UNDERSTANDING HOW TECHNOLOGY MAY IMPACT PROJECT SUCCESS

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Understanding How Technology May Impact Project Success

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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.

The primary purpose of this study was to determine the degree to which technology application is associated with project success. Associations between project success and technology usage at the work function level were investigated. The second objective in this study was to gain more insight into *how* technology usage may impact project success. Cost and schedule performance sensitivity analyses were performed to explain the links between technology usage and project success. Fundamental characteristics associated with the project performance-leveraging work functions were also investigated in further explaining project cost and schedule success.

An industry-wide survey was used to collect project data from more than 200 capital facility projects on the issue of technology usage at the work function (WF) level and overall project success. The data analyzed in this report are representative of the levels of IA technologies used on project work functions rather than that used organization-wide. The project success variables analyzed include project schedule success and project cost success.

Some key findings include the following:

- Project schedule success or failure is particularly leveraged with technology usage (or lack thereof) for the work functions: Acquire and respond to shop drawings and Use as-built information in operator training.
- Project cost success is particularly leveraged with technology usage for monitoring facility energy consumption.
- Project performance-leveraging work functions involve factors or characteristics that may affect project cost and schedule success.
- Data/information-intensive, human resource involved, and management-related Work Function Characteristics may greatly influence the cost or schedule performance of a project.
- Work functions that involve data accuracy and frequent communications between different individuals and organizations deserve the high technology approaches in order to achieve higher levels of project cost and schedule success.
- The priority for technology implementation is associated with the work functions for which worker's or operator's experience is critical to performance.

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

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Table of Contents

List of Tables

List of Figures

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Chapter 1 Introduction

1.1 Study Background, Objectives, and Scope Limitations

This report is the second of such reports that present findings from assessment of associations between technology usage and project success. The first report discussed associations between project success and technology usage at the project and phase level. This report addresses associations between project success and technology usage at the work function level. The links between technology utilization and project success are explored in further detail.

The primary research objectives of this report and associated sub-objectives are presented as follows:

- Quantify the degree to which project success is significantly associated with technology utilization
  - Identify associations between project success and technology usage at the work function level
  - Determine cost and schedule performance-leveraging work functions
- Provide an understanding of the links between technology utilization and project success
  - Perform cost and schedule performance sensitivity analyses to explain the links between technology usage and project success
  - Investigate characteristics associated with the cost and schedule performance-leveraging work functions to gain deeper insights into how technology usage may impact project success

The analyses of technology usage and relationships with project success are based on a nation-wide survey performed between October 1998 and August 1999. Technology usage metrics are based on 68 common project work functions. 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. While a brief overview of the study methodology is contained in this report, full discussion of the study background, scope, and survey process can be found in the first report [O'Connor and Yang, 2003]. Readers are encouraged to review the first report prior to reviewing this document.

It should be acknowledged that several survey participants and interviewees provide invaluable information in this study: Mr. Pat Conners, Mr. Roger Chorba, Dr. Schiller Liao, Mr. Arthur La Guette.Mr. Roman Moreno, Mr. Brian Preston, Mr. John Rickard, Ms. Linda Sellers, Mr. William Thorsen, Mr. Craig Wright, and Mr. Jack Yarbrough.

1.2 Research Hypotheses

The hypotheses shown in Table 1.1 pertain to project performance-leveraging work functions. These hypotheses were developed to investigate associations between project performance and technology usage at the work function level. The project performance variables analyzed include final performance of the projects in terms of cost and schedule success. Technology usage metrics are analyzed at highest levels of technology utilization, Level 3, and the lowest levels of technology utilization, Level 1, in executing work functions. Each level of technology utilization in executing work functions is defined as follows:

- Level 1 – No electronic tools or only the most common electronic tools are used.
- Level 2 – Uncommon electronic tools play key roles in executing the work function, but human workers still dominate.
- Level 3 – While human workers still participate, fully- or nearly fully-automated systems dominate.

Table 1.1: List of Hypotheses for Work Function-Level Technology Usage

Number	Hypothesis
H1	For certain WFs, projects with cost success employ higher levels of work function technology than projects with cost failure
H2	For certain WFs, projects with cost failure employ lower levels of work function technology than projects with cost success
H3	For certain WFs, projects with schedule success employ higher levels of work function technology than projects with schedule failure
H4	For certain WFs, projects with schedule failure employ lower levels of work function technology than projects with schedule success

The cost and schedule performance-leveraging work functions were further analyzed using cost performance sensitivity, schedule performance sensitivity, and Work Function Characteristics (WFCs) analysis to explain the links between technology utilization and project success. Work Function Characteristics are differentiae that characterize the 68 work functions. Six categories of Work Function Characteristics were developed by O'Connor and Won to classify work functions by their attributes and as a way to study differences between work functions relative to technology usage: 1) nature of work function procedures, 2) time/space/cost factors, 3) information and data aspects, 4) WF management, 5) nature of WF product, and 6) nature of human resource. Table 1.2 presents a list of the 31 Work Function Characteristics by category (not all WFCs can be applied to each work function).

Work Function Characteristics were used to better understand project performance-leveraging work functions through analysis of their attributes. WFC analysis reveals characteristics common to the cost and schedule performance-leveraging work functions. To gain more insight into how the use of technology affects project success, the following research hypothesis was developed:

H5: Work Function Characteristics can, in part, explain the links between project success and technology utilization.

