08	Prepare & submit shop drawings	156	3.62	3.19	37
4.13	Update as-built drawings	183	3.58	3.73	38
2.03	Analyze construction methods	161	3.51	3.57	39
5.09	Acquire & record laboratory test information	144	3.47	3.46	40
3.10	Compile quotes into bid	165	3.45	3.20	41
3.04	Link supplier quotes to cost estimate	165	3.39	3.45	42

Project-based raw indices were computed in the same way as for the industry-wide high-tech WF Index values. All associated Work Function Scores were weighted equally and then converting to a 0–10 point score:

Industry-Wide Mid-Tech WF Index (raw)
= (Sum of all industry-wide mid-tech Work Function Scores for a project) / (Total # of industry-wide mid-tech work functions assessed on that project)

3.6 Technology Usage for Industry-Wide Low-Tech WFs

The Industry-Wide Low-Tech WF Index is a measure of technology usage among WFs with generally low usage levels. Table 3-3 presents the work function-level descriptive statistics for the industry-wide low-tech work functions. Ranging from 1.43 to 2.69 in IA Index value, the lowest levels of technology usage pertain to the following 15 work functions:

- 202: Input on construction methods and sequencing
- 301: Determine procurement lead time
- 311: Monitor fabricator progress
- 312: Plan transport routes
- 403: Maintain daily job diary
- 406: Track site material inventory
- 407: Link field material managers to suppliers
- 409: Communicate Requests for Information & responses
- 411: Communicate changes to field
- 412: Communicate status of change orders to field
- 503: Fabricate rebar cages
- 504: Weld pipes
- 506: Provide elevated work platform
- 508: Manipulate/hang sheet rock
- 511: Apply paint/coatings

Project-based raw indices were computed in the same way as previous index values by equally weighting all associated Work Function Scores and then converting to a 0–10 point score:

Industry-Wide Low-Tech WF Index (raw)
= (Sum of all industry-wide low-tech Work Function Scores for a project) / (Total # of industry-wide low-tech work functions assessed on that project)

Table 3.3: Industry-Wide Low-Tech WFs Descriptive Statistics

ID	Work Function	N	Mean	Std. Dev.	Rank
5.03	Fabricate rebar cages	143	1.43	2.42	54
5.08	Manipulate/hang sheet rock	114	1.45	2.46	55
4.07	Link field material managers to suppliers	125	1.52	2.71	56
3.12	Plan transport routes	104	1.59	2.89	57
4.11	Communicate changes to field	189	1.96	3.07	58
3.11	Monitor fabricator progress	147	1.97	3.02	59
2.02	Input on construction methods and sequencing	157	2.17	2.90	60
4.03	Maintain daily job diary	172	2.18	3.25	61
4.12	Communicate status of change orders to field	185	2.19	3.16	62
5.11	Apply paint/coatings	149	2.28	2.57	63
3.01	Determine procurement lead time	165	2.33	3.10	64
5.04	Weld pipes	142	2.43	3.08	65
4.06	Track site material inventory	151	2.62	3.36	66
4.09	Communicate Requests for Information & responses	170	2.62	3.36	67
5.06	Provide elevated work platform	132	2.69	2.72	68

3.7 Technology Usage for Cost/Schedule-Sensitive WFs

The Cost-Sensitive WF Index is a measure of the overall extent of automating those work functions for which cost performance is thought to be particularly sensitive. Some of the 68 work functions are thought to involve factors or characteristics that may affect the cost performance of a project. These cost-sensitive work functions involve significant financial expenditure or are closely associated with cost control. Similarly, the Schedule-Sensitive WF Index is a measure of the overall extent of automating those work functions for which schedule performance is thought to be particularly sensitive. Some of the 68 work functions are thought to involve factors or characteristics that may affect the schedule performance of a project. These schedule-sensitive work functions involve significant time durations or are closely associated with schedule control. In addition, the Cost/Schedule-Sensitive WF Index is a measure of the overall extent of automating those work functions for which cost or schedule performance is thought to be particularly sensitive. The cost- and schedule-sensitive work functions are presented in Table 3.4.

Raw indices were computed by equally weighting all associated Work Function Scores and then converting to a 0–10 point score:

Cost-Sensitive Work Function Index (raw)
= (Sum of all cost-sensitive Work Function Scores for a project)
/ (Total # of cost-sensitive work functions assessed on that project)

Schedule-Sensitive Work Function Index (raw)
= (Sum of all schedule-sensitive Work Function Scores for a project)
/ (Total # of schedule-sensitive work functions assessed on that project)

Cost/Schedule-Sensitive Work Function Index (raw)
= (Sum of all cost- or schedule-sensitive Work Function Scores for a project) /
(Total # of cost- or schedule-sensitive work functions assessed on that project)

Table 3.4: List of Cost- and Schedule-Sensitive WFs

		Classification	
WF ID	**Description**	**Cost Sensitive**	**Schedule Sensitive**
1.01	Conduct market analysis or need analysis for a new facility	X	X
1.02	Develop, evaluation, and refine the project's scope of work	X	X
1.04	Estimate a budget from the scope of work	X	X
1.05	Develop a milestone schedule from the scope of work		X
2.03	Analyze alternative construction methods for effects on cost, schedule, etc.	X	X
2.10	Document the assumptions used in developing the budget, and pass to the next phase	X	
2.14	Track design progress		X
3.01	Determine the lead time required to order equipment and materials	X	X
3.02	Conduct a quantity survey of drawings	X	
3.03	Link quantity survey data to the cost estimating process	X	
3.04	Link supplier cost quotes to the cost estimating process	X	
3.05	Refine the preliminary budget estimate	X	
3.06	Develop the milestone schedule		X
3.11	Monitor the progress of fabricators	X	X
4.01	Develop the construction schedule		X
4.02	Tract field work progress& labor cost code charges	X	X
4.03	Maintain a daily job diary	X	
4.08	Develop short-term work schedules based on labor, equipment, and material availability		X
6.04	Track & analyze the maintenance history of		X

This page intentionally left blank.

Chapter 4 Project-Level Technology Usage and Associations with Project Success

This chapter addresses the associations between project success and technology usage at the project level. Hypotheses are presented and analyzed according to five different data class variables: industry sector, total installed cost (TIC), public vs. private, greenfield vs. expansion vs. renovation, and typical vs. advanced projects. An appropriate statistical test, either an independent-samples *t* test or a Mann-Whitney *U* test, was conducted to determine whether these data provide evidence for a significant difference in technology usage between projects with success and failure. These analyses fall into three categories: 1) projects with cost success vs. projects with cost failure, 2) projects with schedule success vs. projects with schedule failure, and 3) composite project success vs. composite project failure.

