



Construction Industry Institute®

Construction Productivity Research Program Phase V

Paul M. Goodrum, Ph.D.

Yongwei Shan, Ph.D.

University of Colorado at Boulder

Carl T. Haas, Ph.D.

Hassan Nasir, Ph.D.

Jiali Liu

University of Waterloo

Carlos H. Caldas, Ph.D.

JungYeol Kim

The University of Texas at Austin

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CONSTRUCTION PRODUCTIVITY RESEARCH PROGRAM
PHASE V

by

Paul M. Goodrum, Ph.D.
Yongwei Shan, Ph.D.
University of Colorado at Boulder

Carl T. Haas, Ph.D.
Hassan Nasir, Ph.D.
Jiali Liu
University of Waterloo

Carlos H. Caldas, Ph.D.
JungYeol Kim
The University of Texas at Austin

A Report to
Construction Industry Institute
The University of Texas at Austin

Under the Guidance of
CII Research Team 252
Craft Productivity Research Program

CII Research Report 252-11d
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Executive Summary

The CII Construction Productivity Program (RT 252) culminated in a number of analyses, strategies, methods, tools, and metrics to improve jobsite productivity. This final report of the six-year effort provides an overview of the previous phases, plus it details the validation and development of two versions of the Best Productivity Practices Implementation Index (BPPII), one version for industrial projects and another for commercial projects. This research report also details the analyses used to identify the significant body of knowledge regarding construction productivity that was incorporated into the Productivity Handbook.

Previous phases and reports of RT 252 have reported on the research and development of the Industrial BPPII. The BPPII is a metric to measure how effectively the methods, tools, and strategies known to improve construction productivity are being implemented on a construction jobsite. This report details the final validation efforts to confirm its accuracy. Using industrial project data on jobsite productivity, the validation efforts proved that projects with higher BPPII scores reported better productivity. This research report details the statistical analyses of the validation efforts

Recognizing the growing diversity of the type of companies within the Construction Industry Institute, RT 252 developed and validated a BPPII for infrastructure projects. The process of using the Infrastructure BPPII is the same as its Industrial counterpart, but the methods, tools, and strategies are modified to address issues like utility relocation and right-of-way acquisition. Previous phases and reports have not discussed the Infrastructure BPPII, so this report debuts and finalizes both its development and validation. In a similar reporting fashion with the Industrial BPPII, this report details the statistical analyses, which showed that infrastructure projects that scored higher on the Infrastructure BPPII reported better jobsite productivity.

In its last year, the Construction Productivity Program team spent a great deal of effort on developing the Construction Productivity Handbook, which is a stand-alone reference of the body of knowledge regarding construction productivity. It is designed to be both a desktop reference and an educational tool for both construction professionals and universities. While developing the Construction Productivity Handbook, a significant body of analyses was done to examine the validation methodologies used in previous construction related research when identifying productivity improvement strategies. These analyses were used in part to identify the body of knowledge to include in the Productivity Handbook, and the results of those analyses are reported herein.

RT 252 made significant strides in its original mission of developing a roadmap of improving construction productivity. There are still endless opportunities to be explored to improve the industry's productivity. Industry productivity measures continue to show that the productivity of the overall construction industry has been declining for decades, although these measures are counter intuitive to many and raise questions regarding the accuracy of industry measures. The development of the Industrial and Infrastructure BPPIIs addresses a core concern of CII companies, but there is a natural opportunity to extend the development of the BPPII process to commercial projects. What the BPPIIs have taught us is that no single method, strategy or tool is enough to control and improve construction productivity. Instead, it takes a comprehensive and unrelenting effort. The work of RT 252 is by no means a final statement on construction productivity. It is instead a continuation of a long research thread, and hopefully its work will be expanded and built upon by future research teams and academics.

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CHAPTER 1: INTRODUCTION

The Construction Productivity Research Program was initiated in 2007 through the formation of research team (RT 252) with the primary objective of identifying and validating one or more initiatives, techniques, or methods that if implemented would result in significant improvement in construction productivity on CII projects. Construction productivity was defined as having three dimensions: (1) direct work rate, (2) labor productivity, and (3) rework rate (CII 2009a). RT 252 conducted its research in five phases over six years producing over a dozen useful tools published by CII.

Despite a century of sporadic advances in equipment, tools, materials, and prefabrication strategies, direct work still typically amounts to no more than 35-45% of a craft worker's time on the job. Increasing direct work time would offer an opportunity for achieving a breakthrough in productivity in construction. Regardless of whether some micro measures of productivity indicate improvement and some macro measures indicate otherwise, the opportunity for improving construction productivity clearly exists. Understanding where these opportunities exist and how they can be leveraged was a primary focus of this research program (CII 2009a).

Obviously, benefits abound with improved construction worker productivity from reduced costs, mitigation of labor and skill shortages, and improved scheduled performance on construction projects. Even though there has been productivity improvement by advances in heavy equipment, tool, and materials, other opportunities that address craft information, process and organization, and human behavior exist and arguably remain untapped. While innovations

certainly afford opportunities to improve construction productivity, they are likely to have little impact on productivity if established processes and practices that are recognized as being necessary to control and improve productivity are not being effectively utilized first.

The primary objective of this research program was to improve construction worker productivity in order to reduce costs, mitigate skilled labor shortages, and improve project schedule performance. The program's initial strategy involved improving craft performance in three areas: 1) the percentage of time spent on direct work, 2) direct labor productivity based on the actual units of work completed per work hour, and 3) the percent of construction rework. To achieve these improvements, RT 252's rolling, five-phase program (Figure 1-1) presented innovations annually by means of a sequence of innovation workshops, field trials, analysis, and implementation tool delivery. Each phase of the program involved: (1) analyses of the CII BM&M data to identify best practices that appear to have an impact on productivity, (2) exploring opportunities for productivity improvement through craft information, technology support for labor, work packaging/organization, and human behavior, and (3) soliciting innovation input from subject matter experts and team members' expertise. Each phase focused on a specific trade that included: mechanical, electrical, concrete, and steel. Objectives and deliverables for Phases I through IV included the following:

1. Identified through statistical analysis practices described in the CII Benchmark and Metrics program that have a significant positive relationship with craft productivity;
2. Developed a prioritized list of innovations with breakthrough potential for a specific trade based; and

