Relationship between Automation and Integration of Construction Information Systems and Labor Productivity

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Abstract: Information technology (IT) has been used to increase automation and integration of information systems on construction projects for over two decades. However, evidence that overall costs have been reduced or project performance has been improved with IT in construction is limited and mostly focused on application specific studies. A comprehensive understanding of the relationship between IT and project performance helps industry practitioners better understand the likely outcomes of implementation of IT application and likewise benefits researchers in improving the effectiveness in their IT development efforts. An opportunity to examine new evidence exists with the emergence of the Construction Industry Institute's Benchmarking and Metrics database on construction productivity and practices. This article presents an analysis of that data to determine if there is a relationship between labor productivity and level of IT implementation and integration. Data from industrial construction projects are used to measure the relationships between the automation and integration of construction information systems with productivity. Using the independent sample t-test, the relationship was examined between jobsite productivity across four trades (concrete, structural steel, electrical, and piping) and the automation and integration of various work functions on the sampled projects. The results showed that construction labor productivity was positively related to the use of automation and integration on the sampled projects.

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Introduction

Unfortunately, the construction industry has traditionally been viewed as technologically stagnant in comparison with other industries (Rosefielde and Mills 1979). Furthermore, within the industry, a lack of information and some healthy skepticism regarding technological net benefits has contributed to the construction industry's reluctance to implement new technologies (O'Connor and Yang 2004). Nonetheless, most would acknowledge that information technology (IT) has significant potential to influence both company and project performance in construction. There is reason to believe that IT may eventually have a significant net positive impact on construction projects, yet little evidence exists. One vision predicts that future construction sites will become more "intelligent and integrated" as materials, components, tools, equipment, and people become elements of a fully sensed and monitored environment (Wood and Alvarez 2005). Furthermore, it is envisioned that the automation of construction processes will augment manual labor for hazardous and labor-intensive tasks such as welding and high-steel work. In such an environment, whether actively or passively, the construction environment will be required to process and share larger volumes of data across multiple systems. What remains uncertain of this and other visions of future jobsites is whether there has been or will be a net project benefit or even an improvement in construction productivity as a result of the increased automation and integration of construction systems. Labor productivity improvement alone may motivate adoption of IT in construction. Since it was widely recognized that IT adoption boosted the overall productivity in the U.S through the last couple of decades (Siegel 1994; Brynjolfsson and Hitt 1996), it is reasonable to assume that the same could be true in construction.

Increasing the use of IT on construction jobsites, if it improved labor productivity substantially, might help address the shortages of skilled craft workers in the construction industry. In a survey of facility owners on workforce development conducted by the Construction Users Roundtable (CURT) in the summer of 2001, 82% of the respondents reported work force shortages on their projects, and 78% indicated that the trend had worsened over the previous three years (CURT 2004). With the growing likelihood of gaps between craft supply and demand, maintaining or improving construction productivity will be necessary and challenging for the industry. While construction craft workers may not be direct users of IT applications, they may also benefit from improved quality and timeliness of information which may result from implementation of IT. However, the magnitude of the potential benefit of IT to craft labor productivity remains largely unmeasured, and this is a key aspect of work described herein.

The primary objective of this research is to examine the relationship of the automation and integration of construction systems to construction labor productivity through statistical analyses. Part of this objective includes examining relative improvements in productivity as a result of automating and integrating different

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construction work functions. For the purpose of this research, the writers adopted the following definitions of automation and integration as developed by O'Connor and Yang (2004):

- ***IT Automation*** is defined as the use of an electronic or computerized tool by a human being in order to manipulate or produce a product. Hard automation, such as robotics, is not included in this definition.
- ***IT Integration*** is defined as the sharing of information between project participants or melding of information sourced from separate systems.

In regard to productivity, this paper focuses on labor productivity, which is the ratio of output to labor hours rather than factor productivity, which is the ratio of output to capital costs (including the cost of equipment, material, and labor). While factor productivity is also likely influenced by IT, the nature of the analyses influenced the use of labor productivity for two reasons. First, it is easier to accurately measure labor productivity, since the input measure for labor productivity is limited to the work hour requirement for output. Second, factor productivity data did not exist in the database, nor could it be derived from the data that was available. Results of an analysis focused solely on labor productivity must be interpreted carefully. Meanwhile, the writers acknowledge that technology in general has a greater influence on labor productivity versus factor productivity, which is referred to the labor savings bias of technical change (Salter 1966). So, the analysis presented in this paper does not lead to any cost-benefit conclusions but only to answer one part of the puzzle; "does automation and integration in construction lead to improved or decreased labor productivity?"