Table 1.2: List of Work Function Characteristics by Category

(H) Human Resource
H1: Many individuals are involved to perform WF.
H2: WF involves many individuals with different skills and specialties.
H3: User's, worker's or operator's experience is critical to performance.
(P) Work Function Product
P1: Performance of many subsequent WFs relies heavily on this WF.
P2: WF product is physically large and bulky.
P3: Errors are difficult to fix or require a large amount of resources to fix.
(T) Time/Space/Cost
T1: WF is a critical path activity in most cases.
T2: WF activity requires spatial coordination.
T3: WF involves relatively high uncertainty in the following item (cost, schedule, quality, and safety)
T4: WF management operates in close proximity to workers.
T5: WF involves environmental hazard.
T6: WF is costly to execute.
(I) Information & Data
I1: WF involves uncertainty or probabilistic information.
I2: Historical data from previous projects are required for execution.
I3: WF relies on industry technical standards.
I4: WF data are in many different formats.
I5: Data accuracy is crucial to successful WF performance.
I6: Security of related data is very important.
I7: WF involves significant amount of data updating.
(M) Management
M1: A specialty organization is involved in most cases.
M2: Many different types of organizations are involved.
M3: Primary performance driver of the WF is one of the followings (quality, safety, cost, and schedule)
M4: Responsible individual must communicate frequently with others.
M5: WF involves high probability of change.
(D) Work Procedure
D1: WF involves iterations and revisions.
D2: WF is error prone.
D3: WF procedures are driven by regulations.
D4: WF involves repetitive activity.
D5: Some WF resources are often idle.
D6: WF procedures are very complex.
D7: WF relies on or requires physical output products of many previous WF.

1.3 Overview of Research Methodology

- Cost and schedule performance-leveraging work functions are defined as follows: 1) High-Tech/High Cost Success WFs, 2) Low-Tech/Low Cost Success WFs, 3) High-Tech/High Schedule Success WFs, and 4)Low-Tech/Low Schedule Success WFs.
- High-Tech/High Cost Success WFs have substantially greater differences in the number of Level 3 responses (Δ Level 3) when comparing under and over-budget projects. In order to verify that project cost success is substantially more closely associated with Level 3 technology usage than that of the lower level, the difference in the number of responses at Level 2 (Δ Level 2) between under- and over-budget projects was analyzed for each High-Tech/High Cost Success WF. If certain work functions involve a substantial difference between Δ Level 3 and Δ Level 2 (i.e., Δ Level 3 is substantially greater than Δ Level 2), higher levels of project cost success are associated with these work functions when high-tech approaches are applied. This pattern held true for schedule success and work function level technology usage as well.
- Low-Tech/Low Cost Success WFs involve substantial differences in the number of responses at Level 1 (Δ Level 1) when comparing under- and over-budget projects. In order to prove that project cost failure is substantially more closely associated with Level 1 technology usage than that of the higher level, the difference in the number of responses at Level 2 (Δ Level 2) between under- and over-budget projects was examined for each Low-Tech/Low Cost Success WF. If certain work functions involve a substantial difference between Δ Level 1 and Δ Level 2 (i.e., Δ Level 1 is substantially smaller than Δ Level 2), lower levels of project cost success are associated with these work functions when low-tech approaches are applied. This pattern held true for schedule failure and work function level technology usage as well.
- Higher levels of project schedule success are shown to be associated with certain WFs when High-Tech approaches are applied to those WFs. These WFs (i.e. High-Tech/High Schedule Success WFs) involve substantial differences in the number of responses at Level 3 for ahead-of-schedule as opposed to behind-schedule projects. Lower levels of project schedule success are also associated with certain WFs when Low-Tech approaches are applied to those WFs. These WFs (i.e. Low-Tech/Low Schedule Success WFs) show substantial differences in the number of responses at Level 1 when comparing ahead-of- and behind-schedule projects.
- Level 2 is associated with medium levels of technology utilization in executing work functions, which, in general, for analytical purposes may be considered to be the norm for assessing levels of technology usage. As most statistical testing is intended to prove or disprove significance of differences from the norm or mean, this testing is more conservative. Thus, if Level 3 was compared to Level 1, a more rigorous approach was adopted to examine the differences between Level 3 and Level 2 and between Level 2 and Level 1.

- Once cost and schedule performance leveraging work functions were identified, steps were attempted to better understand how technology utilization affects project success. Cost and schedule performance sensitivity associated with project performance-leveraging work functions were analyzed to explain the links between technology usage and project success.
- The value of Work Function Characteristics (WFCs) in further explaining the links was investigated. Work Function Characteristics were used to characterize the project performance-leveraging work functions. WFC analysis of these critical work functions can reveal features that leverage project cost and/or schedule performance. This approach provides deeper insights into how technology usage impacts project success.
- The data collection effort involved characterization of the project performance-leveraging work functions via Work Function Characteristics. Needed data were collected from industry professionals through personal interviews and fax interviews. This data collection tool was used to assess how strongly certain WFCs are related to a given work function. For the assessment of WFC applicability, indices were developed and then converted to a 0 to 10 score.

1.4 Structure of the Report

Chapter 2 addresses associations between project success and technology usage at the work function level. Chapter 3 discusses how technology usage impacts on project success. The links between technology utilization and project performance were explored in further detail. Chapter 4 reiterates key findings and offers recommendations for future research.

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Chapter 2 Work Function-Level Technology Usage and Associations with Project Success

This chapter explores the impacts of work function-level technology usage on project success. Cost and schedule performance-leveraging work functions identified include High-Tech/High Cost Success WFs, Low-Tech/Low Cost Success WFs, High-Tech/High Schedule Success WFs, and Low-Tech/Low Schedule Success WFs. Technology usage metrics analyzed include Level 1, Level 2, and Level 3 technology usage. Levels 1, 2, and 3 are associated respectively with the highest, medium, and lowest levels of technology utilization in executing work functions.