3. Conducted validations of the most promising innovation selected.

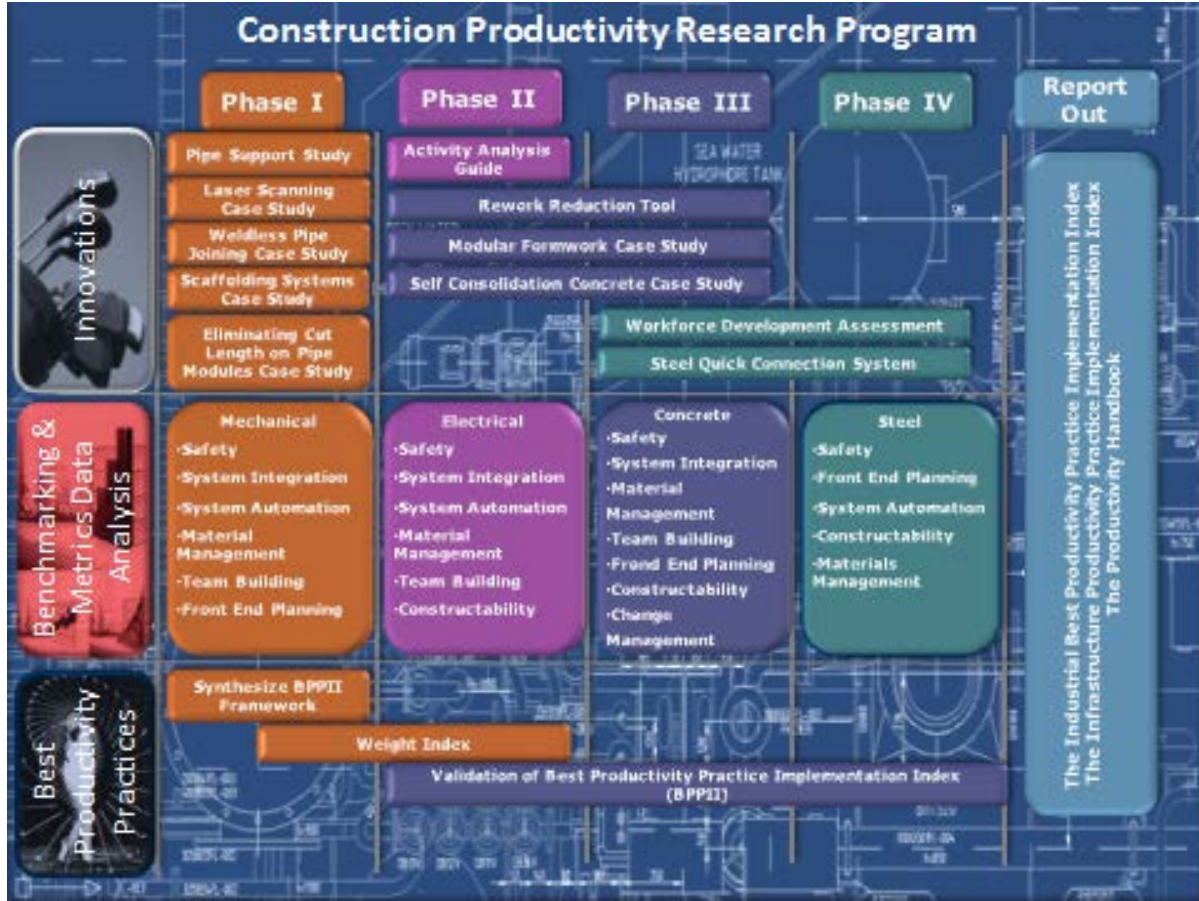


Figure 1-1: RT 252 Productivity Program Timeline

This report is the final report of this six year research program. The second chapter provides a brief overview of each phase of the program. Considering that much has already been provided on the Best Productivity Practices Implementation Index (BPPII) for Industrial Projects, chapter three provides a synopsis and a final update on its successful validation. This year, the program unveiled the BPPII for Infrastructure Projects, which had not been discussed or presented in any prior report or presentation. Therefore, chapter four provides a comprehensive

description of its development and also successful validation. A significant amount of time and effort was expended in the final year of the program on the Construction Productivity Handbook. Typically, CII research reports provide the background on the technical discovery and analyses used in the development of CII research and its implementation resources. During the process of developing the Construction Productivity Handbook, a critical analysis was done on the validation methodologies used in construction engineering and management research domain. The results of the validation analyses were considered when determining which processes and practices to include in the Handbook and are described in chapter five of this report. The last chapter provides the conclusions and lessons learned from this six year research program.

CHAPTER 2: OVERVIEW OF THE CONSTRUCTION PRODUCTIVITY RESEARCH PROGRAM PHASES AND FINDINGS

This chapter provides a brief overview and summary of the previous five phases of the research program of RT 252.

2.1 Overview of Phase I

Achieving significant improvements in construction craft productivity in six years would provide an important benefit to the capital projects industry. The first phase of a six year research program tasked with trying to do just that laid out the path for this. Direct work typically amounts to no more than 35-45% of a craftsman's time on the job (CII 2009a). Improving craft productivity requires improving direct work time. To increase direct work time, the availability of materials, information and tools at the workplace have to be improved. There will be no "magic bullet" that will make this happen, but rather a series of innovations that together produce change. They will include a combination of broad improvements in practice and focused improvements in technology and process.

To achieve these improvements, Research Team 252's (RT 252's) rolling, five phases program injects innovations annually via a sequence of innovation identification, field trials, analysis, and implementation tool delivery. Each phase of the program involves: (1) analyses of the CII BM&M data to identify best practices that appear to have an impact on productivity, (2) exploring opportunities for productivity improvement through craft information, technology support for labor, work packaging/organization, and human behavior, and (3) soliciting innovation input from subject matter experts.

Analysis of BM&M metrics data was focused in the first phase on investigating the relationship between particular field practices and productivity of the mechanical trades. Significant relationships were found between improved productivity and best practices in materials management, safety, team building, front end planning, and automation and integration. These practices, however, are not additive; they are highly correlated and interdependent. Projects that were advanced implementers of these practices experienced as much as a 50% average productivity advantage over projects that were weak implementers (CII 2009a). Clearly, implementing these best productivity practices can make all the difference between a weak and a strong performer. But, it is natural to ask whether CII's BM&M database includes all the best practices or primarily those for which CII has produced products, and whether relatively conventional best practices exist with similar impact.