Background

Previous research has examined the impact of information automation and integration systems on construction performance. O'Connor and Yang (2004) found that increased automation and integration usage may contribute significantly to project performance in terms of cost and schedule success. The researchers developed an integration and automation (IA) index ranging from 0 to 10 according to IA use level on a series of project work functions. O'Connor and Yang (2004) statistical analysis indicated that the schedule success technology relationship was stronger than that for cost. El-Mashaleh et al. (2006) found a similar quantitative result, when they also examined the impact of IT on construction firm performance (especially cost and schedule). The method they used to develop an IT index was similar to that in O'Connor and Yang (2004) research. Their analysis showed that for every 1 unit increase in their IT index, construction firms experienced an increase of 5 and 3% in schedule performance and cost performance, respectively. More specific technology uses and their impacts on productivity are introduced below.

Other research has also examined the impact of more specific IT applications. Griffis et al. (1995) found that 3D model usage was positively related to improvement of cost and schedule performance and reduction of rework. Balli (2002) showed how handheld computers in conjunction with wireless networking technologies could provide accurate, reliable and timely information to construction foremen at locations where it is needed. Balli argued that handheld computers would allow people to access material, tools, equipment and drawing information, which could reduce delay time and boost productivity. Thomas et al. (2004) evaluated the use of design/information technology (D/IT) and relationship between the D/IT use and project performance. The researchers measured the degree of D/IT usage specifically based on the use of four technologies: (1) integrated database; (2) electronic data interchange (EDI); (3) three-dimensional (3D); and (4) computer-aided design (CAD) modeling, and bar coding. Thomas et al. (2004) indicated that D/IT was positively related to project performance, especially cost and schedule. Caldas et al. (2006) investigated the use of global positioning systems (GPS) on improving materials locating processes on industrial projects. This research found that the technology not only provided direct time savings in the material-locating process, but it also reduced the number of lost items, work disruption and labor idle-time. Ergen et al. (2007) indicated that automated tracking and locating technology using radio frequency identification (RFID) combined with GPS technology could eliminate the deficiencies in existing manual methods of identifying, tracking and locating highly customized prefabricated components. Torrent et al. (unpublished, 2008) conducted an extensive field trial of an automated material tracking system for structural steel that also utilized RFID and GPS and was able to tie the use of the system with improvement in labor productivity. From these research results it can be seen that information technology has been impacting construction and will continue to benefit construction in the future, although most of the evidence is limited to specific applications. The research described herein involves a comprehensive measure of information technology as utilized by others (O'Connor and Yang 2004) with specific measures linked to craft productivity.

Researchers focusing on other industries have also investigated a general relationship between information technology and productivity. Siegel (1994) investigated the relationship between IT and manufacturing productivity. He found a significant positive relationship between productivity growth and investments in computers. Although previous manufacturing research did not observe a positive correlation between IT and productivity growth [Solow (1987); Roach (1991); Brynjolfsson (1993); Siegel (1994)] argued that this absence of a positive relationship, at least in the manufacturing sector, could be attributed to measurement error of the industry productivity measures. Brynjolfsson and Hitt (1996) found firms' investment in information systems made a substantial and statistically significant contribution to firm output. Lehr and Lichtenberg (1999) examined information technology and its impact on firm-level productivity among companies in eight industries. The researchers found that the productivity of firms participating in their study was strongly related to the number of personal computers used by a firm and concluded that IT usage, at least in the form of personal computers, did positively contribute to productivity growth.

Although numerous studies have examined the general relationship of IT and productivity, these efforts did not quantitatively examine the impact of IT on craft labor productivity. Previous research that focused on other forms of technology, such as equipment and material technology, found substantial and statistically correlated longitudinal improvements in construction craft productivity associated with equipment and material improvements (Koch and Moavenzadeh 1979; Goodrum and Haas 2002, 2004; and Goodrum et al. 2009). The research described herein contributes to the body of knowledge by providing a practical understanding of whether automation and integration of project work functions are related to construction productivity changes. Understanding the past performance of automation and integration technologies can help companies predict future performance of these technologies when considering whether a financial investment is prudent as well as developers of new technologies to understand the same.

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Methodology

Data Source

The data used in this research are from the Construction Industry Institute (2000) Benchmarking and Metrics (BM&M) Productivity Database. The BM&M program aims to measure and assess capital project performance and find the best practice among similar projects. The dataset is intended to allow participating companies to compare their own projects with similar ones, and improve their performance through implementing the recommended practices identified by the program. The database currently includes 86 projects, providing information about project description, field practices, and labor productivity. The field practices include different aspects of jobsite management systems such as materials management, constructability, and automation and integration of project systems among others. In this research, only the field practices of automation and integration of construction systems among the sampled projects along with their corresponding labor productivity were examined. The database collected activity productivity data among a variety of construction tasks among seven trades. The CII productivity metrics, including the definition of the measuring activities and tasks, were identified through the use of literature reviews, documentation from owner and contractor organizations, and a series of workshops with industry experts (Park et al. 2005). Details on its methods of data collection and standard accounts have been well documented elsewhere (Park et al. 2005). For the purpose of this research, only task productivities in four common trades were examined: concrete, structural steel, electrical and piping, due to restrictions in sample sizes.

Productivity Definition and Normalization

For the purposes of the study, the researchers measured labor productivity among the four trades using the following Eq. (1):

$$Labor\ Productivity = \frac{Actual\ Workhours}{Installed\ Quantity} \tag{1}$$

It is important to note that a lower productivity number per Eq. (1) is better. To ensure company confidentiality and allow comparisons across different tasks and trades, the raw productivities were normalized using the Min-Max method (Han and Kamber 2000) based on the following Eq. (2):

$$P_{norm} = \frac{P_{raw} - P_{raw\ \min}}{P_{raw\ \max} - P_{raw\ \min}}(P_{norm\ \max} - P_{norm\ \min}) + P_{norm\ \min} \tag{2}$$

In Eq. (2), P_{norm}=normalized productivity; P_{raw}=raw productivity measure; $P_{raw\ \min}$ and $P_{raw\ \max}$=minimum and maximum raw productivity values in the construction task; and $P_{norm\ \min}$ and $P_{norm\ \max}$=minimum and maximum normalized productivity values, equal to 1 and 10, respectively. The normalized productivity [Eq. (2)] is consistent with the paper's raw productivity measure [Eq. (1)], a lower value indicates better productivity.

Work Functions

To assess the impact of automated and integrated information systems on construction jobsites, the research examined the level of technology automation and integration that projects had achieved in the following work functions (WF), which had been established by Kang et al. (2006):

1. *Business planning and analysis*: instituting a set of business goals with the project and explaining the reasons why the goals are believed attainable, along with a plan to reach those goals;
2. *Conceptual definition and design*: the stage in the life of a project that culminates in the preparation of a document containing a functional architectural or spatial program, along with a conceptual cost estimate and a set of design standards;
3. *Project definition and facility design*: identifying the mission statement and overall scope of a project, including scope of constructed environment, e.g. buildings, structures, infrastructure, plant and equipment;
4. *Supply management*: managing the methods and processes of acquiring materials, goods, or services and administering the relationship with suppliers;
5. *Project management*: planning, organizing, and managing resources for the successful completion of specific project goals and objectives;
6. *Offsite/pre-construction*: the use of modularization and prefabrication;
7. *Construction*: all the work involved in assembling resources and the materials to form a new or changed facility;
8. *As-built documentation*: documenting drawings and diagrams that provide an accurate representation of how the product or facility is actually built; and
9. *Facility start-up and life-cycle support*: the activities that facilitate the transitional phase between construction completion and operation.

Project management, due to its importance in the project execution process, is further subdivided into five work functions, bringing the total number of work functions examined in this study to 13.

1. *Coordination system*: the system linking various areas of a project to ensure the transfer of information or hardware at interface points at the appropriate times, and the identification of any further necessary resources;
2. *Communications system*: the system transmitting and validating receipt of information to make the recipient understand what the sender intends, and to assure the sender that said intent is understood;
3. *Cost system*: a project-cost accounting system of ledgers, asset records, liabilities, taxes, depreciation expense, raw materials, prepaid expenses, and salaries;
4. *Schedule system*: the system managing or rearranging the activities in a project schedule to improve the outcome based on the latest available information; and
5. *Quality system*: the system for maintaining quality requirements in a product or project.

