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# A COMPREHENSIVE ANALYSIS OF PROJECT MANAGEMENT PRACTICES TO IMPROVE CRAFT PRODUCTIVITY

Yongwei Shan[1], Paul M. Goodrum[2], Carl T. Haas[3], Carlos H. Caldas[4], Dong Zhai[5]
[1]Department of Civil, Environmental, and Architectural Engineering, University of Colorado Boulder
[2]Department of Civil, Environmental, and Architectural Engineering, University of Colorado Boulder
[3]Department of Civil Engineering, University of Waterloo, Waterloo, Ontario, CANADA
[4]Department of Civil, Architectural & Environmental Engineering, University of Texas Austin, TX
[5]Department of Civil Engineering, Zhejiang University, China

**Abstract:** Craft productivity is a paramount factor that affects a construction project's ability to be completed on schedule and budget, while also ultimately affecting the profitability of a company. At a micro-level, improving craft productivity differentiates a company from its peers and keeps it more competitive. At a macro-level, improving craft productivity of the overall construction industry, to some extent, could alleviate the shortage of skilled craft workers. There are numerous rigorous management programs - identified by construction practitioners and construction associates - that claim to improve craft productivity. When it comes to implementation of these different management programs, construction companies tend to speculate if the likelihood of productivity improvement is certain. Though some companies want to implement these programs, they are often overwhelmed by the number of practices associated with each management program and lose the vision of their strategic implementation. Through statistical analysis of the Construction Industry Institute's Benchmark and Metrics Data, this study finds a positive relationship between craft productivity of four major trades (mechanical, electrical, concrete, and steel trades) among seven management areas including: front end planning, materials management, constructability, team building, safety, and information system automation and integration. The productivity difference between above- and below-average implementers in various management areas varied from 14% to 60% for different trades. The study's primary contribution to the overall body of knowledge is that it quantifies the statistical relationship among the above mentioned management practices and productivity among the major construction trades.

## 1. Introduction

The shortage of craft workers has been a recurring issue confronting the North American construction industry. This is partially attributed to the aging of the construction workforce (Haas et. al. 2003; Wang 2008). Prior to the economy downturn, the Construction Labor Research Council (CLRC 2005, Wang et al. 2008) forecasted a need for 185,000 new craft workers per year up to 2016 to replenish the current workforce pool. The Construction Users Roundtable (CURT 2004, Wang et al. 2008) made a similar argument that 200,000 - 250,000 new craft workers are needed every year. Though the economy recession has, to some extent, alleviated the problem, this shortage would reoccur sooner or later when the economy rebounds. In the long run, the shortage of skilled craft workers would continue to concern the construction industry as a whole. Brandenburg et al. (2006) found that "overcoming the labor shortage" was considered as the third most difficult challenge for construction owners, ranked after "meeting budges" and "meeting schedule". To combat this issue, the construction industry needs to invest in continuous workforce development efforts while also expanding its scope in improving the productivity of the existing workforce.

Craft productivity is of essence to a construction project. Typically, labor costs account for 30% of the total construction costs (McNally and Havers 1967; McTague and Jergeas 2002), which is one of the largest cost constituents. The success and profitability of a construction project rest upon craft productivity since it affects a construction project's ability to be completed on schedule and budget. Improving craft productivity has twofold advantages. At a micro-level, improving craft productivity differentiates a company from its peers and keeps it more competitive. At a macro-level, improving craft productivity of the overall construction industry, to some extent, could mitigate the effect of the shortage of craft workers.

Improving craft productivity can be achieved through multiple approaches. First, increase the direct work rate (a.k.a. wrench time). Second, use technologies, new materials, and construction methods to improve efficiency. Third, reduce rework. A variety of construction management programs serve the purpose of productivity improvement through one or multiple combined approaches described above. Though craft workers are the actual executers and the center of the workface, management activities occur away from the workface plays a significant role in craft workers' performance at workface. Delays, cost overruns, and safety and quality problems at the construction workface are the resultant effects of errors, omissions, or other failures occurred away from the workface. Oglesby et al. (1989) describes away-from-the-workface activities as the process of providing necessary commitment, materials supplies, information, working space, staffing, methods, equipment and tools to craft workers to execute work. Construction management programs implemented in construction companies are a systematic categorization of various away-from-the-workface activities.