2.1 Identification of High-Tech/High Cost Success WFs

The work functions with a substantial difference in the number of responses at Level 3 (Δ 3) between under- and over-budget projects are defined as High-Tech/High Cost Success WFs. These work functions (i.e. High-Tech/High Cost Success WFs) both involve significantly more technology usage and are associated with a higher rate of cost success. For each of the 68 work functions analyzed, percentage of responses at Level 3 relative to all response levels was computed for both under-budget and over-budget projects. High-Tech/High Cost Success WFs are associated with a difference of 20 % or greater in Level 3 responses between under-budget and over-budget projects.

In order to verify that project cost success is substantially more closely associated with Level 3 technology usage than that of the lower level, the difference in the number of responses at Level 2 (Δ 2) between under- and over-budget projects was analyzed for each High-Tech/High Cost Success WF. If certain work functions involve a substantial difference between Δ 3 and Δ 2 (i.e., Δ 3 is substantially greater than Δ 2), higher levels of project cost success are associated with these work functions when high-tech approaches are applied.

Table 2.1 presents responses at Level 3 and Level 2 for projects with cost success and failure. A total of 11 work functions with a substantial difference in responses at Level 3 (Δ 3 $\geq$ 20%) were identified. For all of the 11 work functions, the difference between Δ 3 and Δ 2 is substantial (Δ > 30%); therefore, higher levels of project cost success are associated with the following work functions when high-tech approaches are applied:

- 101: Conduct needs analysis
- 103: Model user's process
- 205: Prepare floor plans
- 208: Design electrical systems
- 209: Design HVAC systems
- 303: Link between quantity survey and cost estimate
- 406: Track the inventory of materials on site
- 507: Fabricate roof trusses
- 606: Monitor equipment operations

- 609: Monitor facility energy consumption
- 610: Monitor environment impact from operations

Table 2.1: Responses at Level 3 and Level 2 by Project Cost Performance

ID	WF	% of Responses at Level 3		Δ3 (%)	% of Responses at Level 2		Δ2 (%)	Δ (Δ3-Δ2)
		Under-Budget Projects	Over-Budget Projects		Under-Budget Projects	Over-Budget Projects		
6.09	Monitor facility energy consumption	70	14	56	20	57	-37	93
5.07	Fabricate roof trusses	33	0	33	44	100	-56	89
6.10	Monitor environment impact from operations	43	0	43	43	71	-28	71
2.09	Design HVAC systems	47	14	33	47	86	-39	72
4.06	Track the inventory of materials on site	25	0	25	20	54	-34	59
2.08	Design electrical systems	47	18	29	47	73	-26	55
6.06	Monitor equipment operations	38	13	25	46	75	-29	54
2.05	Prepare floor plans	44	20	24	50	70	-20	44
1.01	Conduct needs analysis	25	0	25	50	67	-17	42
3.03	Link between quantity survey and cost estimate	31	8	23	48	67	-19	42
1.03	Model user's process	21	0	21	64	78	-14	35

2.2 Identification of Low-Tech/Low Cost Success WFs

Low-Tech/Low Cost Success WFs are associated with the work functions with a substantial difference in the number of responses at Level 1 (Δ 1) between over- and under-budget projects. These work functions (i.e. Low-Tech/Low Cost Success WFs) both involve significantly less technology usage and are associated with a lower rate of cost success. For each of the 68 work functions, the percentage of responses at Level 1 relative to all response levels was computed for both under-budget and over-budget projects. Low-Tech/Low Cost Success WFs are associated with a difference of -20 % or less in Level 1 responses between under-budget and over-budget projects.

In order to prove that project cost failure is substantially more closely associated with Level 1 technology usage than that of the higher level, the difference in the number of responses at Level 2 (Δ 2) between under- and over-budget projects was examined for each Low-Tech/Low Cost Success WF. If certain work functions involve a substantial difference between Δ 1 and Δ 2 (i.e., Δ 1 is substantially smaller than Δ 2), lower levels of project cost success are associated with these work functions when low-tech approaches are applied.

Table 2.2 presents responses at Level 1 and Level 2 for projects with cost success and failure. Eight work functions with a substantial difference in responses at Level 1 ($\Delta 1 \leq$ -20%) were identified. For all of the 8 work functions, the difference between Δ 1 and Δ 2 is substantial ($\Delta \leq$ -25%); therefore, lower levels of project cost success are associated with the following work functions when low-tech approaches are applied:

- 210: Document budget assumptions
- 214: Track design progress
- 410: Provide feedback about cost and schedule impacts from changes
- 413: Update as-built drawings
- 415: Owner payment to contractor
- 602: Train facility operators
- 603: Use as-built information in operator training
- 608: Update as-built drawings in response to facility modifications

Table 2.2: Responses at Level 1 and Level 2 by Project Cost Performance

ID	WF	% of Responses at Level 1		Δ1 (%)	% of Responses at Level 2		Δ2 (%)	Δ (Δ1-Δ2)
		Under-Budget Projects	Over-Budget Projects		Under-Budget Projects	Over-Budget Projects		
2.14	Track design progress	17	42	-25	72	42	30	-55
2.10	Document budget assumptions	12	36	-24	82	55	27	-51
6.03	Use as-built information in operator training	40	67	-27	53	33	20	-47
6.08	Update as-built drawings in response to facility modifications	14	40	-26	71	60	11	-37
4.15	Owner payment to contractor	43	63	-20	38	25	13	-33
6.02	Train facility operators	40	63	-23	47	38	9	-32
4.10	Cost & schedule impacts from changes	55	75	-20	36	25	11	-31
4.13	Update as-built drawings	30	50	-20	48	43	5	-25

2.3 Identification of High-Tech/High Schedule Success WFs

The work functions with a substantial difference in the number of responses at Level 3 (Δ 3) between ahead-of- and behind-schedule projects are defined as High-Tech/High Schedule Success WFs. These work functions (i.e. High-Tech/High Schedule Success WFs both involve significantly more technology usage and are associated with a higher rate of schedule success. For each of the 68 work functions, the percentage of responses at Level 3 relative to all response levels was computed for both ahead-of- and behind-schedule projects. High-Tech/High Schedule Success WFs

are associated with a difference of 20 % or greater in Level 3 responses between ahead-of-schedule and behind-schedule projects.