Automation and Integration Use Level

Using scales developed by previous research efforts (Kang et al. 2006), the level of automation of the systems that controlled the above work functions is based on the following five-point CII scale:

Automation Levels

- Level 1 (none/minimal): little or no utilization beyond e-mail;
- Level 2 (some): "office" equivalent software, 2D CAD for detailed design;
- Level 3 (moderate): stand-alone electronic/automated engineering discipline (3D CAD) and project services systems;
- Level 4 (nearly full): some automated input/output from mul-

tiple databases with automated engineering discipline design and project services systems; and
- Level 5 (full): fully or nearly fully automated systems dominate execution of all work functions.

Likewise, the writers used the CII five-point scale to measure the level of integration of control systems within each work systems, which was also developed by Kang et al. (2006).

Integration Levels
- Level 1 (none/minimal): little or no integration of electronic systems/applications;
- Level 2 (some): manual transfer of information via hardcopy of email;
- Level 3 (moderate): manual and some electronic transfer between automated systems;
- Level 4 (nearly full): most systems are integrated with significant human intervention for tracking inputs/outputs; and
- Level 5 (full): all information is stored on a network system accessible to all automation systems and users. All routine communications are automated. The automated process and discipline design systems are fully integrated into 3D design, supply management, and project services systems (cost, schedule, quality, and safety).

Automation and Integration Index

The above definition levels were used to assess the level of automation and integration achieved by projects in specific work functions. It should be noted that these data are self-reported by company participants and are therefore subject to some level of interpretation and possibly less credibility than what might have been achieved as a result of researcher site visits to each project and company. The trade-off is that much more data are available than what would have been affordable in a site-visit approach. For the analyses, the research calculated each project's overall level of automation and integration through the automation and integration indices. Automation and integration indices were calculated based on the 13 work function automation and integration use levels. The range of the index is from 0 to 10.

The method of calculating the automation and integration indices are similar to that developed by O'Connor and Yang (2004). The procedure uses the following steps:
- For each work function, the automation (or integration) use score was calculated based on the following equation:

$$\textit{Automation (or Integration) Use Score} = (n-1)/4 \qquad (3)$$

where n=automation (or integration) scale as described before;
- Next a 10-point automation (or integration) index for each project was derived using the following equation:

Table 1. Automation Index Calculation for a Sample Project

Work function	Automation level	Use score [Eq. (3)]
Business planning & analysis	4	0.75
Conceptual definition & design	3	0.5
Project definition & facility design	3	0.5
Supply management	5	1
Coordination systems	2	0.25
Communication systems	3	0.5
Cost systems	5	1
Schedule systems	4	0.75
Quality systems	3	0.5
Offsite/preconstruction	4	0.75
Construction	3	0.5
As-built documentation	4	0.75
Facility start-up & life cycle support	4	0.75
Mean of automation use score:		0.654

Note: Automation index [Eq. (4)] $=0.654\times10=6.54$

$$\textit{Automation (or integration) Index} = \textit{Mean automation (or integration) Use Score} \times 10 \qquad (4)$$

Based on the automation use levels of the 13 WF, an example calculation for the Automation Index of a sample project is presented in Table 1.

For purposes of the analysis, projects scoring 5% above the overall median among all sampled projects were classified as having a high level of automation or integration, and projects scoring 5% below the median were defined as having a low level of automation or integration. The projects falling within the 5% range were not used in the comparison between the two groups. In the automation related analysis, 4 projects fell within this range, and in the integration related analysis, 9 projects fell within this range. The reason for using the median rather than the mean is that automation and integration indices do not have a perfectly normal distribution. The purposes of using such a 5% range below and above the median are: (1) to create two groups with more distinct differences in automation and integration use levels; and (2) to guarantee that the sample sizes are large enough to perform the statistical analyses. The writers acknowledge that the differences in technology use levels would be larger by using a wider range, such as 10% below and above the median, but the sample sizes would be too small to conduct the analyses. By using a 5% percentage above and below the median, the writers can reach a balance between the technological difference of the two groups and the sample size.

Table 2. Descriptive Statistics of Normalized Productivity

Trade	N (activities)	Mean	Min	Max	Sta.Dev	95% confidence interval of the Mean	
						Lower	Upper
Concrete	81	3.50	1	10	2.33	2.99	4.02
Structural Steel	75	4.15	1	10	2.46	3.58	4.72
Electrical	85	3.88	1	10	2.85	3.27	4.50
Piping	98	4.18	1	10	2.98	3.58	4.78

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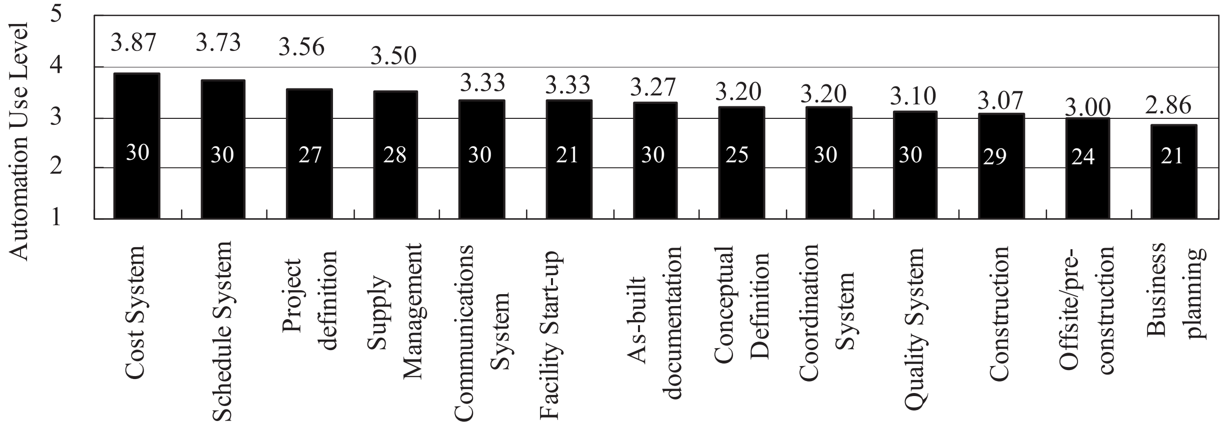

Fig. 1. Average automation use level on each work function

Hypothesis

The research hypothesis is that positive associations exist between labor productivity and automation and integration usage in construction. As a result, the hypothesis test is described as follows:

$$H_0{:}P_H = P_L$$

$$H_1{:}P_H \neq P_L$$

P_H denotes the average productivity of a project with a high level automation (or integration) index. Similarly, P_L denotes the average productivity of a project with a low level automation (or integration) index. The analyses utilized the independent sample T-test with the Levene's test to test the research hypotheses. The Levene's test was used to test if the two groups of productivity data have equal variance, which allowed the writers to perform the T-test with proper knowledge regarding whether the actual variance was equal or unequal.

Actual Productivity Comparison

The described T-test results were based on normalized productivity measures in order to preserve the confidentiality of the CII BM&M data and to also allow analysis across different tasks and trades, since the normalized productivity measures are dimensionless. However, reporting the analyses using normalized productivity obscures the actual effects. To help clarify the results, the researchers calculated the means of raw productivity for the projects with high and low level technology use and then calculated the percentage difference using the following equation:

$$\textit{Percentage Difference of Productivity} = \frac{(\textit{Mean } P_{RawL} - \textit{Mean } P_{RawH})}{\textit{Mean } P_{\mathrm{RawL}}} \times 100, \tag{5}$$

where P_{RawH} denotes the raw productivity with high level automation (or integration) index. Similarly, P_{RawL} denotes the raw productivity with low level automation (or integration) index. As a reminder, raw productivity was measured based on actual work hours per installed quantity, so the percentage difference of productivity indicates the approximate percentage of time saving per installed quantity when using a high versus a low level of technology usage.

Results of Analyses

Descriptive Statistics

In total, 339 activities from 30 projects were included in the analyses. The data in CII's BM&M database were collected through two different questionnaires, one for large projects and the other for small projects. The projects with installed costs less than 5 million dollars were defined as small projects and those with more than 5 million dollars installed costs were defined as large projects. Only 39 of the 86 projects can be identified as large projects, and only in 30 of the 39 projects were both the productivity measurement in the four trades and the automation and integration use levels available. Missing data in the other 9 projects prevented their inclusion in the analyses. The descriptive statistics for the activities' normalized productivity are presented in Table 2. The means of the normalized activity productivities from the four trades ranged from 3.50 for concrete to 4.18 for the piping trade.

Next, the average automation use level for each work function among the 30 sampled projects was calculated. As shown in Fig. 1, the average automation use levels on all of the work functions are greater than 3.00, except business planning. The average automation index is 5.72 (on a 0 to 10 scale) with a 95% confidence interval from 5.53 to 5.90, and its distribution among the sampled projects is shown in Fig. 2. The work function with highest automation use level is *cost system*, followed by *schedule system*.

The average integration use level on the 13 work functions is

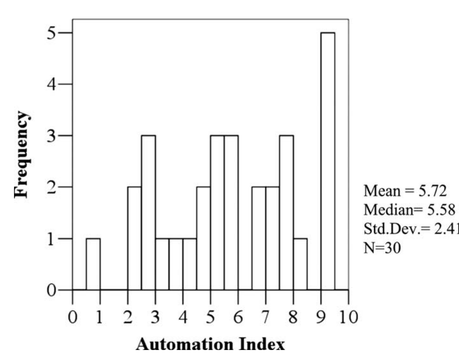

Fig. 2. Histogram of automation index distribution for the sampled projects

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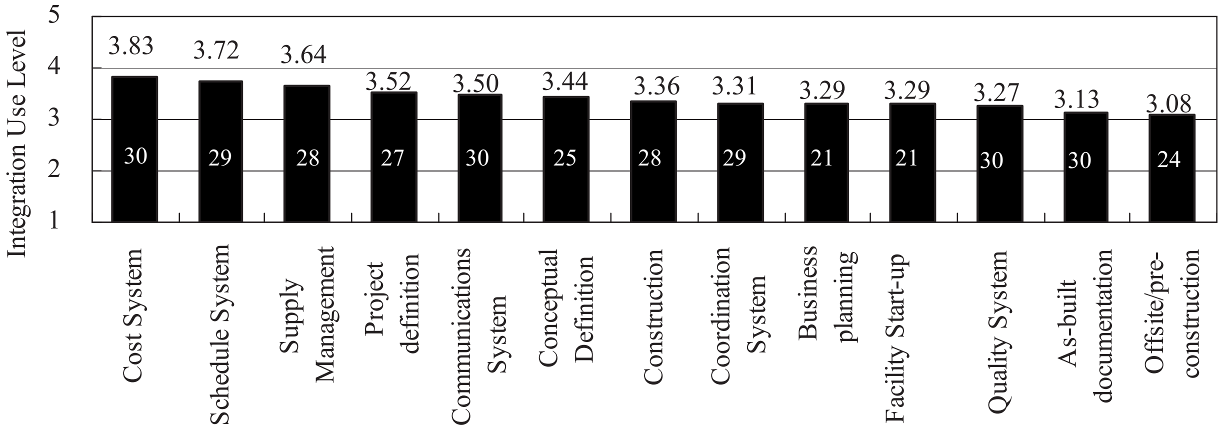

Fig. 3. Average integration use level on each work function

greater than 3.00 (Fig. 3), and the average integration index is 5.98 (on a 0 to 10 scale) with a 95% confidence interval from 5.80 to 6.16 (Fig. 4). The work function with lowest integration use level is *offsite/preconstruction*, followed by *as-built documentation*. The work function with highest integration use level is still *cost system*, followed by *schedule system*. Due to the importance of cost and schedule on construction project performance, it is not unexpected that the two work functions are of the highest automation and integration use level.

Analyses by Trade and Technology Indices with Actual Productivity Comparison

Next, the writers examined differences in productivity across project use of automation and integration technologies using the indices described by Eqs. (3) and (4). The writers examined the productivity among the four trades as well as the productivity among all trades using the normalized productivity measure. All trades productivity is a combination of the four trade-specific normalized productivity datasets, which includes all of the normalized activity-productivity available in this research combined into one dataset.

The results (Table 3, Fig. 5) indicate that automation usage is positively related to structural steel, electrical and all-trade productivity, and all of these relationships are significant at the 0.05 level. The results for the concrete and piping trades lack statistical significance although the relationships are positive. A comparison using actual productivity measures, as described by Eq. (5), was also made between projects that had a high versus low usage of automation technologies. The actual productivity shows that the projects with high level automation usage are associated with 23.3, 33.9, 30.3, and 36.4% time savings per installed quantity in the concrete, structural steel, electrical, and piping trades, respectively. The average time saving across the four trades is 30.9% (Fig. 7).

As indicated in Table 4 and Fig. 6, integration usage was positively related to concrete, structural steel and all-trade productivity at a statistical significance level of 0.05. The relationship in the electrical trade was significant at the 0.15 level. Again, no statistically significant result was observed in the piping trades, although the relationship was positive. The actual productivity shows that the projects with high level integration usage are associated with 56.4, 41.5, 38.4, and 45.9% time savings per installed quantity in concrete, structural steel, electrical and piping trade, respectively. The average time saving across the four trades

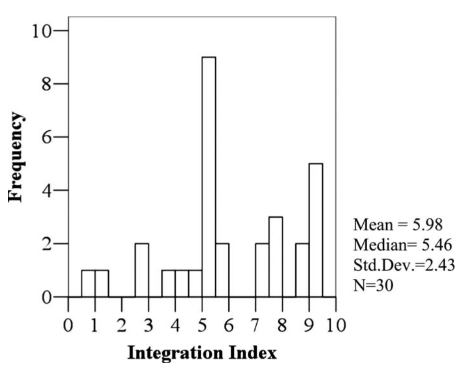

Fig. 4. Histogram of integration index distribution for the sampled projects

Table 3. Results of *t*-Test on Automation Index by Trade

	Normalized productivity			Levene's test for equality of variances		Equal variances assumed		Equal variances not assumed	
Trade	High level automation	Low level automation	Difference	F	Sig.	t	Sig.	t	Sig.
Concrete	3.48 (33)	3.89 (37)	−0.40	4.98	0.03	−0.69	0.49	−0.70	0.49
Structural steel ***	3.74 (40)	5.24 (24)	−1.50	16.91	0.00	−2.42	0.02	−2.14	0.04
Electrical ***	3.65 (52)	5.21 (19)	−1.55	1.51	0.22	−2.04	0.05	−1.91	0.07
Piping	3.96 (53)	4.40 (37)	−0.45	3.97	0.05	−0.71	0.48	−0.69	0.50
All trades ***	3.68 (178)	4.54 (117)	−0.86	20.62	0.00	−2.72	0.01	−2.58	0.01

Note: ***=significance at 0.05. The numbers in the parentheses are the sample sizes (activity productivities).

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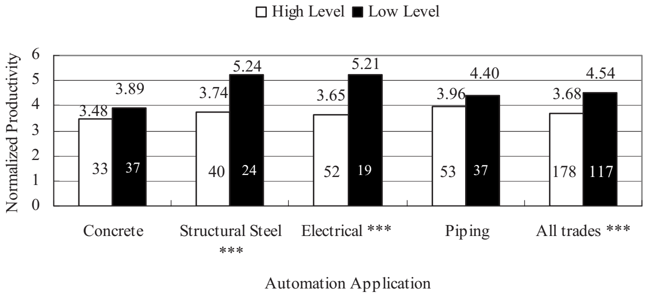

Fig. 5. Normalized productivity comparison by trade (high level automation versus low level automation)

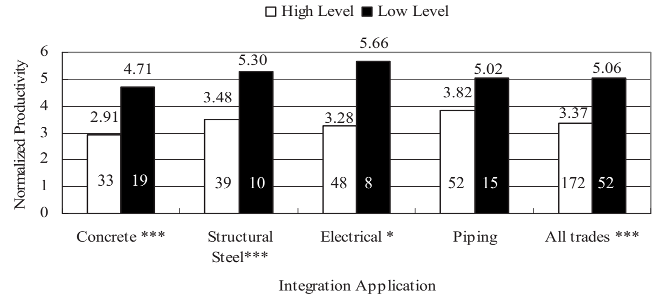

Fig. 6. Normalized productivity comparison by trade (high level integration versus low level integration)

is 45.0% (Fig. 7). While both integration and automation are related with better productivity performance, the analyses suggest that integration has a greater impact.

Discussion of Results

Overall, the analyses show that construction labor productivity is positively correlated with the usage of automation and integration technology on the sampled construction projects. The average time savings per installed quantity were observed to be 30.0 and 45.0% when using a high versus a low level of automation and integration, respectively. Few previous research efforts have provided quantifiable information on the extent to which construction productivity is related to automation and integration, thus it is difficult to validate the results in this research directly. However, related results by previous research efforts do exist. For example, Griffis et al. (1995) found that projects using 3D modeling experienced a 65% reduction in rework. Back and Bell (1995) indicated that the material management process exhibited an 85% time savings and a 75% cost savings by fully exploiting electronic data management technologies to enable the capacities of automation and integration. Although it is not the only factor, productivity improvement is one of the most important factors in time savings. Stiroh's research in 2002, not limited to construction, identified that IT had emerged as an appealing candidate to explain the acceleration of U.S. productivity growth in recent years, and his results strengthen that view by establishing a link between IT capital and subsequent productivity growth across U.S. industries. In particular, Stiroh (2002) found that industries that made the largest investments in computer hardware, software, and telecommunication equipment in the 1980's and early 1990's showed larger productivity gains after 1995.