There are numerous rigorous management programs - identified by construction practitioners and associates - that claim to improve craft productivity. These management programs include the following management programs: pre-project planning, team building, alignment, materials management, information automation and integration, constructability, and safety When it comes to implementation of these different management programs, construction companies tend to speculate if the likelihood of productivity improvement is certain. Though some companies want to implement these programs, they are often overwhelmed by the number of practices associated with each management program and lose the vision of strategic implementation. This is also the motivation of the described research.

## 2. Objectives and Scope

This research is intended to reaffirm the importance of construction management programs described earlier to craft productivity improvement, and identify critical practices within each management program that are correlated to productivity improvement to help construction practitioners facilitate program implementations. These objectives were achieved through the analysis of the Construction Industry Institute's(CII) Benchmarking and Metrics(BM&M) dataset. The BM&M dataset collects CII member companies' productivity data and program implementation level at a project level. This study is also a continuation of a study that examined the relationship between management programs and mechanical craft productivity performed by Shan et al. (2011). The craft workers examined in this study includes four specific trades: mechanical, electrical, concrete, and steel. This study focuses on large industrial projects since most of the CII member companies' projects are industrial projects. By definition, the projects with total construction costs greater than 5 million dollars are considered large projects. The costs associated with the implementation of these programs are not the scope of this study.

## 3. Research Methods

### 3.1 Data Source

This research utilized the BM&M dataset for statistical analyses. The purpose of the BM&M program is to allow CII member companies to compare their performance on capital and maintenance projects with their peer companies. Thus, it allows participating companies to know where they stand among their competitors in terms of project performance, visualize the gap, and identify the practices for productivity improvement. The dataset examined in this research was collected by using Owner/Contractor Questionnaire Version 9.0 administered by the BM&M. The BM&M dataset collects three major categories of information related to a project: 1) general information, such as project description, project delivery system, contract type, etc.; 2) project performance with respect to cost, schedule, changes, and rework; and 3) quantitative measurement of management program performance and craft productivity metrics across four craft trades of mechanical, electrical, concrete and steel trades. Under each management program, there are multiple practices. The authors readily acknowledge that each sampled project was unique and not built under controlled conditions. However, the similar natured projects with similar scope of work were included in the study. As of 2012, BM&M dataset contains 92 projects. The authors included 41 sampled large industrial projects with minimum missing values in the study.

Mechanical, electrical, concrete, and steel trades are the focus of this study. To ensure the consistency of data collection, the BM&M survey outlined detailed instructions on how productivity metrics to be collected and quantitative scales for each practice performance under each management program. Table 1 describes an example of the concrete trades' construction activities where productivity rates were collected at both subcategory and element levels.

Table 1 : Productivity Metrics Collected at Construction Activities in Concrete Trades

| Trade | Subcategory Level | Element Level |
|---|---|---|
| Concrete | Total Slabs | On-Grade |
| | | Elevated Slabs/On Deck |
| | | Area Paving |
| | Total Foundations | < 5 cubic yards |
| | | 5-20 cubic yards |
| | | 21-50 cubic yards |
| | | > 50 cubic yards |

### 3.2 Productivity Definition and Normalization

The CII BM&M program defines labor productivity as the work hours per installed quantity, as described in Equation 1.

[1] $$\text{Labor Productivity} = \frac{\text{Actual Work Hours}}{\text{Installed Quantity}}$$

It should be noted that a better productivity is indicated by a smaller numeric number. To protect participating companies' confidentiality, all of the productivity measures were normalized into a scale ranging from 1 to 10 using Max-min normalization method (Shan et al. 2011; Zhai et al 2009; Hann and Kamber 2000) described in Equation 2.

$$[2] \quad P_{norm} = \frac{P_{actual} - P_{actual\,min}}{P_{actual\,max} - P_{actual\,min}}(P_{norm\,max} - P_{norm\,min}) + P_{norm\,min}$$

where, $P_{norm}$ is the normalized productivity; $P_{actual}$ is the actual productivity value to be normalized; $P_{actual\,min}$ and $P_{actual\,max}$ are the minimum and maximum actual productivity values for a construction activity among sampled projects; and $P_{norm\,min}$ and $P_{norm\,max}$ are the minimum and maximum normalized productivity values, equal to 1 and 10, respectively. The normalized productivity is consistent with the actual labor productivity; a smaller measure indicates a better productivity. The normalized productivity is a unit-free measure, which enables authors to pool the productivity rates collected at different construction task levels and make productivity comparisons with a larger sample size.