4.1 Projects with Cost Success vs. Projects with Cost Failure

Projects with cost success have total installed cost significantly *under* or essentially the *same* as authorized budget (i.e. under or on budget). Projects with cost failure have total installed cost significantly *over* authorized budget (i.e. over budget). The analyses focus on determining if differences between cost performances are related to differences in technology usage.

Project Technology Usage and Impacts on Cost Success

Project technology use indices are derived from mean responses associated with all the work function technology assessments on a project. Table 4.1 shows the levels of project technology usage by project cost performance. The largest differences in levels of project technology usage between projects with cost success and failure are associated with Building projects. Table 4.2 presents the results of the independent-samples *t* test performed on the significance of the difference between Building projects with cost success and failure in terms of project technology usage. The test results indicate that there is no evidence of significant differences in levels of project technology usage between projects with cost success and failure.

Task Automation and Impacts on Cost Success

The Task Automation Index was computed to measure overall progress in automating tasks. Table 4.3 shows the levels of task automation technology usage by project cost performance. The largest differences in levels of task automation technology usage between projects with cost success and failure are associated with Building projects. An independent-samples *t* test was conducted on the significance of the difference between projects with cost success and failure in terms of task automation technology usage. Table 4.4 presents the results of the independent-samples *t* test for Building projects. These analyses reveal statistically significant differences in levels of technology usage for task automation WFs between Building projects with cost success and failure. This suggests that higher levels of technology usage for task automation WFs may contribute significantly to project cost success for Building projects. Other project types did not produce significant results.

Table 4.1: Project Technology Usage vs. Cost Performance by Category

	Projects with Cost Success		Projects with Cost Failure		I/A Mean Difference
Project Type	I/A	N	I/A	N	(Success-Failure)
All projects	4.63	50	3.93	16	0.60
Building	4.40	18	3.12	5	1.28
Infrastructure	3.89	10	2.83	5	1.06
$5-50 mil.	4.17	28	3.15	10	1.02
>$50 mil.	4.16	20	3.96	6	0.20
Private	4.34	34	3.79	9	0.55
Public	3.49	14	3.02	7	0.47
Greenfield	4.35	28	3.78	7	0.57
Typical	4.23	41	3.65	12	0.58

Table 4.2: *t*-Test for Project Technology Usage vs. Cost Performance

	Projects with Cost Success			Projects with Cost Failure						
Project Type	N	Mean	Standard Deviation	N	Mean	Standard Deviation	Mean Diff.	t	Sig. (2-tailed)	Effect Size Statistic (eta square)
Building	18	4.40	2.07	5	3.12	1.67	1.28	1.26	0.221	0.07

Table 4.3: Task Automation vs. Cost Performance by Category

	Projects with Cost Success		Projects with Cost Failure		I/A Mean Difference
Project Type	I/A	N	I/A	N	(Success-Failure)
All projects	4.63	50	3.93	16	0.70
Building	4.96	18	3.45	5	1.51
Infrastructure	4.19	10	3.37	5	0.82
$5-50 mil.	4.75	28	3.59	10	1.16
>$50 mil.	4.83	20	4.48	5	0.35
Private	4.49	34	4.35	9	0.14
Public	3.99	14	3.41	7	0.58
Greenfield	4.92	28	4.24	7	0.68
Typical	5.10	42	4.15	12	0.95

Table 4.4: *t*-Test for Task Automation vs. Cost Performance

Project Type	Projects with Cost Success N	Mean	Standard Deviation	Projects with Cost Failure N	Mean	Standard Deviation	Mean Diff.	t	Sig. (2-tailed)	Effect Size Statistic (eta square)
Building	18	4.96	1.60	5	3.45	1.55	1.51	1.88	0.074	0.14

Integration Link and Impacts on Cost Success

The integration link index is a measure of overall progress in automating the transfer of information between tasks (or organizations). Table 4.5 shows the levels of integration technology usage by project cost performance. . The only category with a substantial difference in integration technology usage between projects with cost success and failure is Infrastructure projects. Table 4.6 presents the results of statistical test performed on the significance of the difference between Infrastructure projects with cost success and failure in terms of integration technology usage. The test results indicate that there is no significant difference in levels of integration technology usage between projects with cost success and failure.

Table 4.5: Integration Link vs. Cost Performance by Category

Project Type	Projects with Cost Success I/A	N	Projects with Cost Failure I/A	N	I/A Mean Difference (Success-Failure)
All projects	3.82	50	3.12	16	0.70
Building	3.85	18	2.66	5	1.19
Industrial	3.93	22	3.83	6	0.10
Infrastructure	3.98	10	2.73	5	1.25
$5-50 mil.	3.51	28	2.83	10	0.68
>$50 mil.	4.03	20	3.42	5	0.61
Private	4.15	34	3.27	9	0.88
Public	3.42	14	2.92	7	0.50
Greenfield	3.85	28	3.38	7	0.47
Typical	4.32	42	3.33	12	0.99

Table 4.6: *t*-Test for Integration Link vs. Cost Performance

Project Type	Projects with Cost Success N	Mean	Standard Deviation	Projects with Cost Failure N	Mean	Standard Deviation	Mean Diff.	t	Sig. (2-tailed)	Effect Size Statistic (eta square)
Infra.	10	3.98	1.34	5	2.73	1.59	1.25	1.62	0.130	0.17

Industry-Wide High-Tech WFs and Impacts on Cost Success

The Industry-Wide High-Tech WF Index is a measure of technology usage among WFs with generally high usage levels. Table 4.7 presents the levels of high-tech WF technology usage by project cost performance. From the descriptive statistics, the categories with a large difference in high-tech WF technology usage between projects with cost success and failure are Building, Infrastructure, Medium-sized, and Public projects.

Independent-samples *t* tests were conducted to determine the statistical significance of the proposed relationships, and the results are shown in Table 4.8. In addition, Table 4.9 shows Mann-Whitney *U* tests used to evaluate the hypotheses that projects with cost success employ higher levels of high-tech WF technology usage than projects with cost failure. The Bonferroni approach is used to control for Type I error across pairwise comparisons. Each comparison is tested at the 0.10/5, or 0.02, level (0.10 divided by the number of tests conducted). The results of the Mann-Whitney *U* tests were significant (p-values < 0.02). Analyses suggest that higher levels of high-tech WF technology usage may contribute significantly to project cost success, particularly for Building, Medium-sized ($5-50 mil.), and Public projects. However, the test for Infrastructure projects was nonsignificant. This indicates that there is no evidence of significant differences for Infrastructure projects.