Thus, RT 252's efforts in the first research phase also focused on a thorough search and definition of best productivity practices. When these practices have become rigorously weighted and properly structured, they will become part of a Best Productivity Practices Implementation Index (BPPII). No existing CII tool addresses productivity as directly as the BPPII will.

For this phase of the program, emerging productivity improvement innovations for the mechanical trades were identified by the team and prioritized. Thorough analyses, including field data analysis, were conducted on each innovation in a structure that included: (1) the problem addressed; (2) definition of the innovation in terms of technology, process, and organizational change; (3) analysis of field data and risks associated with implementing the innovation, and; (4) guidelines for implementation. Six significant innovations were delivered, including: (1) weld-less and modularized pipe supports, (2) laser scanning, (3) quick connect structural steel pipe

supports, (4) cut-length elimination on modules, (5) innovative scaffolding systems, and (6) weld-less pipe joining (CII 2009b).

Implementing the best productivity practices identified in this first phase, as well as the innovations listed above, were expected to result in significant productivity improvement on your projects.

2.2 Overview of Phase II

To accomplish its objective of identifying opportunities to significantly improve craft performance, in phase II of the research program, the team used a three-pronged strategy:

- 1) Found ways to increase the time spent on direct work through activity
- 2) Recommended the implementation of innovations with the potential to reduce the number of work-hours required to complete one unit of work
- 3) Investigated strategies for reducing the amount of rework.

Further, to strengthen this three-part approach, the team worked on developing the Best Productivity Practice Implementation Index (BPPII), a tool designed to provide initial and in-progress assessments of how much a project's planning and best practice implementation influence craft productivity. Meant to provide the basis of a comprehensive productivity improvement roadmap, the BPPII roadmap incorporated data from CII's Benchmarking and Metrics (BM&M) program on the following six broad improvement areas (CII 2010a):

- Materials Management
- Equipment Logistics
- Craft Information Systems
- Human Resource Management
- Construction Methods
- Environment, Health, and Safety.

During Phase I of the Craft Productivity Research Program, RT 252 developed the “infrastructure” for the BPPII roadmap. In this phase, the team formulated the BPPII’s categories, sections, and elements. In Phase II, the team concentrated on developing the weightings for these components of the index. Work continued on the BPPII, and RT 252 plans to test and validate it through work studies on actual projects in phases III and IV.

Analysis of the CII Benchmarking and Metrics data in this second phase investigated the relationship between particular management practices and reported productivity of the electrical trades. Results indicate that, as for the mechanical trades, safety practices had the greatest impact on electrical productivity. In addition, IT systems integration, IT systems automation, materials management, and team building were found to be emerging cross-disciplinary practices, influencing as they did both electrical and mechanical productivity. The other emerging practice for electrical craft was constructability. The overall results of the BM&M analysis of electrical crafts indicated that projects with a high level of implementation of safety programs, automation, integration of information systems, materials management systems, team building, and constructability experienced better labor productivity (CII 2010a). Once these results were compared to the Phase I analysis of the best practices that yielded improved productivity in the

mechanical trades, five common practices began to emerge as having significant positive impacts on productivity. This analysis indicated that successful implementation of these cross-cutting best productivity practices can make a difference between a weak or strong project (CII 2010a). In the light of this promising finding, RT 252 continued to move forward with its investigation of the relationship between best practice implementation and productivity and its development of the BPPII.

Along with its long-term effort at developing the BPPII and its trade-by-trade analysis of the BM&M data, the RT 252 team evaluated innovations that could prove valuable as stand-alone products to improve productivity for each craft studied. This phase involved an extensive set of activity analysis field studies on six industrial construction projects. An extension of work sampling, activity analysis is a continuous improvement method for observing work activity and then categorizing it based on that observation, (e.g., direct work, prep work, tools and equipment receiving or preparation, material handling, waiting, travel, or personal time) (CII 2010b).

Results indicated that one of the six projects stood out, experiencing significantly higher direct work rates than the others. That project was the only one of the six to be actively engaged in on-going activity analysis. Recognizing the potential for productivity improvement but not finding a readily accessible guide on how to conduct activity analysis, RT 252 developed an implementation resource (IR) 252-2a “*Guide to Activity Analysis*” that outlines a program of how companies can implement activity analysis as a continuous improvement process on their projects (CII 2010b).

There are two parts to activity analysis: (1) workplace assessment and (2) the continuous improvement process. The workplace assessment portion of activity analysis is the application of work or activity sampling. The methods developed by RT 252 are a comprehensive and up-to-date version of work sampling. However, it is the coupling of this updated workplace assessment method with a continuous improvement process that is the strength of activity analysis, and that differentiates it from work sampling. The implementation resource discusses how the workplace assessment results can be interpreted to provide recommendations for improvements, how these improvements should be applied, and how to monitor activity levels for continuous improvement.

Improved productivity need no longer be an imaginary goal; organizations can now approach it from several effective angles—combining proven best practices, craft innovations, rework reduction, and activity analysis.

2.3 Overview of Phase III

The third phase of the program, continued to focus on analyses of the Benchmarking and Metrics data, productivity innovations, and development of the Best Productivity Practice Implementation Index (BPPII). The original charter of RT 252 focused exclusively on improving craft workers' direct work rates, however RT 252 felt like more was needed. Therefore, the program revised its charter to not only focus on improving direct work rates but also reduce the number of work hours required to complete one unit of work through innovations, reducing the amount of rework, and using the Best Productivity Practice Implementation Index as a comprehensive productivity improvement roadmap.

Analysis of the CII Benchmarking and Metrics (BM&M) data in phase three of the program investigated the relationship between management practices and productivity in the concrete trades. The concrete BM&M results indicate that projects with a high level of implementation of Safety Programs, Integration of Information Systems, Materials Management Systems, Team Building, Front End Planning, Constructability, and Change Management experienced better labor productivity in the concrete trades. The results reported here suggest an overall level of synergy with the practices that were found to be related to better productivity in the mechanical and electrical trades in the first two phases (CII 2011a).