### 3.3 Management Program Use Index

To quantify the level of each management program used on a project, the BM&M program developed a single composite index for each management program. A higher index score for a management program indicates the project implemented this management program at a higher level. A management program contains a few practices pertaining to the program. The BM&M committee collects data on each practice level under a management program, measuring how well a project performs in each practice. Depending on how well a surveyed project implemented individual practices within a program, respondents were asked to rate the level of implementation based on given instructions in the survey. The composite management program use-score was developed based on the algorithm provided in the survey. Because of the varied scoring systems and maximum scores for each management program, comparison of the levels of use among the programs based on the program use-scores might not be clear. The program use index is the normalization of the program use-score which provides a better way of identifying the weakest area among all of the program uses. For this study, all of the program use-scores were normalized on a 0 to10 scale. Zero (0) indicates that a program was not implemented on the project at all; and ten (10) indicates that a program was fully implemented. Table 2 describes an example of the computing algorithm for automation of information system program use index.

Table 2: The Algorithm of Automation of Information Systems Program Use Index

| Automation Task/ work Functions | Use Level (low to high) | | | | | Score |
|---|---|---|---|---|---|---|
| | 1(0) | 2(.25) | 3(.5) | 4(.75) | 5(1) | |
| Business planning & analysis | | | ✓ | | | 0.5 |
| Conceptual Definition & design | | | ✓ | | | 0.5 |
| Project (discipline) definition & facility design | | | ✓ | | | 0.5 |
| Supply Management | | | | ✓ | | 0.75 |
| Coordination System | | | ✓ | | | 0.5 |
| Communications System | | | ✓ | | | 0.5 |
| Cost System | | | | ✓ | | 0.75 |
| Schedule System | | | | ✓ | | 0.75 |
| Quality System | | | ✓ | | | 0.5 |
| Offsite/pre-construction | | | ✓ | | | 0.5 |
| Construction | | | ✓ | | | 0.5 |
| As-built documentation | | | ✓ | | | 0.5 |
| Facility Start-up & life cycle Support | | | ✓ | | | 0.5 |
| | | | | | Total | 7.25 |
| Maximum score of 13, divide total by 1.3 to scale to 0-10 point range | | | | | | |
| | | | Automation Program Use Index | | | 5.58 |

To create two groups of project samples for later analysis, projects scoring 5% above the overall median of program use index scores in terms of a management program were categorized into high-level implementation group, and project scoring 5% below median were classified as having a low-level of implementation. The author use median in lieu of mean because the indices do not have a normal distribution. The purpose of removing data that fall into the range of ±5% median was to create two distinct groups for statistical comparisons.

### 3.4 Management Programs

The BM&M program surveyed the level of program use in seven areas, including, front end planning, materials management, team building, automation of information systems, integration of information systems, constructability, and safety. Because of the page limit, this paper does not list the individual practices within each management program. For detailed information, the readers can referred to CII BM&M's Contractor/Owner Survey Version 9.0.

***Front End Planning*** The goal of pre-project planning is to maximize the chance of a project's success through developing and acquiring strategic information at the early stage of a project development by prioritizing constrained resources. (Gibson et al. 1993). The CII BM&M survey quantifies the level of implementation of front end planning in 10 specific practices.

***Materials* Management** Materials management program addresses procurement management, site material management systems, material receipt and inspection team and process, and site material layout. The CII BM&M program measures the level of materials management in 12 different aspects.

***Team Building*** The process of team building is to develop shared goals, commitment, trust, interdependence and accountability among team members; and a unanimous process to remove barriers to improve stakeholder relations (Albanese 1995). The CII BM&M program address team building with 8 major practices.