Another important finding in the writers' research is that automation and integration uses have different significance in various trades and on different work functions. It is intriguing that piping was the one trade that showed no significant correlation between automation and integration technologies on a project and productivity. Further research is needed to examine this occurrence. Although it is possible that the results lack significance due to sample size, it is also possible that current automation and integration technologies are indeed not helping piping trades become more productive. In the case of the latter explanation, attempting to understand why current automation and integration technologies are not helping is warranted. Meanwhile, O'Connor and Yang (2004) found similar results in their effort using similar automation and integration indices described herein: the association between project performance (schedule and cost) and automation and integration usage are different on various work functions or phases of construction. In particular, O'Connor and Yang (2004) also found that integration technologies had a more significant impact on project performance compared to automation, which mirrors the results presented herein. From the definition of the automation and integration use levels, it can be seen that automation is a prerequisite to integration, and integration is an enhancement of automation. Therefore, it is not strange to observe that integration has a more significant impact on labor productivity.

Conclusions

These analyses and discussion contribute to the body of knowledge with regard to the relationship of construction productivity to automation and integration technology in three areas:

1. Information technology has been positively impacting construction productivity and will likely continue to do so in the future;

Table 4. Results of *t*-Test on Integration Index by Trade

	Normalized productivity			Levene's test for equality of variances		Equal variances assumed		Equal variances not assumed	
Trade	High level integration	Low level integration	Difference	F	Sig.	t	Sig.	t	Sig.
Concrete ***	2.91 (33)	4.71 (19)	−1.81	19.90	0.00	−3.12	0.00	−2.61	0.02
Structural Steel ***	3.48 (39)	5.30 (10)	−1.82	3.28	0.08	−2.58	0.01	−2.58	0.01
Electrical *	3.28 (48)	5.66 (8)	−2.38	8.15	0.01	−2.36	0.02	−1.73	0.12
Piping	3.82 (52)	5.02 (15)	−1.20	10.59	0.00	−1.39	0.17	−1.12	0.28
All trades ***	3.37 (172)	5.06 (52)	−1.69	28.89	0.00	−4.41	0.00	−3.57	0.00

Note: ***=significance at 0.05; and *=significance at 0.15. The numbers in the parentheses are the sample sizes (activity productivities).

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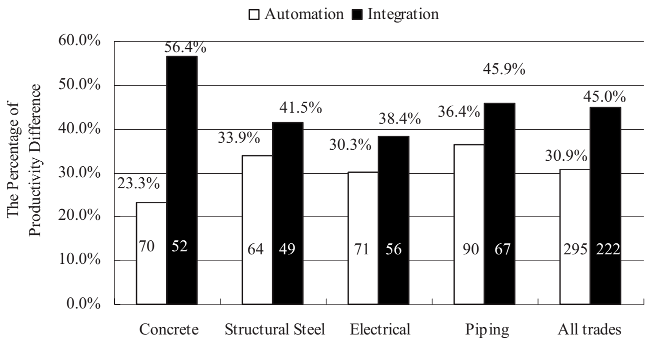

Fig. 7. Actual productivity comparison by trade

2. Both the automation and integration of project information systems are related to better construction labor productivity performance, and the analyses suggest that a stronger relationship exists with integration; and
3. The effectiveness of automation and integration usage was observed to be different across the four trades. Automation usage was observed to be more positively related to structural steel and electrical productivity, while integration usage was observed to be more positively related to concrete and structural steel productivity.

Recommendations

Future research should examine the relationship of construction factor productivity to automation and integration technology. A labor productivity analysis is more straightforward, since its impact is restricted to just the labor component of productivity, but factor productivity represents the ratio of output to all inputs including labor, equipment and materials. Positive results with factor productivity are likely to produce more compelling arguments for construction to adopt new automation and integration technologies.

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