In the third phase, the RT 252 focused on investigating innovations that are both unique to the concrete trades and cross-cutting in their impact across multiple trades. Concrete specific innovations included case studies on the use of modular formwork, self-consolidating concrete and 100 KSI steel reinforcement. The case studies included both quantitative analyses but also valuable lessons learned about when and how companies are using them on projects. The concrete innovation case studies found that: 1) less tonnage of steel reinforcement using 100 KSI versus 60 KSI steel is required in the design of a given concrete beam, but the added material costs of using 100 KSI has to be considered to determine if it is a viable productivity alternative; 2) while self-consolidating concrete can offer faster placement rates, especially for wall sections, lessons learned from jobsites identify the added costs in the required formwork need to also be considered; and finally 3) the potential gains from the use of modular formwork greatly depends on the number of cycles that modular systems are used on a project (CII 2011a).

The RT 252 also focused in this phase on developing the Rework Reduction Guide. The unfortunate reality in the industry is that rework typically costs 2-20% of a project's contract

amount. Reducing rework labor hours translates directly into improved labor productivity.

Efforts to reduce rework are often impeded by a perception that rework is due to forces outside the control of the contractor, by failure to implement a rework reduction program (RRP), and by disincentives to report rework when an RRP's is deployed. RT 252 developed a Rework Reduction Guide as a cross-cutting document that provides guidance for addressing these issues by: (1) explaining how to deploy a rework reduction program, (2) providing a top ten list of rework reduction ideas, and (3) suggesting an innovative approach to incentivize reporting of rework (CII 2011b).

Effective implementation of key management practices related to Front-end Planning, Team Building, Change Management, Materials Management, Safety, Integration of Information Systems, and Constructability were related to 31 to 50% better labor productivity in the concrete trades, at least among the observed construction projects (CII 2011a). After completing the analyses of the Benchmarking and Metrics data from Phase I to Phase III, the team continued observing emerging practices that constantly show significant correlation to the productivity improvement across multiple trades, which included:

- Safety;
- Integration Of Information Systems;
- Materials Management; and
- Team Building.

In recent years, the BM&M survey underwent a significant revision. One of the changes involved the addition of management practices regarding change management, which was found to be significantly correlated to better productivity in both the concrete and electrical trades.

Phase III of the RT 252 also focused on launching the validation efforts of the BPPII. Towards this goal, the RT 252 focused on recruiting new projects to participate in the BPPII validation efforts.

2.4 Overview of Phase IV

In its fourth phase, the Construction Productivity Program advanced the knowledge of practices to improve construction productivity. Phase IV of the program focused on the steel trades, both in its analyses of the Benchmarking and Metrics Data set and in its independent analyses of the quick connection steel systems. Results of this phase's Benchmarking and Metrics Data set analysis found remarkable consistency between the set of project practices that are related to better productivity among the steel trades and those sets of practices related to better productivity among the mechanical, electrical, and concrete trades. Safety and Materials Management stand out as the two practice areas that are related to better productivity among all trades (CII 2012). Based on statistical analysis of the CII BM&M data, project management strategies and practices found to be significantly related to better steel productivity included the following:

- Front End Planning;
- Materials Management;
- Automation of Information Systems;
- Constructability; and
- Safety.

Quick connect techniques continue to be revolutionized. In this phase, RT 252 critically examined the impact that structural steel quick connection systems can have on steel productivity. Quick connections have emerged as a dominant theme in the RT 252 quest for high impact productivity innovations. In Phase I, RT 252 analyzed the impact that quick coupling and modular support systems have on mechanical piping. In Phase II, the research team examined the impact of modular formwork systems on concrete productivity. By acquiring independent field unit rate data of the steel quick connection systems in Phase III, the research team validated the reported substantial gains in productivity among projects that used the systems in comparison to conventional steel connection systems (e.g. bolting and welding). The overall unit rate improvement among those projects was around 40% while the costs of the projects are similar. The results of the analyses were demonstrated through the use of a Building Information Model of a prototypical industrial refinery project (CII 2012).

In partnership with the National Center for Construction Education and Research (NCCER), RT 252 independently analyzed the effectiveness of the Contractors' Workforce Development Assessment (CWDA) tool, which has been developed through an initial effort of the Tri-Partite initiative of the Construction Users Roundtable. The CWDA is a prequalification process intended for Owners to prequalify contractors based on their workforce development efforts. The same can be done on behalf of general contractors for their subcontractors. The results of the CWDA Analyses by RT 252 found that construction firms that score higher on the CWDA also had better safety records and experienced less absenteeism on their projects. Although these metrics are not direct measures of construction productivity, safety and worker absenteeism have direct influences on jobsite productivity (CII 2012).

Finally, the program continued its effort in validating the Best Productivity Practice Implementation Index (BPPII), which is on-schedule for final release during the final phase of the program, Phase V. RT 252 presented initial validation results of the BPPII.

2.5 Overview of Phase V

It is found that many commonly accepted practices for improving construction productivity had not been studied by CII, and that practitioners were looking for a comprehensive synthesis of commonly accepted practices as well as CII practices in the form of an implementation resource. The tool would have to be complementary to known CII Best Practices tools and be simple to be useful. Thus, the BPPII – Industrial and the BPPII – Infrastructure were developed and then validated using data from almost 60 projects (2013a; 2013b; 2013c). It can be concluded, based on the validation analysis, that (CII 2013a):

- The group of projects studied that had high BPPII – Industrial scores had on average 28% better productivity than the low scoring group
- The group of projects studied that had high BPPII – Infrastructure scores had on average 34% better productivity than the low scoring group

Still missing, due to limited resources, are BPPII's for the building, residential, and small projects sectors. As well, only a targeted group of the innovations in processes, materials and tools that are available and emerging in the market were evaluated. More research on improving construction productivity would pay off.

Over the past six years, the CII Construction Productivity Program invested considerable time and effort in assembling best practices that are known to improve construction productivity,

but for one reason or another are rarely implemented in a concerted effort on individual projects. During this endeavor, the program explored volumes of research and bodies of knowledge about the factors that influence productivity, practices used on jobsites to control it, and challenges to accurately measuring productivity in a consistent manner to provide useful industry metrics.

Much like the construction industry itself, information about construction productivity is fragmented and exists in volumes of technical reports, academic journals, student theses, and assorted company handbooks. RT 252 developed the Construction Productivity Handbook (CII, 2013d) to synthesize information about construction productivity into a single source. Although much of the material in this handbook originates from other sources, the handbook also presents a comprehensive body of new knowledge that has resulted from the CII Construction Productivity Research Program. This handbook is intended to be used in three ways: 1) as a reference for productivity experts, 2) as a guide on knowing how to improve productivity for industry practitioners, and 3) as a construction productivity textbook in construction and engineering university programs.