***Automation & Integration of Information Systems*** O'Connor and Yang (2004) define automation as the use of an electronic or computerized tool to manipulate data or produce a product, and integration as the sharing and exchange of information between project participants or separate systems. The CII BM&M program quantifies the level of both programs in 13 work functions(Table 2)

***Constructability*** The CII Constructability Committee explains the concept of constructability as the optimum integration of construction knowledge and experience in planning, engineering, procurement, and field operation to achieve overall project objectives (CII 1993). The BM&M survey address constructability program in 7 areas.

***Safety*** Safety addresses the humanity and well-being of construction craft workers. The CII developed a zero accidents program to help construction projects reach the goal of zero accidents. The BM&M survey quantifies the level of safety program implementation in 18 aspects.

### 3.5 Pearson's correlation

Pearson's correlation was utilized to identify critical practices within each management programs with respect to different craft trades. Practices that were significantly correlated with better labor productivity positively were selected for further analysis. The authors admit that all other practices might be also significant to other project performance areas. However, the focus of this study was to identify practices that are positively correlated with craft productivity associated with four specific craft trades.

### 3.6 Statistical Tests

One of the objectives of this research is to investigate the relationship between the level of management program use and craft productivity. To test whether there is a difference in mean craft productivity between two population groups with high-level implementation and groups with low-level implementation for each management program, the independent sample T-test was utilized to perform the test. The underlying assumption for the dataset is that the productivity of the population is normally distributed.

### 3.7 Actual Productivity Comparison

The statistical test described above used the normalized productivity. To better visualize the productivity difference between low- and high-level program implementers, the actual productivity difference would communicate a clear message about how projects could benefit from a high-level implementation of management programs. The difference of actual productivity mean can be computed through Equation 3.

[3] $$\textit{Percentage difference of actual productivity} = \frac{(\textit{Mean } P_{\textit{Actual L}} - \textit{Mean } P_{\textit{Actual H}})}{\textit{Mean } P_{\textit{Actual L}}} \times 100\%$$

where, $P_{Actual\ H}$ denotes the actual productivity of a construction activity from a project with a high-level of management use in a particular management program; $P_{Actual\ H}$ denotes the actual productivity of a construction activity from a project with a low-level of management use in a particular management program.

### 4. Discussion of Results

The writers performed statistical analyses to examined the relationship between craft productivity across four trades and management program use on the sampled projects. Figure 1 shows the results of the management programs that are positively correlated to the craft productivity across the four craft trades. This means sampled projects with a high-level use of management programs had higher craft productivity than their counterparts. The readers should note that all the results showed in Figure 1 are statistically significant at a 95% confidence level, and a lower measure of productivity is better.

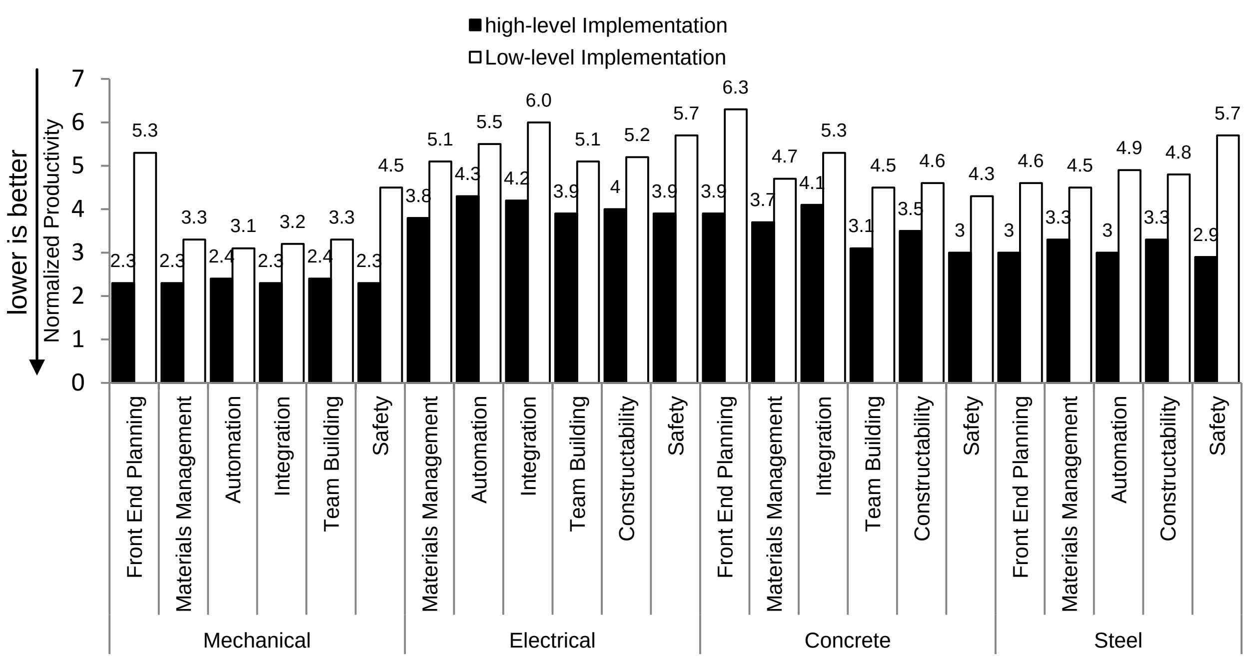


Figure 1: The relationship between Craft Productivity and Management Program Use by Trade
Note: Normalized Productivity Measured by Equation 2.

Figure 2 presents the actual productivity difference in percentage between the low and high-level program use across the mechanical, electrical, concrete, and steel trades. For instance, as Figure 2 shows that, on average, the steel craft productivity of sampled projects with a high-level safety program implementation experienced 61.3% better than that of sampled projects with a low-level implementation. The overall productivity differences are very significant, ranging from 13.9% to 61.3%. Among the seven management programs, safety and materials management constantly show a strong correlation with better craft productivity across all trades. These two management programs can be considered as the classic site management programs. However, other programs, including front end planning, automation and integration of information systems, team building, and constructability, should be given adequate awareness as well since they are at least significantly correlated to better craft productivity in three trades.

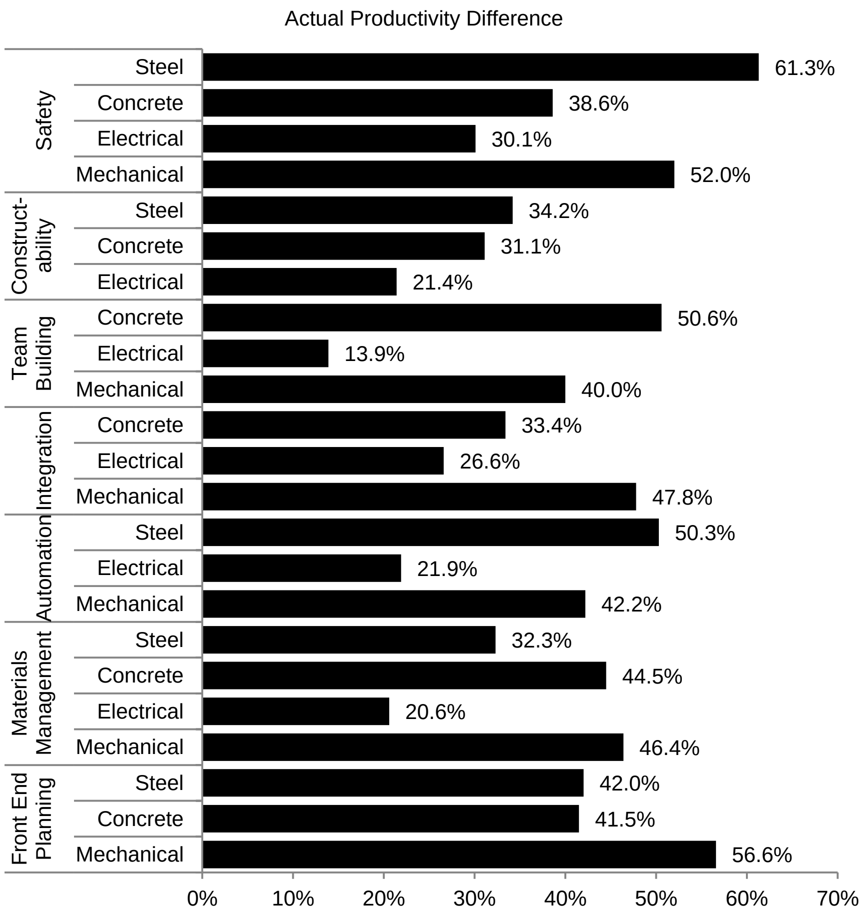


Figure 2. Actual Productivity Difference in Percentage between low- and high-level Program use by trades and Practice