Table 4.7: High-Tech WF Usage vs. Cost Performance by Category

	Projects with Cost Success		Projects with Cost Failure		I/A Mean Difference
Project Type	I/A	N	I/A	N	(Success-Failure)
All projects	6.20	50	4.73	16	1.47
Building	6.87	18	4.42	5	2.45
Industrial	5.90	22	5.72	6	0.18
Infrastructure	6.30	10	3.85	5	2.45
$5-50 mil.	6.50	28	4.51	10	1.99
>$50 mil.	6.27	20	5.11	6	1.16
Private	6.53	34	5.20	9	1.32
Public	6.52	14	4.13	7	2.39
Greenfield	6.74	28	5.11	7	1.63
Typical	5.96	41	5.01	12	0.95

Table 4.8: *t*-Tests for High-Tech WF Usage vs. Cost Performance

	Projects with Cost Success			Projects with Cost Failure						
Project Type	N	Mean	Standard Deviation	N	Mean	Standard Deviation	Mean Diff.	t	Sig. (2-tailed)	Effect Size Statistic (eta square)
All projects	50	6.20	1.94	16	4.73	2.15	1.47	2.56	0.013	0.09
Infra.	10	6.30	2.19	5	3.85	1.36	2.45	2.26	0.041	0.28

Table 4.9: **Mann-Whitney *U* tests for High-Tech WF Usage vs. Cost Performance**

Project Type	Projects with Cost Success N	Mean Rank	Sum of Ranks	Projects with Cost Failure N	Mean Rank	Sum of Ranks	z	Sig. (2-tailed)
Building	18	14.11	254.00	5	4.40	22.00	-2.85	0.002
Medium	28	22.48	629.50	10	11.15	111.50	-2.78	0.004
Public	14	13.43	188.00	7	6.14	43.00	-2.59	0.010

Industry-Wide Mid-Tech WFs and Impacts on Cost Success

The Industry-Wide Mid-Tech WF Index is a measure of technology utilization among industry-wide mid-tech WFs. Table 4.10 presents the levels of mid-tech WF technology usage by project cost performance. The only category with a substantial difference (1.96) in mid-tech WF technology usage between projects with cost success and failure is Infrastructure projects. Table 4.11 presents the results of statistical tests conducted to determine the statistical significance of the proposed relationship for Infrastructure projects. The test results indicate that there is no significant difference in levels of mid- tech WF usage between projects with cost success and failure for Infrastructure projects.

Table 4.10: Mid-Tech WF Usage vs. Cost Performance by Category

Project Type	Projects with Cost Success I/A	N	Projects with Cost Failure I/A	N	I/A Mean Difference (Success-Failure)
All projects	4.02	50	3.49	16	0.53
Building	3.97	18	3.05	5	0.92
Industrial	4.31	22	4.28	6	0.03
Infrastructure	4.95	10	2.99	5	1.96
$5-50 mil.	3.77	28	3.06	10	0.71
>$50 mil.	4.26	20	4.21	6	0.05
Private	4.71	34	3.70	9	1.01
Public	3.44	14	3.22	7	0.22
Greenfield	4.54	28	3.57	7	0.97
Typical	4.00	42	3.64	12	0.36

Table 4.11: *t*-Test for Mid-Tech WF Usage vs. Cost Performance

Project Type	Projects with Cost Success N	Mean	Standard Deviation	Projects with Cost Failure N	Mean	Standard Deviation	Mean Diff.	t	Sig. (2-tailed)	Effect Size Statistic (eta square)
Infra.	10	4.95	2.60	5	2.99	1.71	1.96	1.52	0.153	0.15

Industry-Wide Low-Tech WFs and Impacts on Cost Success

The Industry-Wide Low-Tech WF Index is a measure of technology usage among WFs with generally low usage levels. Table 4.12 presents the levels of low-tech WF technology usage by project cost performance. The only category with a large difference, 1.12, in low-tech WF technology usage between projects with cost success and failure is Public projects. Table 4.13 presents the results of statistical tests performed on the significance of the difference between Public projects with cost success and failure in terms of low-tech WF usage. The test results indicate no significant differences.

Table 4.12: Low-Tech WF Usage vs. Cost Performance by Category

Project Type	Projects with Cost Success		Projects with Cost Failure		I/A Mean Difference
	I/A	N	I/A	N	(Success-Failure)
All projects	2.33	50	2.26	16	0.07
Building	2.27	18	2.09	5	0.18
Infrastructure	1.90	10	1.64	5	0.26
$5-50 mil.	2.41	28	2.06	10	0.35
>$50 mil.	2.63	20	2.60	6	0.03
Private	2.71	34	2.68	9	0.03
Public	2.83	14	1.71	7	1.12
Greenfield	3.00	28	2.96	7	0.04
Typical	2.72	42	2.39	12	0.33

Table 4.13: *t*-Test for Low-Tech WF Usage vs. Cost Performance

Project Type	Projects with Cost Success			Projects with Cost Failure			Mean Diff.	t	Sig. (2-tailed)	Effect Size Statistic (eta square)
	N	Mean	Standard Deviation	N	Mean	Standard Deviation				
Public	10	4.95	2.60	5	2.99	1.71	1.96	1.52	0.153	0.15

Cost-Sensitive WFs and Impacts on Cost Success

The Cost-Sensitive WF Index is a measure of the overall extent of automating those work functions for which cost performance is thought to be particularly sensitive. Table 4.14 presents the levels of cost-sensitive WF technology usage by project cost performance. The only category with a large difference, 1.82, in technology usage between projects with cost success and failure is Infrastructure projects. Table 4.15 presents the results of statistical tests conducted on the significance of the difference between Infrastructure projects with cost success and failure in terms of technology usage for cost-sensitive work functions. The results indicate that higher levels of cost-sensitive WF technology usage may contribute to the cost success of Infrastructure projects.

Table 4.14: Cost-Sensitive WF Usage vs. Cost Performance by Category

Project Type	Projects with Cost Success I/A	N	Projects with Cost Failure I/A	N	I/A Mean Difference (Success-Failure)
All projects	4.48	50	3.66	16	0.82
Building	5.07	18	4.07	5	1.00
Infrastructure	4.65	10	2.83	5	1.82
$5-50 mil.	4.77	28	3.46	10	1.31
>$50 mil.	4.05	20	4.00	6	0.05
Private	4.43	34	3.89	9	0.54
Public	4.49	14	3.37	7	1.12
Greenfield	5.13	28	3.95	7	1.18
Typical	4.98	42	4.13	12	0.85

Table 4.15: *t*-Test for Cost-Sensitive WF Usage vs. Cost Performance

Project Type	Projects with Cost Success N	Mean	Standard Deviation	Projects with Cost Failure N	Mean	Standard Deviation	Mean Diff.	t	Sig. (2-tailed)	Effect Size Statistic (eta square)
Infra.	10	4.65	1.81	5	2.83	1.73	1.82	1.86	0.086	0.21

4.2 Projects with Schedule Success vs. Projects with Schedule Failure

Projects with schedule success are defined as having an actual project completion date significantly *earlier* than or essentially the *same* as the planned date. Projects with schedule failure have an actual project completion date significantly *later* than planned. The following analyses focus on determining if differences between schedule performances are related to differences in technology usage.