CHAPTER 3: BEST PRODUCTIVITY PRACTICES IMPLEMENTATION INDEX (BPPII) FOR INDUSTRIAL PROJECTS: A FINAL RECAP

Based on observations of industrial construction sites, it is evident that most industrial projects do not effectively implement historically successful productivity practices, and they are seldom implemented consistently from project to project. To help address this problem, the authors developed the Best Productivity Practices Implementation Index for Industrial Projects (BPPII Industrial). The BPPII Industrial is a new method and metric for assessing the planning and implementation levels of the essential practices needed to ensure high levels of productivity of the craft workers. The practices included are those that are widely accepted in academia and industry to have a positive impact on craft worker productivity.. This chapter provides highlights on the development and validation of the BPPII Industrial. Steps in the research method included synthesis of the literature and experience, workshops, survey based weighting, and finally statistical analysis of BPPII score versus productivity performance for a sample of large industrial construction projects. As mentioned in the report's introduction, much has already been reported on the BPPII Industrial in previous phase I-IV research reports, so the reader is referred to those references for even greater detail than reported here.

3.1 Introduction

Over the last few decades, the construction industry has made significant, progress through advances in heavy equipment, tools, and materials. Nevertheless, craft productivity can always be improved. According to the Construction Industry Institute's (CII) research, non-value added activities consume 50-75% of the productive time on a typical jobsite (CII 2005).

Therefore, maintaining and improving craft worker productivity is key to making a construction

project successful.

For a construction project to be successful, many management practices are essential. Quite often, however, managers on a construction project fail to follow historically successful or innovative practices that lead to better craft worker productivity. Thus, our research team developed a method, called the Best Productivity Practices Implementation Index for Industrial Projects (BPPII Industrial), that can be used by members of a construction project's management team to assist in the planning and implementation of practices that have the potential to improve construction productivity on industrial projects.

The goal of the BPPII Industrial is to produce a comprehensive checklist in the form of audits to assess the implementation levels of essential practices needed to ensure high levels of productivity by the craft workers. The method also provides a scoring system to quantitatively evaluate projects team's level of preparedness in addressing these issues. The practices included are those that are widely accepted throughout the construction industry as having a positive impact on craft worker productivity.

The development and validation of the BPPII Industrial encompassed the following steps: 1) conduct literature review regarding factors and practices affecting craft productivity, 2) identify practices that can improve craft productivity, 3) develop the BPPII Industrial method, and 4) validate the BPPII Industrial metric with project performance data.

3.2 Literature Review

Over the last few decades, the factors affecting labor productivity have received increasing attention among construction researchers. The Department of Energy (DOE)

conducted a survey of 12 nuclear energy-related construction projects. Among these industrial projects, the DOE surveyed both craft workers and foremen to determine and quantify the diverse factors that both negatively and positively impact construction productivity and worker motivation. From the craftsmen questionnaire surveys, the researchers identified nine major factors and ranked them according to their relative impacts on labor productivity: (1) material availability, (2) tool availability, (3) rework, (4) overcrowded work area, (5) inspection delays, (6) foremen incompetence, (7) crew interfacing, (8) craft turnover and absenteeism, and (9) foremen changes (Borcherding et al. 1980; Borcherding and Garner 1981). Despite the fact that this study focuses on industrial projects, these factors are considered by many to be universal, and therefore can be generalized to the whole construction industry. However, others factors, such as the increased lead-time in engineering design for these projects are very specialized and unique and cannot be applied to all kinds of construction projects.

Several studies have also attempted to assess construction labor productivity trends. These have tried to explain and understand the causes and implications of these trends (Allmon et al. 2000, Rojas and Aramvareekul 2003). One study reviewed the principal factors affecting construction labor productivity. Six factors were identified: (1) project uniqueness, (2) technology, (3) management, (4) labor organization, (5) real wage trends, and (6) construction training (Thomas et al. 1987). This study also exposed four ways to improve labor productivity through management practices: (1) planning, (2) resource supply and control, (3) supply of information and feedback, and (4) selection of the right people to control certain factors (Thomas et al. 1987). Consequently, numerous research programs looked into the potential ways to improve management and make it more effective in supporting craft workers on a jobsite.

In 2003, Rojas and Aramvareekul (2003) conducted a survey on productivity drivers (e.g. materials management) and opportunities (e.g. strategic management and planning). The study can be credited with bringing in a broad spectrum of the participants. The results of this survey point out two main areas that have a huge impact on productivity: management skills and manpower issues (e.g., experience and motivation). The survey analysis of the drivers regrouped the results under four categories: (1) management systems and strategies, (2) manpower, (3) industry environment, and (4) external conditions. They also noticed that certain factors have different impacts on labor productivity. The main finding of this research brings out the controllable characteristic of labor productivity, representing a huge opportunity for productivity improvements. Thus, labor productivity is seen as a manageable issue. Moreover, it is observed that the introduction of innovations helps to improve labor productivity but can't solve all the problems related to it (Rojas and Aramvareekul 2003).

Also in 2003(start here), Liberda et al. interviewed 20 industry experts with an average of 27 years of construction industry experience to examine the construction productivity impacts related to human, management, and external factors (Liberda et al. 2003). Understanding the relationship between construction productivity and project performance is crucial to being able to efficiently address the issues. The study investigated 51 factors – 8 in the human category, 35 in that of management and 8 in the external category. The authors identified the top 15 factors that had the most significant impact on construction productivity as the following: (1) lack of detailed planning, (2) worker experience and skills, (3) inadequate supervision, (4) worker motivation, (5) non-availability of materials, (6) worker attitude and morale, (7) crew team-spirit (8) non-availability of information, (9) changes in drawings and specifications, (10) non-

availability of tools, (11) non-availability of equipment, (12) project size and complexity, (13) lack of procedures for construction methods, (14) changes in contract, and (15) congested work areas. Note that there are three management factors in the top five. This fact confirms the notion that productivity can be managed and is controllable through the effective implementation of certain management practices (Liberda et al. 2003). This notion is crucial to improving construction productivity through implementing management practices.