Note: Difference in Actual Productivity Measured by Equation 3

When it comes to program implementation, construction companies are always constrained by limited resources. To a company that does not have sound management programs in place, appropriating equal resources to all the practices under all programs at the same time on their projects might be cumbersome. Implementing management programs is also a process of learning. To help construction companies improve the learning curve of implementation, the writers identified the critical practices within each management program using Pearson's correlation. Tables 3 to 8 list all of the critical practices that are positively correlated with craft productivity across four trades. However, these tables should be interpreted with caution; it does not necessarily mean that only implementing these listed critical practices would guarantee a better productivity. On the contrary neglecting other practices would hurt the productivity. This statement is extremely true when considering implementing safety program. Safety is one of the most significant drivers for the success of a project. Construction practitioners should implement all of the 18 practices associated with the safety program. Though some of them are not correlated with craft productivity, they definitely are correlated with the safety performance. Inadequately addressing safety issues would result in more incidences that could cause interruption to construction activities, hence compromises craft productivity. In addition, the results of the statistical analyses highly depend on the quality of data. Thus, some of the practices that may contribute to the productivity improvement might not be identified by the analyses. From the analyses, the significance of front end planning was not observed in the electrical trades. This does not necessarily mean front end planning should not address the electrical trades; instead front end planning should be given adequate attention to all trades, since it is the stage that has the most influence on the outcome of a project with the least committed costs.

Table 3. The Critical Front End Planning Practices Correlated to Better Craft Productivity

| Practice | Mechanical | Electrical | Concrete | Steel |
|---|---|---|---|---|
| Clearly conveying project objectives and concepts to the front-end planning team | ✓ | | | |
| Integration and alignment of the front-end planning team | ✓ | | | ✓ |
| Integration of constructability into the front-end planning process | ✓ | | ✓ | |
| Use of checklists to ensure consistency of the front-end planning effort | ✓ | | | |
| Use of the PDRI to determine how well a project is defined | ✓ | | | ✓ |
| Designation of adequate contingency fund | | | ✓ | |
| Clear definitions regarding the front-end planning team's priorities | ✓ | | | |
| Timely performance on behalf of the front-end planning team | ✓ | | ✓ | |
| Quality of the front-end planning team in meeting its objectives | ✓ | | | |

Table 4. The Critical Automation/Integration of Information Systems Practices Correlated to Better Craft Productivity

| Work Function | Mechanical | | Electrical | | Concrete | | Steel | |
|---|---|---|---|---|---|---|---|---|
| | A* | I** | A | I | A | I | A | I |
| Business planning & analysis | ✓ | ✓ | | | | | | |
| Conceptual Definition & design | ✓ | ✓ | | ✓ | | | ✓ | |
| Project (discipline) definition & facility design | ✓ | ✓ | | ✓ | | ✓ | ✓ | |
| Supply Management | ✓ | ✓ | | | | | ✓ | |
| Coordination System | ✓ | ✓ | | ✓ | | | | |
| Communications System | ✓ | ✓ | ✓ | ✓ | | | | |
| Cost System | ✓ | ✓ | | ✓ | | | | |
| Schedule System | ✓ | ✓ | ✓ | | | ✓ | | |
| Quality System | ✓ | ✓ | ✓ | | | | ✓ | |
| Offsite/pre-construction | ✓ | ✓ | | ✓ | | | ✓ | |
| Construction | ✓ | ✓ | | ✓ | | | ✓ | |
| As-built documentation | ✓ | ✓ | | ✓ | | | | |
| Facility Start-up & life cycle Support | ✓ | ✓ | | ✓ | | ✓ | | |