Project Technology Usage and Impacts on Schedule Performance

Table 4.16 shows the levels of project technology usage by project schedule performance. Observations on the project technology use index values by different variables were developed to identify suspected relationships. The largest differences in levels of project technology usage between projects with schedule success and failure are found in Building projects. Statistical tests were conducted to determine the statistical significance of the proposed relationship. Table 4.17 presents the results of the Mann-Whitney *U* test for Building projects. These analyses suggest that Building projects may achieve higher levels of schedule success with increased technology usage.

Table 4.16: Project Technology Usage vs. Schedule Performance by Category

Project Type	Projects with Schedule Success I/A	Projects with Schedule Success N	Projects with Schedule Failure I/A	Projects with Schedule Failure N	I/A Mean Difference (Success-Failure)
All projects	4.10	36	3.95	21	0.15
Building	4.33	12	3.17	9	1.16
$5-50 mil.	4.29	26	3.96	16	0.33
>$50 mil.	4.51	10	3.94	5	0.57
Private	4.78	16	4.15	13	0.63
Public	3.73	16	3.63	8	0.10
Expansion	3.89	10	3.38	8	0.51
Typical	4.12	28	4.04	18	0.08

Table 4.17: Mann-Whitney *U* Test for Project Technology Usage vs. Schedule Performance

Project Type	Projects with Schedule Success N	Mean Rank	Sum of Ranks	Projects with Schedule Failure N	Mean Rank	Sum of Ranks	z	Sig. (2-tailed)
Building	12	14.58	175.00	9	6.22	56.00	-3.06	0.001

Task Automation and Impacts on Schedule Success

The Task Automation Index is a measure of the level of technology used in task automation work functions of a project. Table 4.18 shows the levels of task automation technology usage by project schedule performance. From the descriptive statistics, the only category found with a large difference in task automation technology usage between projects with schedule success and failure is Building projects with a mean of 5.38 and 3.64 respectively. An independent-samples *t* test was conducted on the significance of the difference between Building projects with schedule success and failure in terms of task automation technology usage. Table 4.19 presents the results of the test for Building projects. These analyses reveal statistically significant differences in levels of technology usage for task automation WFs between projects with schedule success and failure, which suggests that higher levels of task automation technology usage may contribute to project schedule success for Building projects.

Table 4.18: Task Automation vs. Schedule Performance by Category

Project Type	Projects with Schedule Success I/A	N	Projects with Schedule Failure I/A	N	I/A Mean Difference (Success-Failure)
All projects	4.67	36	4.46	21	0.21
Building	5.38	12	3.64	9	1.74
$5-50 mil.	4.99	26	4.40	16	0.59
>$50 mil.	4.95	10	4.71	5	0.24
Private	4.92	16	4.60	13	0.32
Public	5.02	16	4.26	8	0.76
Expansion	4.34	10	3.81	8	0.53
Typical	4.67	28	4.56	18	0.11

Table 4.19: *t*-Test for Task Automation vs. Schedule Performance

Project Type	Projects with Schedule Success N	Mean	Standard Deviation	Projects with Schedule Failure N	Mean	Standard Deviation	Mean Diff.	t	Sig. (2-tailed)	Effect Size Statistic (eta square)
Building	12	5.38	1.46	9	3.64	1.50	1.74	2.66	0.015	0.27

Integration Link and Impacts on Schedule Success

The Integration Link Index is a measure of the level of technology used in integration link work functions of a project. Table 4.20 shows the levels of integration technology usage by project schedule performance. The largest differences in levels of integration technology usage between projects with schedule success and failure are associated with Building projects with a difference of 2.28. Statistical tests were conducted on the significance of the difference between projects with schedule success and failure in terms of integration technology usage. Table 4.21 presents the results of the independent-samples *t* test showing that significant differences in levels of integration technology usage between Building projects with schedule success and failure are observed. This suggests that higher levels of integration technology usage may contribute significantly to project schedule success for Building projects.

Table 4.20: Integration Link vs. Schedule Performance by Category

Project Type	Projects with Schedule Success		Projects with Schedule Failure		I/A Mean Difference (Success-Failure)
	I/A	N	I/A	N	
All projects	4.05	36	3.53	21	0.52
Building	4.66	12	2.38	9	2.28
$5-50 mil.	4.14	26	3.61	16	0.53
>$50 mil.	4.07	10	3.29	5	0.78
Private	4.29	16	3.60	13	0.69
Public	3.95	16	3.42	8	0.53
Expansion	3.35	10	2.99	8	0.36
Typical	3.63	28	3.68	18	0.11

Table 4.21: *t*-Test for Integration Link vs. Schedule Performance

Project Type	Projects with Schedule Success			Projects with Schedule Failure			Mean Diff.	t	Sig. (2-tailed)	Effect Size Statistic (eta square)
	N	Mean	Standard Deviation	N	Mean	Standard Deviation				
Building	12	4.66	1.93	9	2.38	1.47	2.28	2.95	0.008	0.31

Industry-Wide High-Tech WFs and Impacts on Schedule Success

The Industry-Wide High-Tech WF Index is a measure of technology usage among WFs with generally high usage levels. Table 4-22 presents the levels of high-tech WF technology usage by project schedule performance. From the descriptive statistics, two categories found with a large difference in high-tech WF technology usage between projects with schedule success and failure are Building and Expansion projects. Tests were conducted to determine the statistical significance of the proposed relationships, and the results are shown in Table 4-23. The Bonferroni approach was used to control for Type I error across pairwise comparisons. Each comparison is tested at the 0.10/2, or 0.05, level. These analyses reveal statistically significant differences in levels of high-tech WF technology usage for Building projects with schedule success and failure, which suggests that higher levels of high-tech WF technology usage may contribute to the schedule success of Building projects. However, the results indicate that there is no evidence for Expansion projects.

Industry-Wide Mid-Tech WFs and Impacts on Schedule Success

The Industry-Wide Mid-Tech WF Index is a measure of technology usage among industry-wide mid-tech WFs. Table 4.24 presents the levels of mid-tech WF technology usage by project schedule performance. Building and Private projects show a substantial difference in mid-tech WF technology usage between projects with schedule success and failure. Table 4.25 presents the results of statistical tests performed on the significance of the difference between Building or Private projects with schedule success and failure in terms of mid-tech WF technology usage. The Bonferroni approach was used to control for Type I error across pairwise comparisons. Each comparison is tested at the 0.10/2, or 0.05, level. These analyses reveal statistically significant differences in mid-tech tech WF technology usage between projects with schedule success and failure for Building and Private projects.