Klanac and Nelson (2004) worked on a research project aimed at identifying factors that cause variation in construction productivity. They selected the following factors as the ones having the most significant impact on labor productivity: (1) project characteristics, (2) site conditions, (3) project execution, (4) weather effects, (5) supervision effects, (6) management of time, (7) local labor market conditions, and (8) availability of tools and construction equipment (Klanac and Nelson 2004).

Following these studies, a more recent study was conducted on worker perceptions of these factors. The research surveyed 1,996 craft workers throughout the United States (including foremen and general foremen) to determine the overall priorities of 83 productivity factors according to craftsmen. At the same time, workers were asked to evaluate the overall labor productivity of their project. In addition, this survey was completed with a statistical analysis on the real impact on productivity of factors that were perceived as having low influence. The results of this survey show that the following six categories, listed in order of importance, have the greatest impact on labor productivity: (1) tools and consumables, (2) materials, (3) engineering drawing management, (4) construction equipment availability, (5) supervisor direction, and (6) safety (Dai et al. 2009). Finally this study raised a very important point about

worker motivation. Workers appreciated that the research program took account of their points of view. This suggests the huge influence that management practices have on labor productivity. However, this survey reveals that depending on the trade, the impacts of the categories varied. This should be taken into account in future studies when using craft worker input (Dai et al. 2009).

In summary, despite several studies conducted on factors affecting construction productivity, researchers have not agreed on a general list of factors that have a substantial impact on craft worker productivity. Moreover, there is no universal assessment method regarding the impacts of the factors affecting craft worker productivity. Such a method could be very practical for a management team trying to eliminate negative impact factors, promote positive factors, and consequently improve their jobsite labor productivity.

3.3 Practices Identification

This research project used two main methods for identifying and organizing craft productivity practices. First, the relevant literature discussed in the previous section was reviewed. Indeed, an extensive background review was performed on factors affecting labor productivity and practices improving craft productivity. Second, productivity experts were consulted to help identify the essential practices needed to ensure high craft productivity on industrial projects.

These practices were grouped into six categories, namely: (1) materials management, (2) equipment logistics, (3) craft information systems, (4) human resources management, (5) construction methods, and (6) environmental safety and health. The following sub-sections

present justifications for the importance of these six categories, in terms of the relationships between each category and construction craft productivity.

Materials Management

Previous studies have indicated that, when properly implemented, material management practices have a significant positive impact on craft labor productivity. For instance, a 1986 CII study examined the impact of materials management on cost effectiveness and labor productivity. The study, which involved 20 large industrial projects, proved that a formal materials management program could have a significant positive influence on both cost effectiveness and labor productivity on industrial construction projects (CII 1986).

In 1989, a research program by Thomas et al. (1989) followed up on the 1986 CII study. It looked at the effects of materials management systems on construction productivity. The results pointed out that a lack of an efficient materials management plan could lead to additional work hours and idle time. Such conditions significantly reduce labor productivity. When a materials management system is lacking, this study revealed, a project is more likely to experience a shortage of materials, lack of housekeeping, poor planning for material delivery, deficient documentation of material delivery schedules, and improper organization of storage areas (Thomas et al. 1989).

Thomas and Napolitan (1995) investigated the productivity data of three industrial projects and concluded that a lack of on-site materials for performing activities reduced craft output by 30%. Thomas and Sanvido (2000) conducted another study where they also investigated productivity data of three construction projects and found that improper material management could decrease labor productivity by 50%.

In 2006, Dai et al. 2009 pointed out that onsite materials management was considered one of the most important factors affecting construction productivity among its research population of industrial construction firms. As a result, the researchers highly recommended that future research examine potential ways to improve on-site materials availability. In 2009, Grau et al. (2009) conducted case studies on a new automated materials-tracking technology as part of another CII study in an industrial construction setting. The results showed that materials management is highly improved by the use of automated materials identification and localization technology. In conclusion, materials management practices can significantly benefit implementation of materials management systems for craft labor productivity.

Equipment Logistics

Equipment logistics also has a positive impact on construction labor productivity. This research considers equipment to be construction machinery and tools. By surveying piping and electrical crafts, Diekmann and Heinz (2001) investigated the impact of extra construction equipment on craft productivity. They found that increasing the availability of construction equipment improves labor productivity. One of the recommendations from them regarding the availability of construction equipment is to develop a buffer of extra construction equipment to handle the periods of high demand. Moreover, poor onsite management of construction equipment negatively impacted labor productivity (CII 2001). Moreover, Dai et al. (2008) determined that construction equipment was the most significant factor affecting construction productivity based on workers' accounts. Dai and Goodrum (2009) illustrated this perspective based on the following craft worker statement, "I have to wait for people and/or equipment to move the material I need".

Craft Information Systems

A series of previous studies have identified the importance of communication within a construction project team. Workers need to have access to accurate project information. Indeed, workers should, when they need it, have access to relevant and accurate project information related to the activities they have to perform. The appropriate access to this information can increasingly enhance both labor productivity and worker motivation. For instance, rework rates can be reduced by quality requirements, project and tasks schedules, project safety guidelines, and milestones of activities. These also help workers effectively plan different tasks. The availability of project information can definitely increase a worker's productive time. Advanced project information management systems allow an effective integration of work processes. Besides, demand-based resource management represents a huge opportunity to improve craft productivity; such processes make sure craft workers have the necessary information to perform their tasks. Significant increases in construction productivity result from appropriate access to task guidance mechanisms, improvements in crafts coordination, and project state intelligence. Recently, the Construction Owners Association of Alberta (COAA) developed a workplace planning model. Information integration was worked on by Back and Moreau (2000), and Kang et al. (2008). Information integration represents a huge challenge but at the same time, if implemented, it increases quality and reduces costs. Information needs to be shared throughout the entire construction project team. Thus to have significant impact on project cost and schedule, it has to be integrated and easily exchanged between the actors involved in the construction project (Back and Moreau 2000; Kang et al. 2008).

In 2003, Libertad et al. conducted a survey on the importance of the availability of project information for craft workers. After interviewing about 20 industry experts, they found that one of the most important factors affecting craft labor productivity was the lack of information and detailed planning (Libertad et al., 2003).