In order to verify that project schedule success is substantially more closely associated with Level 3 technology usage than that of the lower level, the difference in the number of responses at Level 2 (Δ 2) between ahead-of- and behind-schedule projects was analyzed for each identified High-Tech/High Schedule Success WF. If certain work functions involve a substantial difference between Δ 3 and Δ 2 (i.e., Δ 3 is substantially greater than Δ 2), higher levels of project schedule success are associated with these work functions when high-tech approaches are applied.

Table 2.3 presents responses at Level 3 and Level 2 for projects with schedule success and failure. A total of 11 work functions with a substantial difference in responses at Level 3 (Δ 3 $\geq$ 20%) were identified. However, for the work function 410: Provide feedback about cost and schedule impacts from changes, the difference between Δ 3 and Δ 2 is not substantial (Δ = -1%); thus, higher levels of project schedule success are associated with the following work functions when high-tech approaches are applied (WF 410 is excluded):

- 101: Conduct needs analysis
- 102: Develop scope of work
- 103: Model user's process
- 105: Prepare milestone schedule
- 309: Acquire and respond to shop drawings
- 401: Develop detailed construction schedule
- 409: Communicate Requests for Information & response
- 502: Carry out earthwork & grading
- 602: Train facility operators
- 603: Use as-built information in operator training

2.4 Identification of Low-Tech/Low Schedule Success WFs

Low-Tech/Low Schedule Success WFs are associated with the work functions with a substantial difference in the number of responses at Level 1 (Δ 1) between behind- and ahead-of-schedule projects. These work functions (i.e. Low-Tech/Low Schedule Success WFs) both involve significantly less technology usage and are associated with a lower rate of schedule success. For each of the 68 work functions, the percentage of responses at Level 1 relative to all response levels was computed for both ahead-of- and behind-schedule projects. Low-Tech/Low Schedule Success WFs are associated with a difference of -20 % or less in Level 1 responses between ahead-of-schedule and behind-schedule projects.

In order to show that project schedule failure is substantially more closely associated with Level 1 technology usage than that of the higher level, the difference in the number of responses at Level 2 (Δ 2) between ahead-of- and behind-schedule projects was investigated for each Low-Tech/Low Schedule Success WF. If certain work functions involve a substantial difference between Δ 1 and Δ 2 (i.e., Δ 1 is

substantially smaller than Δ 2), lower levels of project cost success are associated with these work functions when low-tech approaches are applied.

Table 2.4 presents responses at Level 1 and Level 2 for projects with schedule success and failure. Eleven work functions with a substantial difference in responses at Level 1 (Δ 1 ≤ -20%) were identified. However, for the work function 102: Develop scope of work, the difference between Δ 1 and Δ 2 is not substantial (Δ = -16%); therefore, lower levels of project schedule success are associated with the following work functions when low-tech approaches are applied (WF 102 is excluded):

- 211: Detect physical interferences
- 304: Link between supplier cost quotes and cost estimate
- 309: Acquire and respond to shop drawings
- 410: Provide feedback about cost and schedule impacts from changes
- 414: Submit contractor's request for payment
- 506: Provide elevated work platform
- 509: Acquire and record material lab test results
- 603: Use as-built information in operator training
- 607: Request facility maintenance or modifications
- 608: Update as-built drawings in response to facility modifications

Table 2.3: Responses at Level 3 and Level 2 by Project Schedule Performance

ID	WF	% of Responses at Level 3		Δ3 (%)	% of Responses at Level 2		Δ2 (%)	Δ (Δ3-Δ2)
		Ahead-of-Schedule Projects	Behind-Schedule Projects		Ahead-of-Schedule Projects	Behind-Schedule Projects		
1.01	Conduct needs analysis	33	0	33	33	86	-53	86
1.03	Model user's process	42	8	34	42	77	-35	69
4.01	Develop detailed construction schedule	33	11	22	50	84	-34	56
6.02	Train facility operators	33	8	25	33	58	-25	50
1.05	Prepare milestone schedule	40	10	30	60	76	-16	46
1.02	Develop scope of work	36	0	36	64	74	-10	46
5.02	Earthwork & grading	24	0	24	76	88	-12	36
6.03	Use as-built information in operator training	33	8	25	33	31	2	23
3.09	Acquire & respond to shop drawings	22	0	22	44	44	0	22
4.09	Communicate Requests for Information & response	25	5	20	31	32	-1	21
4.10	Cost & schedule impacts from changes	24	0	24	47	22	25	-1

Table 2.4: Responses at Level 1 and Level 2 by Project Schedule Performance

ID	WF	% of Responses at Level 1		Δ1 (%)	% of Responses at Level 2		Δ2 (%)	Δ (Δ1-Δ2)
		Ahead-of-Schedule Projects	Behind-Schedule Projects		Ahead-of-Schedule Projects	Behind-Schedule Projects		
4.10	Cost & schedule impacts from changes	29	78	-49	47	22	25	-74
5.06	Provide elevated work platform	46	69	-23	54	15	39	-62
3.04	Link between supplier cost quotes and cost estimate	19	50	-31	63	36	27	-58
6.07	Request facility maintenance or modifications	20	50	-30	50	30	20	-50
6.08	Update as-built drawings in response to facility modifications	13	43	-30	63	50	13	-43
5.09	Acquire & record material lab test results	29	50	-21	57	36	21	-42
4.14	Submit contractor's request for payment	29	53	-24	53	42	11	-35
2.11	Detect physical interferences	20	41	-21	40	29	11	-32
6.03	Use as-built information in operator training	33	62	-29	33	31	2	-31
3.09	Acquire & respond to shop drawings	33	56	-23	44	44	0	-23
1.02	Develop scope of work	0	26	-26	64	74	-10	-16

2.5 Summary

Tables 2.5 and 2.6 present an overview of the cost and schedule performance-leveraging work functions. Attention should be paid to the work functions pertaining to both High-Tech/High Schedule Success WFs and Low-Tech/Low Schedule Success WFs. Project schedule success or failure is particularly leveraged with technology usage (or lack thereof) for the work functions: Acquire and respond to shop drawings and Use as-built information in operator training. In addition, project cost success is particularly leveraged with technology usage for monitoring facility energy consumption.