* Automation of Information Systems
** Integration of Information Systems

Table 5. The Critical Materials Management Practices Correlated to Better Craft Productivity

| Practice | Mechanical | Electrical | Concrete | Steel |
|---|---|---|---|---|
| Integration of designated materials management organization across project team | | | ✓ | |
| Plan for addressing the effects of change orders on materials management | | ✓ | | |
| Automated material management system used to identify, track, report, and facilitate control of construction materials | ✓ | ✓ | | |
| Effective site materials management during the construction phase | | | ✓ | ✓ |
| Effective materials tracking and reporting system | | | ✓ | ✓ |
| Effective purchasing plans & procedures over the life of the project | | | ✓ | ✓ |
| Effective receipt and inspection procedures for critical materials and equipment | ✓ | ✓ | ✓ | ✓ |
| Adequate pre-qualification process for securing the appropriate suppliers of major equipment and materials | | | ✓ | |
| Materials management plan utilizing quality management practices | | | ✓ | |

Table 6. The Critical Team Building Practices Correlated to Better Craft Productivity

| Practice | Mechanical | Electrical | Concrete | Steel |
|---|---|---|---|---|
| Project phases involved team building process | | | | |
| Pre-project planning | ✓ | | | |
| Design | ✓ | | | |
| Procurement | | | | |
| Construction | ✓ | | | |
| Startup | | | | |
| Parties involved in team building involvement | | | | |
| Owner | | ✓ | | |
| Engineer(s) & Designer(s) | | ✓ | | |
| Constructor(s) | | ✓ | | |
| Major Supplier(s) | | | ✓ | |

Table 7. The Critical Constructability Practices Correlated to Better Craft Productivity

| Practice | Mechanical | Electrical | Concrete | Steel |
|---|---|---|---|---|
| Emphasizing communication of constructability principles on the project | | ✓ | | |
| Assigning constructability coordinator to the project | | | | ✓ |
| Overall extent of constructability implementation on the project | | ✓ | | |
| Tracking lessons learned and saving/effects on the project due to the constructability program | | ✓ | ✓ | ✓ |
| Documentation of constructability program implemented for the project | | ✓ | | |

Table 8. The Critical Safety Practices Correlated to Better Craft Productivity

| Practice | Mechanical | Electrical | Concrete | Steel |
|---|---|---|---|---|
| Implementation of project safety plan | | | | ✓ |
| Prioritization of safety as a topic at pre-construction and construction meetings | ✓ | ✓ | ✓ | |
| Performance of safety audits by corporate safety personnel | ✓ | | ✓ | ✓ |
| Adequate ratio of workers per safety person on site | ✓ | ✓ | | |
| Utilization of safety incentives. | | ✓ | | |
| Utilization of safety performance as a criterion of contractor/subcontractor selection | | ✓ | ✓ | |
| Formal investigation of near misses | | | ✓ | |
| Requirement of pre-employment substance abuse tests for contractor employees | ✓ | ✓ | ✓ | ✓ |
| Performance of random alcohol and drugs screening for contractor employees | | ✓ | ✓ | ✓ |
| Substance abuse tests after accidents | ✓ | ✓ | ✓ | ✓ |
| Substance abuse testing for reasonable cause | ✓ | | | |

## 5. Conclusions and Recommendations

This research has examined the relationship between prevalent construction management programs and craft productivity in the mechanical, electrical, concrete, and steel trades. It also quantified the productivity difference between low- and high-level implementers of the programs and identified the most significant practices under each management area through a comprehensive analysis of the CII BM&M dataset. The study found that sampled projects with a high level of implementation of the described programs consistently experienced better craft productivity. This research has a significant contribution to the existing body of knowledge. This is the first research study that has ever conducted such a extensive quantitative analysis on a large variety of management programs and four major categories of craft productivity. The identified critical practices could serve as a guideline for construction practitioners to prioritize resources to strategically implement the programs. However, the readers should note that this study is based on a recent available BM&M dataset; the validity of the results relies on the quality of the data as well.

The focus of this research is craft productivity, which only considered work hours as the input and did not include implementation costs in the study. From the business perspective, cost-benefit analysis is always used to justify if a practice/program/technology is worth to invest. Instead of using craft productivity, future research can utilize factor productivity, which considers the money input of labor, equipment, and material. This would provide construction practitioners a better justification about whether a program is worth to be implemented on their projects.

In addition, the relationship between craft productivity and each program was examined independently. It is assumed that the programs are independent to each other. This might not be the case. There might be a synergy among the management programs. The future research will examine the relationship between each programs, and quantify how much synergy exists between the programs.

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