Human Resource Management

Over the past several years, the construction industry has faced a shortage of skilled labor. This major challenge has fortunately been offset by advancements in technologies, work packaging, and construction site organization. Nevertheless, we can no longer ignore the consistent evidence that the construction industry faces such a shortage and that it has been failing to overcome it. And even all the advancements made in the industry cannot wholly offset this shortage. Many reasons have been offered to explain this shortage—the decline of construction real wages, construction industry reputation, poor construction work environment, workforce demographics, and a lack of adequate training opportunities. An appropriate and adequate solution to the labor shortage issue may involve improving craft worker motivation and satisfaction as well as encouraging the trust between workers and supervisors. Indeed, hidden in this shortage issue is a strong behavioral dimension. These proposed changes are crucial to creating a friendly working atmosphere, an environment where workers feel heard, valued, and trusted. Such a work environment would help improve craft productivity.

Wang et al. (2010) pointed out the significant benefits that result from craft training (improvements in craft labor productivity and reductions in turnover and absenteeism). Besides, the shortage of certified workers should encourage the establishment of a craft-training program.

Sanders and Thompson (1999) developed a tool to help companies implement an adequate incentive plan that should result in significant craft labor productivity improvements.

Previous research efforts recommended the following six considerations: 1) involving craft workers in project planning as much as possible to increase worker motivation, 2) establishing open communication between craft workers and management team to build a relationship based on trust for both good and bad news or comments to easily be conveyed, 3) enhancing the benefits of training by utilizing and rewarding craft skill certifications, 4) pairing beginners with experienced workers to set up mentoring systems, 5) encouraging foremen and superintendents to participate in supervisory training programs, and 6) reducing competition among project superintendents to promote a more collaborative environment.

Construction Methods

In construction, how exactly should work be structured? Sources for the current thinking on this question include Taylorism, Ford's assembly line, Alfred P. Sloan's ideas on industrialization, just-in-time delivery strategies, lean construction philosophy, prefabrication, preassembly, and modularization. Specific tools or methods that have been developed in the past include: high-performance work teams, work packaging, Tier I and Tier II workforce management strategies, short interval planning methods, constructability, design for maintainability, multi-skilling, and innovative crew scheduling. These have had varying degrees of impact.

A foundational idea of the Industrial Revolution was the augmenting of workers' skills with automation and advanced technology. Early cottage industry weavers were steadily replaced by large automated looms centered in mill towns throughout England and America, allowing for

extraordinary increases in productivity over a short time and an improved quality of life in the long term. In the early 1950s, hydraulic power facilitated the introduction of much more productive construction equipment. Improvements in power and controls implemented since then, based in part on better materials and computing technology, have allowed the introduction of smaller, more adaptable and more capable equipment. Examples of such equipment include skid steer machines, orbital welding tools, nail guns, and battery-powered hand tools. Their impact on craft productivity has been tremendous. The last twenty years have seen even more sophisticated solutions that substitute capital for labor.

Environment, Safety, and Health

Environment, safety and health corresponds to the implementation of practices that ensure the safety and health of craft workers on construction sites. Research shows that the implementation of a formal safety program definitely improves labor productivity. Such programs reduce incident and injury rates (Hinze and Wilson 2000). A study conducted by Hinze and Parker (1978) showed that superintendents who had completed projects on schedule and under budget were also those with the best safety records.

In 1990, CII conducted the research program Zero Accident Task Force to identify techniques that were implemented by contractors to achieve zero accidents. CII Research Team 160, Making Zero Accidents a Reality, identified nine key areas that lead to better safety performance. The most important things are safety orientation and training, safety planning, safety evaluation followed by reward/recognition (incentives), and drug and alcohol testing (CII 2003). They also highlighted the usefulness of toolbox safety meetings. In addition, CII member companies have made environmental safety and health performance their number one priority

and thus excel in this domain. That safer projects are more productive ones seems an obvious fact. However, very few research programs have looked into the relationship between construction productivity and the implementation of safety practices.

3.4 BPPII – Industrial Framework

The expertise and knowledge of the research team members were used to select and obtain inputs to prioritize and organize the management practices into elements, sections, and categories. Literature review was used extensively to accurately define and describe the elements. In addition, the research team members reviewed, adjusted, and refined the elements descriptions. As a result, the BPPII Industrial structure was developed, consisting of 53 elements grouped into 18 sections, themselves organized into 6 categories. The elements were defined and an audit form for each of them was developed. The audit form included the identified practices that are essential to properly plan and implement the element in order to help the project management team to objectively evaluate the level of planning and implementation of the element.

Elements of the BPPII Industrial correspond to construction management practices. Each practice is organized into sections that include similar practices and each also has an audit form. Between two and four sections are grouped into categories. Each category focuses on factors that studies recognized as having significant impact on craft productivity. Table 3-1, BPPII Industrial Categories, Sections and Elements, shows each category and their sections and elements.

Table 3-1. BPPII Industrial Categories, Sections and Elements

I - MATERIALS MANAGEMENT A. Material Management Systems A1. Project Team Material Status Database A2. On-site Material Tracking Technology A3. Material Delivery Schedule A4. Procurement Plan for Materials And Equipment B. Receipt And Inspection Of Materials B1. Material Inspection Process B2. Material Inspection Team B3. Post-receipt Preservation and Maintenance II - EQUIPMENT LOGISTICS A. Site Tool Management A1. Site Tool and Consumables Management Strategy A2. Tool Tracking Systems A3. Onsite Tool Maintenance A4. Control System For Tool Delays B. Machinery Availability B1. Construction Machinery Productivity Analysis B2. Equipment Maintenance III - CRAFT INFORMATION SYSTEMS A. Short Interval Planning A1. Short Interval Planning B. Workface Planning B1. Well Defined Scope of Work B2. Utilization of Software to Assist in Generating Work Packages B3. Project Model Requirements B4. Dedicated Planner B5. Identify Required Permitting B6. Engineering Work Packages (EWP) B7. Construction Work Packages (CWP) B8. Installation Work Packages (IWP) C. Constructability Review C1. Design Readiness for Construction C2. PPMOF Evaluation IV - HUMAN RESOURCES MANAGEMENT A. Training and Development A1. Trades Technical Training A2. Career Development	B. Behavior B1. Non-financial Incentive Programs B2. Financial Incentive Programs B3. Social Activities C. Organizational Structure C1. Maintain Stability of Organizational Structure C2. Clear Delegation of Responsibility D. Employment D1. Retention Plan for Experienced Personnel D2. Exit Interviews V - CONSTRUCTION METHODS A. Sequence and Scheduling of Work A1. Integrated Schedule A2. Work Schedule Strategies A3. Schedule Execution and Management B. Start-up, Commissioning, and Turnover Plan B1. Planning for Start-up B2. Testing Procedures B3. System Turnover Procedure C. New Technology Investigation C1. New Equipment Investigation C2. New Information System Investigation C3. New Materials Technologies Investigation D. Site Layout Plan D1. Dynamic Site Layout Plan D2. Site Security Plan D3. Equipment Positioning Strategy VI – ENVIRONMENT, SAFETY AND HEALTH A. Job Safety A1. Zero Accident Techniques A2. Task Safety Analysis A3. Identification of Potential Hazards A4. Housekeeping A5. System Test Hazards Planning B. Substance Abuse Programs B1. Substance Abuse Programs C. Safety Training and Orientation C1. OSHA Compliance Training C2. Toolbox Safety Meeting
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Weighting the BPPII Industrial Elements