Thus, degrees of technology used in executing the project performance-leveraging work functions may have a significant impact on project cost or schedule success. These cost and schedule performance-leveraging work functions were further analyzed using cost performance sensitivity, schedule performance sensitivity, and Work Function Characteristics analysis to explain the links between technology utilization and project success. This discussion is presented in the subsequent chapter.

Table 2.5: List of Cost Performance-Leveraging WFs

ID	WF	Cost Performance-Leveraging WFs	
		High-Tech/High Cost Success WFs	Low-Tech/Low Cost Success WFs
1.01	Conduct needs analysis	x	
1.03	Model user's process	x	
2.05	Prepare floor plans	x	
2.08	Design electrical systems	x	
2.09	Design HVAC systems	x	
2.10	Document budget assumptions		x
2.14	Track design progress		x
3.03	Link between quantity survey and cost estimate	x	
4.06	Track the inventory of materials on site	x	
4.10	Cost & schedule impacts from changes		x
4.13	Update as-built drawings		x
4.15	Owner payment to contractor		x
5.07	Fabricate roof trusses	x	
6.02	Train facility operators		x
6.03	Use as-built information in operator training		x
6.06	Monitor equipment operations	x	
6.08	Update as-built drawings		x
6.09	Monitor facility energy consumption	x	
6.10	Monitor environment impact from operations	x	

Table 2.6: List of Schedule Performance-Leveraging WFs

ID	WF	Schedule Performance-Leveraging WFs	
		High-Tech/High Schedule Success WFs	Low-Tech/Low Schedule Success WFs
1.01	Conduct needs analysis	x	
1.02	Develop scope of work	x	
1.03	Model user's process	x	
1.05	Prepare milestone schedule	x	
2.11	Detect physical interferences		x
3.04	Link between supplier cost quotes and cost estimate		x
3.09	Acquire & respond to shop drawings	x	x
4.01	Develop detailed construction schedule	x	
4.09	Communicate Requests for Information & response	x	
4.10	Cost & schedule impacts from changes		x
4.14	Submit contractor's request for payment		x
5.02	Earthwork & grading	x	
5.06	Provide elevated work platform		x
5.09	Acquire & record material lab test results		x
6.02	Train facility operators	x	
6.03	Use as-built information in operator training	x	x
6.07	Request facility maintenance or modifications		x
6.08	Update as-built drawings		x

Chapter 3 Explaining the Links between Technology Usage and Project Success

In this chapter the links between technology utilization and project success are explored in further detail. The techniques used for analyzing the associations include cost performance sensitivity, schedule performance sensitivity, and analysis of Work Function Characteristics (WFCs). Cost and schedule performance sensitivity analyses of project performance-leveraging work functions are employed as a way to gain greater understanding of the connection between technology usage and project performance. In addition, WFCs were investigated as an additional basis for gaining deeper insights into how technology usage may impact project success.

3.1 Cost Performance Sensitivity

According to the analysis of technology usage at the work function level, a total of 19 work functions that may leverage project cost performance were identified. Discussion of issues relating to identification of cost performance-leveraging WFs was presented in Chapter 3. Table 3.1 presents these cost performance-leveraging WFs and their properties. It is reasonable to think that these work functions involve factors or characteristics that may affect the cost performance of a project. Cost performance sensitivity analysis of the cost performance-leveraging work functions may provide some explanation of the connection between technology utilization and project cost success. Seven of the 19 cost performance-leveraging work functions are thought to be cost-sensitive. These cost-sensitive work functions involve significant financial expenditure or are closely associated with cost control.

3.2 Schedule Performance Sensitivity

As discussed in Chapter 3, a total of 18 work functions that may leverage project schedule performance were identified. Table 3.2 lists the schedule performance-leveraging WFs and their properties. These schedule performance-leveraging work functions as a matter of logic involve factors or characteristics that likely affect the schedule performance of a project. Schedule performance sensitivity analysis of these work functions may be helpful in explaining the connection between technology utilization and project schedule success. Nine of the 18 schedule performance-leveraging work functions are thought to be schedule-sensitive. These schedule-sensitive work functions involve significant time duration or are closely associated with schedule control.

3.3 Work Function Characteristic Analysis and Data Collection

In order to identify characteristics associated with the cost/schedule performance-leveraging work functions, a total of 10 project performance-leveraging work functions were selected for analysis. The selected work functions for Work Function

Characteristic (WFC) analysis are listed in Table 3.3. Two of the selected work functions were previously assessed in Won's study (2002) in determining the priorities for technology R&D: Carry out earthwork & grading and Update as-built drawings in response to facility modifications. Previous WFC data associated with these two work functions were used in this study to help identify common WFC trends for cost and schedule performance-leveraging WFs.

Table 3.1: List of Cost Performance-Leveraging WFs and Properties

ID	Work Function	Technology Usage		Cost Success/ Failure Leverage	Responsible Organization	Thought to Be Cost-Sensitive
		Mean	Std. Dev.			
1.01	Conduct market analysis or need analysis for a new facility	4.30	3.36	Success	Owner	X
1.03	Model user's process	4.91	3.45	Success	Owner	X
2.05	Prepare floor plans	6.70	3.18	Success	A/E	
2.08	Design electrical systems	6.58	3.10	Success	A/E	
2.09	Design HVAC systems	6.28	3.23	Success	A/E	
2.10	Document the assumptions used in developing the budget, and pass to next phase	4.56	3.09	Failure	A/E	X
2.14	Track design progress	4.97	3.50	Failure	A/E	
3.03	Link quantity survey data to the cost estimating process	4.43	3.40	Success	GC	X
4.06	Track the inventory of materials on site	2.62	3.36	Success	GC	X
4.10	Constructors provide feedback about the effects of design changes on cost and schedule	2.70	3.25	Failure	GC	X
4.13	Update as-built drawings	3.58	3.73	Failure	GC	
4.15	Owner payment to contractor	3.01	3.87	Failure	Owner	
5.07	Fabricate roof trusses	4.43	3.45	Success	GC	
6.02	Train facility operators	3.68	3.33	Failure	Owner	
6.03	Use as-built information in operator training	2.99	3.25	Failure	Owner	
6.06	Monitor equipment operations	4.63	3.61	Success	Owner	
6.08	Update as-built drawings in response to facility modifications	3.99	3.29	Failure	Owner	
6.09	Monitor/track/control facility energy usage	5.83	3.94	Success	Owner	X
6.10	Monitor environment impact from operations	4.63	3.71	Success	Owner	

The data collection effort involved characterization of these selected work functions. For the selected WFs, data were collected from 11 industry professionals from the Owner, A/E, or GC groups. Respondents to the survey included presidents, vice presidents, project managers, project engineers, and project planners. Tables 3.4 and 3.5 present the numbers of participants by organization type and industry sector. These professionals averaged 22 years of experience, with a minimum of 12 years and a maximum of 30 years.

Table 3.2: List of Schedule Performance-Leveraging WFs and Properties

ID	Work Function	Technology Usage		Schedule Success/ Failure Leverage	Responsible Organization	Thought to Be Schedule-Sensitive
		Mean	Std. Dev.			
1.01	Conduct market analysis or need analysis for a new facility	4.30	3.36	Success	Owner	X
1.02	Develop, evaluate, and refine the project's scope of work	4.49	3.28	Success	Owner	X
1.03	Model user's process	4.91	3.45	Success	Owner	
1.05	Develop a milestone schedule from the scope of work	5.62	3.56	Success	Owner	X
2.11	Detect physical interferences	4.86	4.02	Failure	A/E	X
3.04	Link between supplier cost quotes and cost estimate	3.39	3.45	Failure	GC	
3.09	Acquire & review shop drawings; send response	2.81	3.35	Both	A/E	X
4.01	Develop detailed construction schedule	5.14	2.90	Success	GC	X
4.09	Communicate Requests for Information & response	2.62	3.36	Success	GC	X
4.10	Constructors provide feedback about the effects of design changes on cost and schedule	2.70	3.25	Failure	GC	X
4.14	Submit contractor's request for payment	3.21	3.43	Failure	GC	
5.02	Earthwork & grading	4.94	2.30	Success	GC	
5.06	Provide elevated work platform	2.69	2.72	Failure	GC	
5.09	Acquire & record material lab test results	3.47	3.46	Failure	GC	
6.02	Train facility operators	3.68	3.33	Success	Owner	
6.03	Use as-built information in operator training	2.99	3.25	Both	Owner	
6.07	Request facility maintenance or modifications	3.19	3.43	Failure	Owner	
6.08	Update as-built drawings in response to facility modifications	3.99	3.29	Failure	Owner	X

Table 3.3: Work Functions Selected for WFC Analysis

ID	Work Function	Cost/Schedule Leverage	Responsible Organization
2.11	Detect physical interferences	Schedule	A/E
2.14	Track design progress	Cost	A/E
3.04	Link between supplier cost quotes and cost estimate	Schedule	GC
4.13	Update as-built drawings	Cost	GC
4.14	Submit contractor's request for payment	Schedule	GC
5.02	Earthwork & grading	Schedule	GC
5.06	Provide elevated work platform	Schedule	GC
5.07	Fabricate roof trusses	Cost	GC
6.02	Train facility operators	Cost and schedule	Owner
6.08	Update as-built drawings in response to facility modifications	Cost	Owner

Table 3.4: Summary of Participants by Organization Type

Organization Type	Owner	A/E	GC	Total
Respondents	2	3	6	11

Table 3.5: Summary of Participants by Industry Sector

Industry Sector	Building	Infrastructure	Industrial	Total
Respondents	7	1	5	11

Note: Multiple Responses

3.3.1 Characterizing Work Functions

For each subject work function, the survey asks participants to assess the extent to which individual WFCs apply to that work function. This survey offers respondents five optional responses: Strongly Agree, Agree, Neutral, Disagree, or Don't Know. For any given WFC, the assessed degree to which a WF relates to that WFC was established as the WFC Score. In order to perform quantitative analysis, responses were converted to WFC Scores as follows: Strongly Agree = 4, Agree = 3, Neutral = 2, and Disagree = 1. The WFC applicability index was computed and then translated to a 0-10 point score:

Mean WFC Applicability Index = [(Sum of WFC Scores associated with all project performance-leveraging WFs / Total number of project performance-leveraging WFs)-1] * 10/3

A WFC Applicability Index score of zero indicates "not applicable." A value of 6.67 or greater indicates "highly applicable." Figure 3.1 illustrates the degree to which individual WFCs relate to the cost and schedule performance-leveraging WFs. Figure 3.2 displays the data set representing the WFCs that may explain leveraging. Each data point represents a Work Function Characteristic. The farther to the right a point is located, the more strongly the WFC is associated with the cost performance-leveraging WFs. Similarly, the higher a point is located, the more strongly the WFC relates to the schedule performance-leveraging WFs. The plot is divided into four quadrants. The points located at the upper right quadrant represent WFCs with high applicability for both cost and schedule leveraging WFs. If a data point is located in the lower left quadrant, it indicates that the WFC has little applicability to the leveraging WFs.

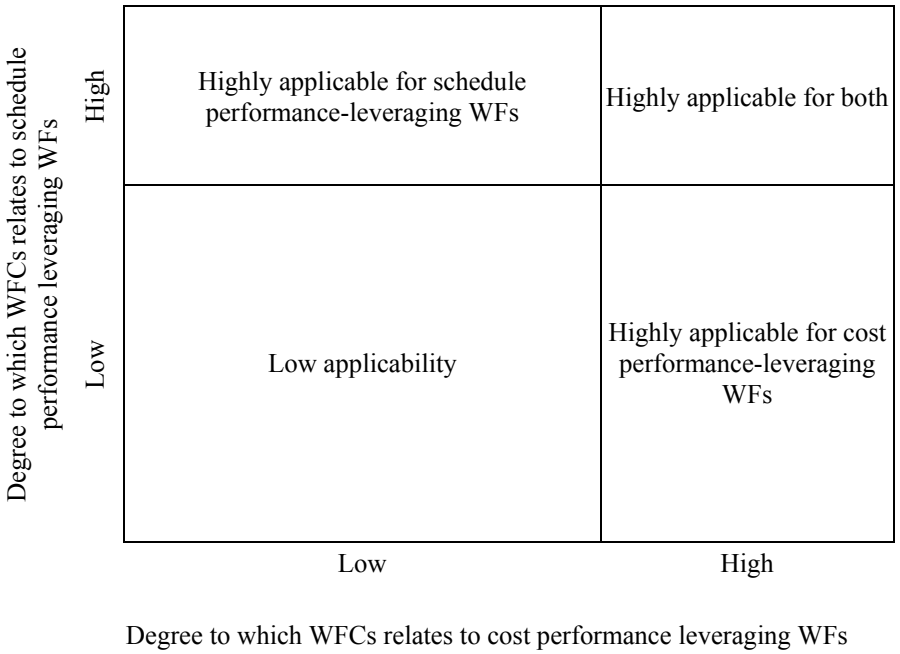

Figure 3.1: Relationships between WFCs and Project Performance-Leveraging WFs

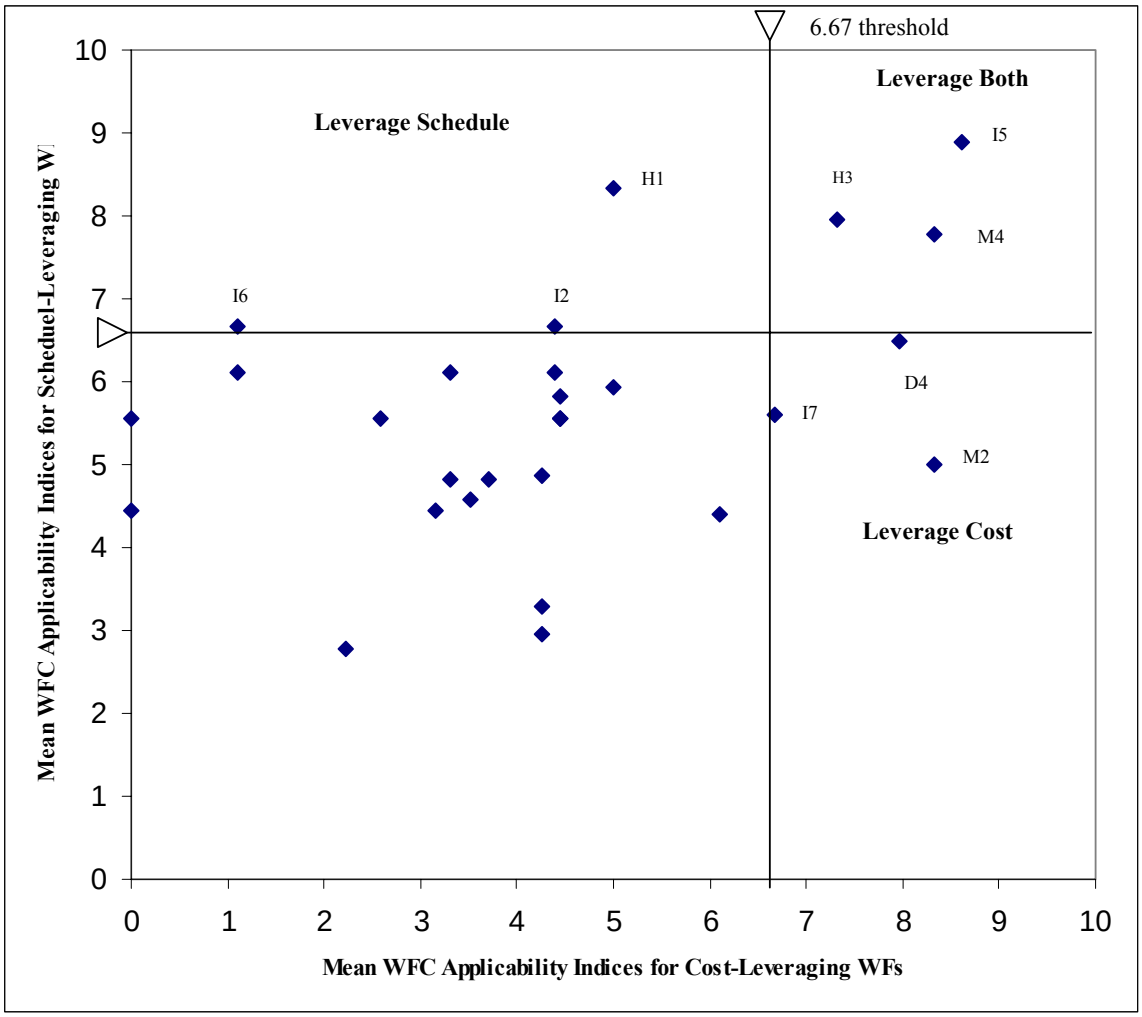

Figure 3.2: WFC Analysis for Project Performance-Leveraging WFs

3.3.2 Identification of Common WFCs Trends

Mean WFC applicability index values of 6.67 or greater are associated high applicability WFCs. Nine WFCs that may explain leveraging were identified in the WFC analysis. These WFCs show a strong association with the cost and/or schedule performance work functions. Table 3.6 presents the WFCs that may explain leveraging. Most of the WFCs that may explain leveraging fall in the following three WFC categories: 1) human resource, 2) information & data, and 3) management. This indicates that information/data-intensive, human resource involved, and management-related WFCs may greatly influence project cost and schedule success.

Table 3.6: WFCs That May Explain Leveraging

Category	WFCs	Cost Leverage	Schedule Leverage
Human Resource	H1: Many individuals are involved in the WF		X
	H3: User's, worker's or operator's experience is critical to performance	X	X
Information & Data	I2: Historical data from previous projects are required for execution		X
	I5: Data accuracy is crucial to successful WF performance	X	X
	I6: Security of related data is very important		X
	I7: WF involves significant amount of data updating	X	
Management	M2: Many different types of organizations are involved	X	
	M4: Responsible individual must communicate frequently with others	X	X
Work Procedure	D4: WF involves repetitive activity	X	

Work Function Characteristics that may explain cost performance-leveraging were identified in order to explore project cost success determinants. The analyses suggest that data/information-intensive and management-related Work Function Characteristics may greatly influence the cost performance of a project. Work functions that involve significant amount of data updating and repetitive activities deserve the execution with high technology approaches. In addition, degrees of technology used in executing the work functions that involve many different types of organizations and frequent communication between individuals likely affect the cost performance of a project. The priority for technology implementation is also associated with the work functions for which data accuracy and user's experience are critical to performance. Work Function Characteristics with high applicability for cost performance-leveraging include:

- I5: Data accuracy is crucial to successful WF performance
- M2: Many different types of organizations are involved
- M4: Responsible individual must communicate frequently with others
- I7: WF involves significant amount of data updating
- D4: WF involves repetitive activity
- H3: User's, worker's or operator's experience is critical to performance

Work Function Characteristics that may explain schedule performance-leveraging were identified to further explain the links between technology utilization and project schedule success. The analysis results indicate that data/information-intensive and human resource involved Work Function Characteristics may have potential influence on the schedule performance of a project. Technology usage for work functions associate with historical data and data security may help improve project schedule performance. Consideration should be also given to employ higher levels of technology usage for the work functions that involve many individuals and personnel

communication. In addition, the priority for technology implementation is associated with the work functions for which data accuracy and user's experience are critical to performance. Work Function Characteristics with high applicability for schedule performance-leveraging include the following:

- I2: Historical data from previous projects are required for execution
- H1: Many individuals are involved in the WF
- I5: Data accuracy is crucial to successful WF performance
- M4: Responsible individual must communicate frequently with others
- I6: Security of related data is very important
- H3: User's, worker's or operator's experience is critical to performance

Chapter 4 Conclusions and Recommendations

The purpose of this study was to investigate technology utilization on capital facility projects and its associations with project cost and schedule success. Hypotheses were analyzed to identify relationships between project success and technology usage at the work function level. In explaining the links between technology usage and project success, work functions associated with project performance and their characteristics were identified.

4.1 Work Function-Level Technology Usage Linked with Project Success

For each of the 68 work functions, levels of technology usage were analyzed to identify cost and schedule performance-leveraging work functions. Degrees of technology used in executing these project performance-leveraging work functions may have a significant impact on project success. These analyses suggest that project schedule success or failure is particularly leveraged with technology usage (or lack thereof) for acquiring and responding to shop drawings and using as-built information in operator training. In addition, project cost success is particularly leveraged with technology usage for monitoring facility energy consumption.

4.2 Insights into the Links between Technology Usage and Project Success

The techniques used for analyzing the associations between technology usage and project success include cost performance sensitivity, schedule performance sensitivity, and analysis of Work Function Characteristics (WFCs). Cost and schedule performance sensitivity analyses of project performance-leveraging work functions were used as a way to gain greater understanding of the connection between technology usage and project success. WFCs were also investigated as an additional basis for gaining deeper insights into how technology usage may impact the cost and schedule performance of a project. The results indicate that the project performance-leveraging work functions involve factors or characteristics that may affect project cost and schedule success. These analyses also suggest that data/information-intensive, human resource involved, and management-related Work Function Characteristics may greatly influence the cost or schedule performance of a project. Work functions that involve data accuracy and frequent communications between different individuals and organizations deserve the high technology approaches in order to achieve higher levels of project cost and schedule success. In addition, the priority for technology implementation is associated with the work functions for which worker's or operator's experience is critical to performance. Work Function Characteristics with high applicability for both cost and schedule performance-leveraging include the following:

- Data accuracy is crucial to successful WF performance
- Responsible individual must communicate frequently with others
- User's, worker's or operator's experience is critical to performance

4.3 Recommendations for Further Research

Recommendations for future study are offered:

- A graphical flow chart that integrates all 68 work functions in sequence may be helpful in illustrating dependency and leveraging between work functions.
- Work Function Characteristics have been employed as a way to gain greater insights into how technology usage may impact project success. Additional possible uses of Work Function Characteristics should be examined in future studies.

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