Table 4.22: High-Tech WF Usage vs. Schedule Performance by Category

Project Type	Projects with Schedule Success		Projects with Schedule Failure		I/A Mean Difference
	I/A	N	I/A	N	(Success-Failure)
All projects	6.04	36	5.81	21	0.23
Building	6.93	12	5.00	9	1.93
$5-50 mil.	6.23	26	5.77	16	0.46
>$50 mil.	6.30	10	5.92	5	0.38
Private	6.54	16	5.78	13	0.76
Public	6.33	16	5.84	8	0.49
Expansion	6.54	10	4.97	8	1.57
Typical	6.11	28	5.98	18	0.13

Table 4.23: Mann-Whitney *U* Tests for High-Tech WF Usage vs. Schedule Performance

Project Type	Projects with Schedule Success			Projects with Schedule Failure			z	Sig. (2-tailed)
	N	Mean Rank	Sum of Ranks	N	Mean Rank	Sum of Ranks		
Building	12	13.50	162.00	9	7.67	69.00	-2.15	0.034
Expansion	10	11.60	116.00	8	6.88	55.00	-1.95	0.068

Table 4.24: Mid-Tech WF Usage vs. Schedule Performance by Category

Project Type	Projects with Schedule Success		Projects with Schedule Failure		I/A Mean Difference
	I/A	N	I/A	N	(Success-Failure)
All projects	4.08	36	3.64	21	0.44
Building	5.41	12	2.52	9	2.89
$5-50 mil.	4.26	26	3.54	16	0.72
>$50 mil.	4.13	10	3.94	5	0.19
Private	5.46	16	3.90	13	1.56
Public	4.17	16	3.21	8	0.96
Expansion	4.29	10	3.45	8	0.84
Typical	3.80	28	3.62	18	0.18

Table 4.25: Mann-Whitney *U* Tests for Mid-Tech WF Usage vs. Schedule Performance

Project Type	Projects with Schedule Success			Projects with Schedule Failure			z	Sig. (2-tailed)
	N	Mean Rank	Sum of Ranks	N	Mean Rank	Sum of Ranks		
Building	12	14.83	178.00	9	5.89	53.00	-3.28	0.000
Private	16	18.16	290.50	13	11.12	144.50	-2.22	0.025

Industry-Wide Low-Tech WFs and Impacts on Schedule Success

The Industry-Wide Low-Tech WF Index is a measure of technology usage among WFs with generally low usage levels. Table 4.26 presents the levels of low-tech WF technology usage by project schedule performance. The difference in low-tech WF technology use index between successful and non-successful Building projects is 1.65. Tests were conducted to determine if there is a significant relationship for Building projects, and the results are shown in Table 4.27. These analyses reveal statistically significant differences in levels of low-tech WF technology usage between Building projects with schedule success and failure, which suggests that levels of low-tech WF technology usage are positively associated with Building projects' levels of schedule success.

Table 4.26: Low-Tech WF Usage vs. Schedule Performance by Category

Project Type	Projects with Schedule Success		Projects with Schedule Failure		I/A Mean Difference (Success-Failure)
	I/A	N	I/A	N	
All projects	2.37	36	2.33	20	0.04
Building	2.77	12	1.12	8	1.65
$5-50 mil.	2.64	26	2.36	15	0.28
>$50 mil.	2.43	10	2.26	5	0.17
Private	2.54	16	2.46	12	0.08
Public	2.47	16	2.13	8	0.34
Expansion	2.18	10	1.41	8	0.77
Typical	2.39	28	2.29	17	0.10

Table 4.27: Mann-Whitney *U* Test for Low-Tech WF Usage vs. Schedule Performance

Project Type	Projects with Schedule Success			Projects with Schedule Failure			z	Sig. (2-tailed)
	N	Mean Rank	Sum of Ranks	N	Mean Rank	Sum of Ranks		
Building	12	13.04	156.50	8	6.69	53.50	-2.36	0.016

Schedule-Sensitive WFs and Impacts on Schedule Success

The Schedule-Sensitive WF Index is a measure of the overall extent of automating those work functions for which schedule performance is thought to be particularly sensitive. Table 4-28 presents the levels of technology usage for schedule-sensitive work functions by project schedule performance. Building projects with schedule success have the highest mean at 6.87 and Building projects with schedule failure have the lowest mean of 3.16, making this category have the largest differences in levels of technology usage for schedule-sensitive work functions. Tests were conducted to determine if the observed differences were significant, and the results are shown in Tables 4.29 and 4.30. The Bonferroni approach was used to control for Type I error across pairwise comparisons. Each comparison is tested at the 0.10/2, or 0.05, level. The test results suggest that higher levels of technology usage for schedule-sensitive WFs may contribute to the schedule success of Building and Expansion projects.

Table 4.28: Schedule-Sensitive WF Usage vs. Schedule Performance by Category

	Projects with Schedule Success		Projects with Schedule Failure		I/A Mean Difference
Project Type	I/A	N	I/A	N	(Success-Failure)
All projects	4.85	36	4.28	21	0.57
Building	6.87	12	3.16	9	3.71
$5-50 mil.	5.09	26	4.23	16	0.86
>$50 mil.	4.68	10	4.43	5	0.25
Private	4.81	16	4.22	13	0.59
Public	5.43	16	4.38	8	1.05
Expansion	5.12	10	3.52	8	1.60
Typical	4.97	28	4.36	18	0.61

Table 4.29: Mann-Whitney *U* Test for Schedule-Sensitive WF Usage vs. Schedule Performance

	Projects with Schedule Success			Projects with Schedule Failure				
Project Type	N	Mean Rank	Sum of Ranks	N	Mean Rank	Sum of Ranks	z	Sig. (2-tailed)
Building	12	15.13	181.50	9	5.50	49.50	-3.53	.000

Table 4.30: *t*-Test for Schedule-Sensitive WF Usage vs. Schedule Performance

	Projects with Schedule Success			Projects with Schedule Failure						
Project Type	N	Mean	Standard Deviation	N	Mean	Standard Deviation	Mean Diff.	t	Sig. (2-tailed)	Effect Size Statistic (eta square)
Expansion	10	5.12	.74	8	3.52	1.11	1.60	3.69	0.002	0.46

4.3 Composite Project Success vs. Composite Project Failure

This section provides a composite analysis of project cost and schedule success. There was inadequate data to provide breakouts at the category level, but results are informative nonetheless because they represent a synthesis of two critical project performance metrics. Composite project success is defined to have occurred when the projects were on or under budget and on or ahead of schedule. The following analyses focus on determining if differences between composite project performances are related to differences in technology usage.

Project Technology Usage and Impacts on Composite Project Success

Table 4.31 shows the levels of project technology usage by composite project performance. The mean project technology use index value for projects with cost & schedule success is found to be 4.43 while the mean for projects with cost & schedule failure is 3.40. The difference between these two values is 1.03.

Table 4.32 presents the results of the independent-samples *t* test performed on the significance of the difference between projects with composite project success and failure in terms of project technology usage. These analyses reveal statistically significant differences in levels of project technology usage between projects with composite success and failure. This suggests that higher levels of project technology usage may contribute significantly to composite cost and schedule project success.

Table 4-31: Project Technology Usage vs. Cost & Schedule Performance for All Projects

Projects with Cost & Schedule Success		Projects with Cost & Schedule Failure		I/A Mean Difference
I/A	N	I/A	N	(Success-Failure)
4.43	20	3.40	18	1.03

Table 4.32: *t*-Test for Project Technology Usage vs. Cost & Schedule Performance

	Projects with Cost & Schedule Success			Projects with Cost & Schedule Failure						
Project Type	N	Mean	Standard Deviation	N	Mean	Standard Deviation	Mean Diff.	t	Sig. (2-tailed)	Effect Size Statistic (eta square)
All projects	20	4.43	1.93	18	3.40	1.60	1.03	1.78	0.083	0.08

Task Automation and Impacts on Composite Project Success

Table 4.33 shows the levels of task automation technology usage by project cost & schedule performance. The mean index values for projects with success and failure are 5.13 and 4.08 respectively. The difference between these two values is 1.05. Statistical tests were conducted to determine if the difference was significant. Table 4.34 presents the results of the independent-samples *t* test, and these analyses reveal significant differences.

Table 4.33: Task Automation vs. Cost & Schedule Performance for All Projects

Projects with Cost & Schedule Success		Projects with Cost & Schedule Failure		I/A Mean Difference (Success-Failure)
I/A	N	I/A	N	
5.13	20	4.08	18	1.05

Table 4.34: *t*-Test for Task Automation vs. Cost & Schedule Performance

Project Type	Projects with Cost & Schedule Success			Projects with Cost & Schedule Failure			Mean Diff.	t	Sig. (2-tailed)	Effect Size Statistic (eta square)
	N	Mean	Standard Deviation	N	Mean	Standard Deviation				
All projects	20	5.13	1.92	18	4.08	1.84	1.05	1.71	0.096	0.08

Integration Link and Impacts on Composite Project Success

Table 4.35 shows the levels of integration technology usage by project cost & schedule performance. The mean integration technology use index value for projects with cost & schedule success is 4.17 while the mean project technology use index value for projects with cost & schedule failure is 3.73. The difference between these two values is not substantial; therefore, no statistical test of significance was conducted.

Table 4.35: Integration Link vs. Cost & Schedule Performance for All Projects

Projects with Cost & Schedule Success		Projects with Cost & Schedule Failure		I/A Mean Difference (Success-Failure)
I/A	N	I/A	N	
4.17	20	3.73	18	0.44

Industry-Wide High-Tech WFs and Impacts on Composite Project Success

Table 4.36 shows the levels of high-tech WF technology usage by composite project performance. The mean technology use index value for projects with cost & schedule success is 6.85 while the mean index value for projects with cost & schedule failure is 5.05. The difference between these two values is 1.80. Statistical tests were conducted to determine the significance of the difference. Table 4.37 presents the results of the independent-samples *t* test. These analyses reveal significant differences suggesting that levels of high-tech WF technology usage are positively associated with projects' levels of cost and schedule success.

Table 4.36: High-Tech WF Usage vs. Cost & Schedule Performance for All Projects

Projects with Cost & Schedule Success		Projects with Cost & Schedule Failure		I/A Mean Difference (Success-Failure)
I/A	N	I/A	N	
6.85	20	5.05	18	1.80

Table 4.37: *t*-Test for High-Tech WF Usage vs. Cost & Schedule Performance

Project Type	Projects with Cost & Schedule Success			Projects with Cost & Schedule Failure			Mean Diff.	t	Sig. (2-tailed)	Effect Size Statistic (eta square)
	N	Mean	Standard Deviation	N	Mean	Standard Deviation				
All projects	20	6.85	2.29	18	5.05	2.12	1.80	2.51	.017	.15

Industry-Wide Mid-Tech WFs and Impacts on Composite Project Success

Table 4.38 shows the levels of mid-tech WF usage by project cost & schedule performance. The mean technology use index value for projects with cost & schedule success is 4.32 while the mean for projects with cost & schedule failure is 3.32. The difference between these two values is 1.00. Statistical tests were conducted to determine the statistical significance. However, the results indicate that there is no significant difference in levels of mid-tech WF technology usage between projects with composite success and failure.

Table 4.38: Mid-Tech WF Usage vs. Cost & Schedule Performance for All Projects

Projects with Cost & Schedule Success		Projects with Cost & Schedule Failure		I/A Mean Difference (Success-Failure)
I/A	N	I/A	N	
4.32	20	3.32	18	1.00

Industry-Wide Low-Tech WFs and Impacts on Composite Project Success

Table 4.39 shows the levels of low-tech WF technology usage by project cost & schedule performance. The mean technology use index value for projects with cost & schedule success is 2.71 while the mean index value for failure is 2.68. The difference between these two values is not substantial. Thus, no statistical test was conducted.

Table 4.39: Low-Tech WF Usage vs. Cost & Schedule Performance for All Projects

Projects with Cost & Schedule Success		Projects with Cost & Schedule Failure		I/A Mean Difference (Success-Failure)
I/A	N	I/A	N	
2.71	20	2.68	18	0.03

Cost/Schedule-Sensitive WFs and Impacts on Composite Project Success

Table 4.40 shows the levels of technology usage for cost- or schedule-sensitive work functions by composite project performance. The mean technology use index value for success is 5.45 while the mean for failure is 4.06. The difference between these two values is 1.39. Statistical tests were conducted to determine if this difference was significant. Table 4.41 presents the results of the independent-samples t test, and these analyses reveal significant differences in technology usage for different levels of project success. This suggests that levels of technology usage for cost- or schedule-sensitive WFs are positively associated with projects' levels of cost and schedule success.

Table 4.40: Cost/Schedule-Sensitive WF Usage vs.

Cost & Schedule Performance for All Projects

Projects with Cost & Schedule Success		Projects with Cost & Schedule Failure		I/A Mean Difference
I/A	N	I/A	N	(Success-Failure)
5.45	20	4.06	18	1.39

Table 4.41: *t*-Test for Cost/Schedule-Sensitive WF Usage vs.

Cost & Schedule Performance

Project Type	Projects with Cost & Schedule Success			Projects with Cost & Schedule Failure			Mean Diff.	t	Sig. (2-tailed)	Effect Size Statistic (eta square)
	N	Mean	Standard Deviation	N	Mean	Standard Deviation				
All projects	20	5.45	2.38	18	4.06	2.20	1.39	1.86	0.071	0.09

This page intentionally left blank.

Chapter 5 Phase-Level Technology Usage and Associations with Project Success

This chapter addresses the findings from analysis of associations between project success and technology usage at the *phase* level. *Phase*-level technology usage metrics analyzed include Phase 1 & 2 and Phase 3, 4 & 5 technology usage. Phase 6 technology usage is excluded from the analysis because the success measures analyzed (cost and schedule performance) are less representative of Phase 6 work functions. These analyses fall into three categories: 1) projects with cost success vs. projects with cost failure, 2) projects with schedule success vs. projects with schedule failure, and 3) composite project success vs. composite project failure. The results of these analyses and details regarding their statistical significance are presented here.

5.1 Projects with Cost Success vs. Projects with Cost Failure

The focus of the analyses discussed here was to determine if there is a statistically significant difference between projects with cost success and failure in terms of technology usage at the phase level.

Phase 1 & 2 Technology Usage and Impacts on Cost Success

Phase 1 & 2 technology usage is a measure of the level of technologies used in the Front-End and Design phases of sampled projects, which are information-intensive phases. Indices were developed to represent mean responses for the various work function assessments in the Front-End and Design phases of projects. Table 5.1 shows the levels of Phase 1 & 2 technology usage by project cost performance. It was observed that cost-successful Building projects have the highest mean of 5.60 and cost-failure Building projects have the lowest mean project technology use index, 3.43, representing the largest observed differences. Statistical tests were conducted to analyze if there is a statistically significant difference between projects with cost success and failure in terms of Phase 1 & 2 technology usage. Table 5.2 presents the results of the independent-samples *t* test. These analyses reveal significant differences in levels of Phase 1 & 2 technology usage between projects with cost success and failure, which suggests that higher levels of technology usage in the Front-End and Design phases may contribute to project cost success.

Phase 3, 4 & 5 Technology Usage and Impacts on Cost Success

Phase 3, 4 & 5 technology usage is a measure of the level of technologies used in the procurement and on-site phases of a project. This index represents the mean of responses associated with the work function assessments in the Procurement, Construction Management, and Construction Execution phases. Table 5.3 shows the levels of Phase 3, 4 & 5 technology usage by project cost performance. No statistical test of significance was performed.

Table 5.1: Phase 1 & 2 Technology Usage vs. Cost Performance by Category

Project Type	Projects with Cost Success I/A	Projects with Cost Success N	Projects with Cost Failure I/A	Projects with Cost Failure N	I/A Mean Difference (Success-Failure)
All projects	5.35	46	3.99	15	1.36
Building	5.60	18	3.43	5	2.17
Industrial	5.21	20	4.80	6	0.41
$5-50 mil.	5.26	26	3.70	9	1.56
>$50 mil.	5.45	18	4.41	6	1.04
Private	5.71	32	4.22	9	1.49
Public	4.79	12	3.63	6	1.16
Greenfield	5.52	24	4.20	7	1.32
Typical	5.27	38	4.39	11	0.88

Table 5.2: *t*-Test for Phase 1 & 2 Technology Usage vs. Cost Performance

Project Type	Projects with Cost Success N	Mean	Standard Deviation	Projects with Cost Failure N	Mean	Standard Deviation	Mean Diff.	t	Sig. (2-tailed)	Effect Size Statistic (eta square)
All projects	46	5.35	2.07	15	3.99	2.43	1.36	2.12	0.038	0.07

Table 5.3: Phase 3, 4 & 5 Technology Usage vs. Cost Performance by Category

Project Type	Projects with Cost Success I/A	Projects with Cost Success N	Projects with Cost Failure I/A	Projects with Cost Failure N	I/A Mean Difference (Success-Failure)
All projects	3.48	50	3.07	15	0.41
Industrial	3.71	22	3.71	6	0.00
Infrastructure	3.21	10	2.80	5	0.41
$5-50 mil.	3.72	28	3.00	10	0.72
>$50 mil.	3.58	20	3.23	5	0.35
Private	3.69	34	3.20	8	0.49
Public	3.70	14	2.93	7	0.77
Greenfield	4.06	28	3.29	6	0.77
Typical	3.97	42	3.23	11	0.74

5.2 Projects with Schedule Success vs. Projects with Schedule Failure

The following analyses focus on differences between projects with schedule success and failure in terms of technology usage at the phase level.

Phase 1 & 2 Technology Usage and Impacts on Schedule Success

Table 5.4 shows the levels of Phase 1 & 2 technology usage by project schedule performance. The descriptive statistics show that categories with large differences in Phase 1 & 2 technology usage between projects with schedule success and failure are Building, Private, and Expansion projects. Tests were conducted to determine the statistical significance of the proposed relationships, and the results are presented in Table 5.5. The Bonferroni approach was used to control for Type I error across pairwise comparisons and each comparison is tested at the 0.10/3, or 0.033, level. Analysis results indicate that higher levels of technology usage in the Frond-End and Design phases may contribute to project schedule success for Building and Expansion projects. However, the data does not show significant results for Private projects.

Table 5.4: Phase 1 & 2 Technology Usage vs. Schedule Performance by Category

	Projects with Schedule Success		Projects with Schedule Failure		I/A Mean Difference
Project Type	I/A	N	I/A	N	(Success-Failure)
All projects	5.46	30	4.69	21	0.77
Building	5.79	12	3.26	9	2.53
Infrastructure	5.90	10	5.79	5	0.11
$5-50 mil.	5.63	22	4.69	16	0.94
>$50 mil.	5.41	18	4.68	6	0.73
Private	5.73	16	4.47	13	1.26
Public	5.24	10	5.03	8	0.21
Expansion	7.18	8	4.19	8	2.99
Typical	5.42	22	4.93	18	0.49

Table 5.5: *t*-Tests for Phase 1 & 2 Technology Usage vs. Schedule Performance

	Projects with Schedule Success			Projects with Schedule Failure						
Project Type	N	Mean	Standard Deviation	N	Mean	Standard Deviation	Mean Diff.	t	Sig. (2-tailed)	Effect Size Statistic (eta square)
Building	12	5.79	2.76	9	3.26	1.92	2.53	2.35	0.030	0.23
Expansion	8	7.18	2.38	8	4.19	1.23	2.99	3.17	0.009	0.42
Private	16	5.73	2.02	13	4.47	2.60	1.26	1.46	0.156	0.07

Phase 3, 4 & 5 Technology Usage and Impacts on Schedule Success

Table 5.6 shows the levels of Phase 3, 4 & 5 technology usage and their associations with project schedule performance. It was observed that the category with the largest differences in levels of Phase 3, 4 & 5 technology usage between projects with schedule success and failure is Building projects and the smallest differences are associated with Typical projects. Tests were conducted to determine the statistical significance of the proposed relationships and Table 5.7 presents the results. The Bonferroni approach was used to control for Type I error across pairwise comparisons. Each comparison is tested at the 0.10/2, or 0.05, level. These analyses reveal that Building and Expansion projects with higher levels of Phase 3, 4 & 5 technology usage have higher levels of schedule success.

Table 5.6: Phase 3, 4 & 5 Technology Usage vs. Schedule Performance by Category

Project Type	Projects with Cost Success I/A	Projects with Cost Success N	Projects with Cost Failure I/A	Projects with Cost Failure N	I/A Mean Difference (Success-Failure)
All projects	3.81	36	3.37	21	0.44
Building	4.76	12	2.64	9	2.12
Infrastructure	4.10	16	3.82	5	0.28
$5-50 mil.	3.79	26	3.37	16	0.42
>$50 mil.	3.53	9	3.35	5	0.18
Private	3.63	16	3.48	13	0.15
Public	4.04	16	3.18	8	0.86
Expansion	3.41	10	2.62	8	0.79
Typical	3.45	28	3.35	18	0.10

Table 5.7: *t*-Tests for Phase 3, 4 & 5 Technology Usage vs. Schedule Performance

Project Type	Projects with Schedule Success N	Projects with Schedule Success Mean	Projects with Schedule Success Standard Deviation	Projects with Schedule Failure N	Projects with Schedule Failure Mean	Projects with Schedule Failure Standard Deviation	Mean Diff.	t	Sig. (2-tailed)	Effect Size Statistic (eta square)
Building	12	4.76	1.74	9	2.64	1.24	2.12	3.11	0.006	0.34
Expansion	10	3.41	0.82	8	2.62	0.66	0.79	2.23	0.041	0.24

5.3 Composite Project Success vs. Composite Project Failure

This section focuses on differences in technology use between projects with cost & schedule success and cost & schedule failure.

Phase 1 & 2 Technology Usage and Impacts on Composite Project Success

Table 5.8 shows the levels of phase 1 & 2 technology usage by project cost & schedule outcome. The mean phase 1 & 2 technology use index value for projects with cost & schedule success is 5.31 and 4.31 for failure. The significance of this difference was tested statistically, but as indicated in Table 5.9 no significant relationship was found. When the data was divided into categories, no groups contained adequate sample sizes for analysis. Therefore, no other comparisons were conducted statistically.

Table 5.8: Phase 1 & 2 Technology Usage vs. Cost and Schedule Performance for All Projects

Projects with Cost & Schedule Success		Projects with Cost & Schedule Failure		I/A Mean Difference (Success-Failure)
I/A	N	I/A	N	
5.31	16	4.31	18	1.00

Table 5.9: *t*-Test for Phase 1 & 2 Technology Usage vs. Cost and Schedule Performance

Project Type	Projects with Cost & Schedule Success			Projects with Cost & Schedule Failure			Mean Diff.	t	Sig. (2-tailed)	Effect Size Statistic (eta square)
	N	Mean	Standard Deviation	N	Mean	Standard Deviation				
All projects	16	5.31	2.05	18	4.31	2.10	1.00	1.40	.171	.06

Phase 3, 4 & 5 Technology Usage and Impacts on Composite Project Success

Table 5.10 shows the levels of phase 3, 4 & 5 technology usage by project cost & schedule performance. The mean index value for projects with cost & schedule success is 3.66 while the mean for projects with cost & schedule failure is 3.08. The difference between these two values is not substantial. Therefore, no comparison between projects with success and failure was conducted statistically.

Table 5.10: Phase 3, 4 & 5 Technology Usage vs. Cost and Schedule Performance for All Projects

Projects with Cost & Schedule Success		Projects with Cost & Schedule Failure		I/A Mean Difference (Success-Failure)
I/A	N	I/A	N	
3.66	20	3.08	15	0.58

This page intentionally left blank.

Chapter 6 Conclusions and Recommendations

The purpose of these analyses was to quantify whether project success is significantly associated with technology usage. The analyses indicate that projects with success have, on average, higher levels of technology utilization than project with failure for all technology usage metrics analyzed. In addition, technology utilization may make a significant contribution to a project's cost and schedule success, particularly for certain types of projects.

Specific key findings are recapped in this chapter.

6.1 Project-Level Technology Usage Linked with Project Success

From the analysis of the associations between project success and technology usage at the project level, the following can be concluded:

- Technology usage for industry-wide high-tech WFs may positively influence project cost success, particular for Building and Public projects.
- For Infrastructure projects, cost-sensitive WF technology usage may contribute to project cost success.
- For Building projects, task automation technology usage may positively influence project cost success. Also, project technology usage may contribute to project schedule success, integration link, task automation, and schedule-sensitive WFs in particular.
- For Private projects, technology usage for industry-wide mid-tech WFs may positively influence project schedule success
- For Expansion projects, levels of technology usage for schedule-sensitive WFs are positively associated with project' levels of schedule success.
- Technology usage may positively influence both project cost and schedule success, particularly task automation technology usage and for industry-wide high-tech WFs and cost/schedule-sensitive WFs.
- Project schedule success is more closely associated with technology utilization than is project cost success.
- Technology usage for task automation work functions may positively influence both project cost and schedule success. However, technology usage for integration link work functions may contribute more significantly to project schedule success.

6.2 Phase-Level Technology Usage Linked with Project Success

From analysis of the associations between project success and technology usage at the phase level, the following can be concluded:

- Technology usage in the Front-End and Design Phases may positively influence project cost success.
- For Building projects, technology usage in the Front-End and Design Phases may contribute to project schedule success.

- For Building projects, technology usage in the Procurement and Construction Phases may positively influence project schedule success.
- For Expansion projects, levels of technology usage in the Front-End and Design Phases are positively associated with projects' levels of schedule success.

6.3 Recommendations for Further Research

Recommendations for future study are offered:

- One of the limitations during the data analysis was sample size. Certain statistical tests were not conducted due to small sample size, particularly for Advanced projects and Renovation projects. A larger number of project assessments should be involved in future data collection efforts to increase the reliability of the analysis and lead to greater insights into the associations between technology usage and project success.
- For Building projects, project schedule success seems to be closely associated with technology utilization. It would be worthwhile to examine Building projects and their unique features in further exploring determinants of project schedule success.
- Consideration should be given to expanding the survey resolution for work function technology usage from three optional responses to four: 1) none or only very common electronic tools, 2) a few specialized electronic tools, 3) several specialized electronic tools, and 4) integrated electronic tools.

References

Kumashiro, M.E. (1999). “Measuring automation and integration in the construction industry.” MS thesis, University of Texas, Austin, Tex.

O’Connor, James T., Kumashiro, Mark E., Welch, Keith A., Hadeed, Shane P., Braden, Kristine E., and Deogaonkar, Mandar J. (2000). “Project- and Phase-Level Technology Use Metrics for Capital Facility Projects.” *Report No.16*. Center for Construction Industry Studies, University of Texas, Austin, Tex.

Welch, K. A. (1998). “Development of a tool for assessing the degree of automation and integration on capital projects.” MS thesis, University of Texas, Austin, Tex.

This page intentionally left blank.