Not all of the 53 elements are equally weighted in the BPPII Industrial. Each element is weighted based on its perceived relative importance in influencing craft productivity. In addition, each section was weighted relative to the other sections, as well as categories.

A survey was conducted to assign weights to the BPPII Industrial elements. The objective of this survey was to assign them according to the relative impact on craft productivity. According to previous studies, one of the best ways to develop reliable and accurate weights for decision support methods like the BPPII Industrial is to rely on a broad spectrum of experienced and knowledgeable members of the construction industry (Cho 2000). The results of this survey led to the BPPII-weighted score sheet.

In this BPPII-weighting effort, several steps were followed. Surveys were sent to both owners and construction companies throughout North America. The participants in the survey were asked to rank the elements according to their importance based on their experience, knowledge, and lessons learned from previous projects. In assessing the relative importance of a category, a section, and an element, the main factor considered was the impact of each item on labor productivity. Next, an analysis was performed, and weights were attributed to categories, sections, and elements. Finally, a linear interpolation was used to distribute the total weight of the element to five different implementation levels.

In theory, the higher the score an element receives in the BPPII Industrial, the greater its influence in improving construction productivity. Thus if the practice is fully planned and implemented, it should be represented by a high score thanks to its highly positive impact on productivity. Conversely, if the practice is poorly or not implemented, it should be represented

by a low score. In some scenarios, some elements may be non-applicable due to the unique characteristics of construction projects. These non-applicable elements are removed from the BPPII Industrial score calculations to not impact the results.

All survey participants were asked to provide their demographic information which included the number of years of experience within the construction industry, the location, the industry sector, the type of organizations, and other useful information, included in the BPPII-weighting form file. At the end, a total of 103 BPPII-weighting forms were collected. Of these, 73 were from experts from contractor organizations and 30 from owner organizations. The involvement of both owners and contractors was critical to obtaining unbiased input from different perspectives.

Using survey data from 103 completed forms, the average importance factor of each category, section, and element was calculated. Once the averages had been calculated, the maximum scores of the 53 elements, 18 sections, and 6 categories were determined. This corresponded to a situation where the planning and implementation level (PIL) of all elements was 5 (i.e. maximum) on a 1 to 5 scale. The research team defined that the maximum attainable BPPII Industrial score for a project was set to 2000, representing the best level of practice planning and implementation (i.e. all elements have a PIL of 5). The lowest score (i.e. all elements have a PIL of 1 with no non-applicable elements) was set to zero. Table 3-2 shows the maximum scores of the categories. The BPPII Industrial score can also be represented as a percentage of the maximum score that can be achieved, when none of the non-applicable elements is considered.

Table 3-2. Maximum Scores of the BPPII Industrial Categories

CATEGORIES	MAXIMUM SCORE
Materials Management	357
Equipment Logistics	293
Craft Information Systems	295
Human Management Behavior	283
Construction Methods	378
Environmental Safety and Health	394

All of the elements that are non-applicable (N/A) to a construction project, for whatever reason, are given a score of zero. A level one of planning and implementation was given a score of 1 for all the elements. To determine the score of the other PIL, the scores were linearly interpolated between levels one through five using the following formulas:

$$\text{PIL 2 Score} = (\text{PIL 5 Score} - 1)/4 + 1$$

$$\text{PIL 3 Score} = (\text{PIL 5 Score} - 1)/4 + \text{PIL 2 Score}$$

$$\text{PIL 4 Score} = (\text{PIL 5 Score} - 1)/4 + \text{PIL 3 Score}$$

Then, each PIL score was rounded to its closest integer. Table 3-3 shows the distribution of the PIL Score for the elements of the Materials Management Systems section as an example.

Table 3-3. Example PIL Scores of the Elements of Materials Management Systems

I - MATERIALS MANAGEMENT						
Section						
Element	0	1	2	3	4	5
A. Materials Management Systems						
1. Project team material status database	0	1	10	19	28	36
2. On-site material tracking technology	0	1	12	23	34	45
3. Material delivery schedule	0	1	15	29	43	59
4. Procurement plan for materials and equipment	0	1	15	29	43	56
Total Maximum Score of Material Management Systems Section						196

Calculating the Project's BPPII Industrial Score

A project team can calculate a project's BPPII Industrial score by evaluating the implementation levels of all 53 BPPII Industrial elements. There are, for each element, five possible definition levels (See Table 3-4 for rating Section A as an example). The BPPII

Industrial tool includes a description of each of these elements, as well as an explanation of the meaning of each of its five possible implementation levels (See Figure 3-1 for Element A1 as an example). A value of “0” indicates that an element was “not applicable” to the project. The score of each element is determined by its implementation level and weight. The total project BPPII Industrial score is the sum of the scores of all elements.

Table 3-4. BPPII Industrial Rating Example

I - MATERIALS MANAGEMENT						
Section						
Element	0	1	2	3	4	5
A. Materials Management Systems						
1. Project team material status database	0	1	10	19	28	36
2. On-site material tracking technology	0	1	12	23	34	45
3. Material delivery schedule	0	1	15	29	43	59
4. Procurement plan for materials and equipment	0	1	15	29	43	56

Figure 3-1. BPPII Industrial Element Description Example

A1. