BENCHMARKING THE U.S. INDUSTRY'S USE OF AUTOMATION AND INTEGRATION TECHNOLOGIES ON PROJECTS

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Abstract: There has never been an industry-wide benchmarking study of the levels of technology used across the various life-cycles or phases of projects. The primary objective of this study was to measure the extent to which task integration and task automation (IA) technologies are being used in executing capital facility projects, including those used in facility operations and maintenance.
The data obtained and analyzed in the study discussed here are project-specific. The data collection tool makes use of 68 common project work functions in assessing levels of technology usage. Work function technologies not related to capital facility projects are outside the scope of this study.
The data collection tool was used to collect data on all types of projects in the Building, Industrial and Infrastructure sectors. Only low-volume home-building operations were deliberately neglected.

1. Introduction

Study Motives

The construction industry has been criticized for its slow adoption of emerging technologies. However, it is believed that in recent years this trend has been changing. Greater demands for more cost-effective and schedule-efficient projects have led to new project delivery processes, many of which exploit technologies that serve to either automate or integrate tasks.

The construction industry is a very competitive industry and the best companies are in constant search for proven technologies that offer a competitive advantage. Likewise, these companies generally avoid technologies that do not provide some proven added value. Yet, as some technologies have been adopted and others abandoned, there has never been an industry-wide benchmarking study of the levels of technology used on projects. This is the primary objective of this study: to measure technology usage on capital facility projects.

In addition to the lack of measurement of technology usage, there has been no comprehensive industry-wide study on the impacts of technology usage on project outcomes. Certainly lack of information regarding technology benefits along with uncertain competitive advantage from new technology have resulted in industry reluctance to implement new technologies.

Thus, a study of the relationship between technology utilization and project success is necessary. Quantitative analysis of the effects of Integration and Automation technologies on the success of projects should provide companies with additional information on whether to use certain technologies.

Study Objectives

The primary objective of this study was to investigate the extent to which IA technologies are being used in executing capital facility projects (including facility operations and maintenance). A related objective that pertains to the technology metrics data (and that is not fully addressed here) is to determine the extent, if any, to which IA technologies contribute to project success. Such work is ongoing and will be treated in future papers.

Lastly, a related objective for future study is to determine how the uses of IA technologies are changing over time. The data collection efforts discussed in this report occurred between October 1998 and August 1999. In order to analyze changes over time, it is recommended that the study be repeated in the 2002-03 timeframe.

Scope Limitations

The data collection tool was used to collect information about all types of projects in the Building, Industrial and Infrastructure sectors. Only low-volume home-building operations were deliberately neglected.

The data obtained and analyzed in this study are project-specific, meaning the data is representative of the levels of IA technologies used on projects (rather than that used organization-wide, for example). Work function technologies not related to project delivery are outside the scope of this study.

The data collection tool makes use of 68 common project work functions in assessing levels of technology usage. Owing to the fundamental differences in projects, not all of the 68 work functions are applicable to all projects. Accordingly, steps were taken to help ensure that computed IA indices are representative of the levels of IA technology used on projects.

2. Research Steps

Literature Review

A literature review was conducted on published research related to project automation and integration [Kumashiro 1999]. Due to length limitations, observations are not included here.

Development of the Data Collection Tool

Welch's thesis provides a complete discussion of the development and testing of the data collection tool [Welch 1998]. After the cover page, the survey requests the participant to provide general information about the project and final performance of the project in terms of cost, schedule, safety and stakeholder success. Additional-ly, this section obtains information about key study variables, such as the Industry Sector and Total Installed Cost of the project. The remainder of the survey assesses the levels of technology applied on the project.

For the purpose of this study a project's life cycle is structured in six phases: Front End (which includes scoping, feasibility, and preliminary design activities), Design, Procurement, Construction Management, Construction Execution, and Startup/Operations/Maintenance.

Each phase is comprised of work functions, some of which represent tasks (for possible automation) and some of which represent task-to-task integration links. There are a total of 68 work functions that make up a project. Table 1 shows the distribution of these work functions for each phase.

Study participants were first asked to identify a recent familiar project for assessment. For the subject project, the survey then asks participants to assess the degree of technology used in executing each work function for that project. The survey offers respondents three optional levels of technology utilization: Level 1, Level 2, or Level 3. Each level is defined as follows:

- Level 1 - No electronic tools or only the most common electronic tools are used; Informa-tion is conveyed verbally or on paper and transmitted via “snail mail”, fax, or courier.
- Level 2 – Uncommon electronic tools play key roles in executing the work function, but human workers still dominate. Information is stored primarily in stand-alone electronic formats and is transmitted via isolated electronic media such as disks or as e-mail attachments, etc.
- Level 3 – While human workers still participate, fully- or nearly fully-automated systems dominate; Information is stored on a networked system accessible by all appropriate participants.

In addition, “Not Applicable” and “Don’t Know” responses were offered as possible responses for each work function assessment. Thus, participants were encouraged to provide honest, informed responses.

Table 1: Distribution of Work Functions by Phase

Phase	Description	# of Work Functions
1	Front End	6
2	Design	14
3	Procurement	12
4	Constr. Mgmt.	15
5	Construction Execution	11
6	Startup, Operations & Maintenance	10
Total		**68**

Data Collection

Researchers proceeded to use the tool to conduct a nation-wide survey of technology use levels on capital facility projects. A total of 210 project responses were collected from all sources and by all means, including personal interviews, phone/fax interviews, and mail-in surveys of forms. Out of the 210, a total of 170 survey responses resulted from the in-office or on-site personal interviews. These responses represented 30 major metropolitan areas in 24 different U.S. states. The overall yield percentage (i.e., the ratio of surveys distributed to surveys received) was 78%, with several areas having yield percentages of 100%. In general, participants were enthusiastic to participate in the study.

In order to obtain a truly representative sample, not only was the geographic mix of projects intentionally diverse, but a diverse mix of participation was sought with respect to Contact Type, Sector of Industry, and Project Size.

In order to obtain a representative sample of the entire U.S. industry, a specified mix of Architect, Contractor, and Owner respondents was targeted based on published industry demographic data.

Individuals interested in participating in the study were identified by one of three methods: 1) a search in various online databases, 2) a search from various industry associations, or 3) a listing out of the local phone book. . No single method of identifying study participants was dominant. Both the targeted and actual mixes of study participants are presented in Table 2.

Except for the Building sector, the mix of actual responses according to the population characteristics presented in Table 2 was within 5% of the ideal mix as established by known industry demographics.

Data Modeling and Database Structure

Once data was collected, a database was structured to house the data and facilitate analysis. The database was constructed in this manner so that 1) the input data could be easily checked for errors and 2) all the data fields could be updated as the information was entered.

Table 2: Mix of Projects Analyzed

Population Characteristic	Classes	Targeted Mix (%)	Actual Mix (%)	Deviation (+/-)
Industry Sector	Buildings	60	51.8	-8
	Industrial	20	23.4	+3
	Infrastructure	20	24.8	+5
Total Installed Cost	<$5 Million	35	33.2	-2
	$5-20 Million	30	29.4	-1
	$20-50 Million	15	15.9	+1
	$50-100 Million	10	11.7	+2
	>$100 Million	10	9.8	0
Company Type	Owner	25-40	36.0	0
	General Contractors	25-35	40.3	+5
	A/E Companies	20-30	23.7	0
Project Typicality	Typical	90	85.2	-5
	Advanced	10	14.9	+5

Data Analysis: Descriptive Statistics

After populating the database, researchers sought to develop descriptive statistics according to data class variables. Included in the descriptive statistics are the frequencies, means, standard deviations, and ranges of the computed indices for each data class variable. The purpose of generating the descriptive statistics was to determine the current (1998-99) levels of Integration and Automation technologies in use according to data class variable.

There are six primary data class variables: Industry Sector, Project Phase, Total Installed Cost, Initial Site, Owner Regulation and Project Typicality. These variables are defined as follows:

1. Industry Sector - Buildings, Industrial or Infrastructure
2. Total Installed Cost – Five optional cost categories are presented: <$5 Million, $5-20 Million, $20-50 Million, $50-100 Million, and >$100 Million.
2. Project Phase –Work functions in six phases are assessed: Front End (including scoping, feasibility, preliminary design, etc.), Design, Procurement, Construction Management, Construction Execution, and Startup/ Operations/ Maintenance.
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 optional responses: Greenfield (or new), Renovation, or Expansion.

Additional analyses of the data are ongoing. These pertain to IA descriptive statistics at the work function level and investigation of any relationships between technology use and project success.

3. Sampling Issues

Obtaining a Representative Sample

Regarding how representative the 68 work functions are of all project types, ongoing research work indicates that, except for Phase 6, the work functions are very representative of the breadth of projects. While Phase 6 (Operations/Maintenance) work functions assessments include nearly 33% of "N/A" (i.e., Not Applicable) responses, only two other work functions have such a response at 30% or higher frequency. (These two work functions are "Fabricate roof trusses," and "Manipulate and hang sheet rock.") This indicates that a significant majority of respondents found the work functions applicable to the wide variety of subject projects.

Dealing with Incomplete Data

Researchers attempted to ensure representative response data by establishing a rule regarding upper limits to the number of "Don't Know" work function assessments allowable for inclusion in data analysis.

This helped ensure that sufficient knowledge was obtained about each phase of a project.

In addition, a rule was established regarding lower limits to the number of phases (out of the total of six) that must contain sufficient data. This approach helped ensure that sufficient knowledge was obtained about the entire project in order to be truly representative of the actual project.

4. Development of Indices

Six indices were developed for measuring the use of Integration and Automation technologies:

- Phase IA Index,
- Project IA Index,
- Project Task Automation Index,
- Project Integration Link Index,
- Phase Task Automation Index, and
- Phase Integration Link Index.

The mean values of these indices are used to characterize the level of IA technologies in use at the time of the survey (Oct. 1998 - Aug. 1999). Additional more specific insights are possible when these indices are analyzed according to the six data class variables.

Phase Integration and Automation Index

The Phase IA Index is a measure of the level of technologies used in a single phase of projects.

The first step was to determine if the response data associated with a particular project and phase was adequate to be representative. A minimum response rate of 70% of all work functions associated with a phase was established as the criterion for acceptance. Acceptable work function assessments included any of the three technology level responses (1-2-3) or the N/A (not applicable) response.

The equation for the phase response rate associated with any project and all phases is:

$$\textbf{Phase Response Rate} = \frac{\textbf{(\# of phase work functions with 1/2/3 response + \# of `N/A' responses for that phase)}}{\textbf{Total \# of phase work functions}}$$

If a particular phase of a project didn't meet the 70% rate criterion, then no phase index was computed for that phase of that project. Once the 70% criterion was met, the next step was to calculate the Phase Index score.

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 in such a way as to weight equally all Work Function Scores:

$$\textbf{Phase IA Index (raw)} = \frac{\textbf{Sum of phase Work Function Scores}}{\textbf{(Total \# of phase work functions - \# of phase ``N/A'' responses - \# of phase ``Don't Know'' responses)}}$$

The scale of the *raw* Phase IA Index is the same 1-2-3 scale of the Work Function Score.

To translate the raw index to a more familiar 0-10 point scale, the Phase IA Index was computed in the following way:

$$\textbf{Phase IA Index} = \textbf{(raw Phase IA Index} - \textbf{1)} * \textbf{5}$$

Thus, all Phase IA Index values are presented on a 0-10 scale.

Project Integration and Automation Index

In order to compute a Project IA Index, it was established that a project had to have at least three of six phase indices (each of which met the 70% rule). In addition, at least two of the phase indices had to pertain to either the Design, Construction Management, or Construction Execution phases. This criterion was developed to ensure that Project IA Index values adequately reflected project design- and construction-related activity, which are of primary interest to the researchers.

Once these criteria were met, the index was computed as follows:

$$\textbf{Project IA Index} = \frac{\textbf{Sum of Phase IA Index scores}}{\textbf{\# of Phases with a computed index}}$$

Thus, each represented phase is effectively weighted equally.

Task Automation & Integration Link Indices

The project-level Task Automation Index and Integration Link Index were computed in order to distinguish overall progress in automating tasks from overall progress in automating the transfer of information between tasks. As stated previously, two types of work functions are included in the survey assessment form: task automation work functions and task-to-task integration (or "integration link") work functions.

Before project-level task and link indices can be computed, indices must be computed first at the phase level. Raw Phase Task Indices and raw Phase Link Indices are the computed averages of 1-2-3 scale responses associated with each of the respective task automation and integration link work function assessments in a single phase. Unlike the Phase IA Indices, no response rate restrictions were applied in computing the Phase Task Index and Phase Link Index. The small number of categorized work functions in several phases was the primary justification for this approach.

The formulas for computation of the raw Phase Task Index and Phase Link Index are as follows:

Phase Task Index (raw) =

Sum of all task automation Work Function Scores in phase

Total # of task automation work functions assessed in phase

Phase Link Index (raw)=

Sum of all integration link Work Function Scores in phase

Total # of integration link work functions assessed in phase

Raw index values were then converted to a 0–10 scale in a similar manner as before with the Phase IA Index values. The Project Task Index and Project Link Index were then calculated as follows:

Project Task Index =

Sum of Phase Task Index values

Total # of phases with task indices

Project Link Index =

Sum of Phase Link Index values

Total # of phases with link indices

Thus, phases are weighted equally for both.

5. Key Findings

At the time of this data collection, on an index scale of 0 to 10, the U.S. industry was at 3.8 in usage of project automation and integration technologies.

Types or aspects of projects that involve higher usage of technology include the following:

- Industrial sector
- Front End and Design phases
- Infrastructure projects in Phases 1 and 2
- Task Automation, especially for Building and Industrial sectors.
  - Advanced Industrial projects
  - Medium- and large-size projects
  - Medium-size Greenfield and Renovation/Expansion projects
  - Phases 1, 2 and 6 of Advanced projects
  - Medium sized projects in Phases 1 and 2
  - Task Automation on Advanced projects
  - Task Automation on Medium sized projects
- Expansion and Greenfield projects
- Expansion Infrastructure projects
- Greenfield Industrial projects
- Renovation Building projects
- Infrastructure Expansion projects.
- Public Expansion projects.
- Greenfield Private projects
- Expansion projects in Phase 6.
- Greenfield projects in Phase 1
  - Public projects in Phases 1, 2, and 3
  - Private projects in Phase 2
- Task Automation for Expansion projects
- Integration Links for Expansion and Greenfield projects
- Both Task Automation and Integration Links in Phase 2

Types or aspects of projects that involve lower usage of technology include the following:

- Building and Infrastructure sectors.
- Phases 4 and 5
- Building projects in Phase 5
- Integration Links
  - Small-size projects
  - Small Greenfield projects
  - Phase 5 of Advanced projects
  - Small projects in Phase 4
  - Integration Links for both Typical and Advanced projects
  - Integration Links for Small projects
- Renovation projects
- Expansion Building projects
- Greenfield Infrastructure projects
- Renovation Infrastructure projects
- Private Expansion projects.
- Greenfield Public projects
- Renovation projects in all phases
- Public and Private projects Phase 5
- Task Automation for Renovation projects
- Integration Links for Renovation projects
- Task Automation in Phase 5
- Integration Links in Phase 4

Notable differences or similarities in technology usage include the following:

- Infrastructure projects are most variable.
- the differences between Private and Public projects is negligible.
- Buildings with TIC < $5 million involve significantly lower levels of IA technology than those with TIC > $5 million.
- Private projects with TIC of $5-20 million involve higher levels of technology than those with TIC < $5 million.
- Infrastructure projects involve significantly higher levels of IA technology

during Procurement than do Industrial projects.

- The level of technology applied in the Construction Management
- Phase 4 technology use does not differ across the three industry sectors.
- Infrastructure projects involve significantly higher levels of IA technology in Phase 5 than Buildings projects.
- Industrial projects involve very significantly higher levels of IA technology in Phase 6 compared to Infrastructure projects.
- Task automation levels are similar to task integration levels for Infrastructure projects.
- Advanced projects use only slightly more technology than Typical projects.
- The difference in technology use between Medium and Small-size projects is large.
- Large and Small projects differ significantly
- Medium and Small Greenfield projects differ significantly
- Small and Medium Typical projects differ significantly
- Advanced and Typical projects are virtually the same for Phases 1 and 5
- Advanced and Typical projects differ significantly for Phase 6 and Phase 4.
- Phase 5 technology use does not vary significantly by project size
- Large and Small projects for Phase 6 differ significantly
- Medium and Small projects differ significantly for Phases 1 through 4
- Task automation generally involves more technology than does task-to-task integration.
- Integration link technologies are essentially at the same level for both Typical and Advanced projects.
- The increment from integration to automa-tion technology levels for Advanced projects is three times that of Typical projects.
- With respect to both Task Automation and Integration Links, Medium and Large projects are relatively similar in their level of technology use; respective values for Small projects are sharply lower.
- Renovation projects have the highest variability
- Typical project technology usage doesn't vary much across the 3 Site types
- Greenfield Public projects have high variability
- Phase 6 technology usage has high variability
- Design and Construction Execution technology use differs by nearly 2 pts..
- Expansion projects are comparable to Greenfield projects for Phases 2, 3, 4, and 5.
- Expansion and Renovation projects differ significantly in Phase 6.
- For the Procurement phase, projects simply don't differ much by Initial Site.
- Public projects differ substantially between Phases 1 and 5 and between Phases 2 and 5
- Public and Private projects both differ significantly between Phases 1 and 5 and between Phases 2 and 5
- Public and private projects differ significantly in Phase 6
- Phase 5 for Private projects has low variability.
- Task Automation levels are higher than Integration Links for Phases 2, 3, 4, and 6.
- Task Automation and Integration Links differ the most between Phase 4 and Phase 3
- Task Automation and Integration Links differ the least for Phase 6
- Phase 2 task automation differs very substantially from Phase 5
- Phase 2 task integration differs very substantially from Phase 4
- Task integration for Phase 5 is highly variable
- Phase 4 Task Automation has tight variability

The IA indices values computed and analyzed in this study are a fair representation of the state of U.S. industry practice at the time of the assessments - Fall 1998 through Summer 1999. However, technology is advancing at a rapid pace and it will be necessary to repeat this study in the near future in order to understand how technology applications are expanding. This is particularly true given the emergence of web applications for the industry.

References

Kumashiro, M.E. (1999). *Measuring Automation and Integration in the Construction Industry*. M.S. Thesis, Dept. of Civil Engineering, The University of Texas at Austin.

O'Connor, James T., Kumashiro, Mark E., Welch, Keith A., and Hadeed, Shane P. (2000), *Methodology for Study of Integration and Automation Metrics for Capital Facility Projects*, Center for Construction Industry Studies, Report No. 12, University of Texas at Austin.

O'Connor, James T., and Hadeed, Shane P., (2000) *Project Integration and Automation Metrics: Industry Sector and Owner Regulation Variables*, Center for Construction

Industry Studies, Report No. 13, University of Texas at Austin.

O'Connor, James T., and Braden, Kristen E. (2000), *Project Integration and Automation Metrics: Total Installed Cost and Project Typicality Variables*, Center for Construction Industry Studies, Report No. 14, University of Texas at Austin.

O'Connor, James T., and Deogaonkar, Mandar J., (2000) *Project Integration and Automation Metrics: Initial Site and Project Phase Variables*, Center for Construction Industry Studies, Report No. 15, University of Texas at Austin.

Welch, K.A. (1998). *Development of a Tool for Assessing the Degree of Automation and Integration on Capital Projects*. M.S. Thesis, Dept. of Civil Engineering, The University of Texas at Austin.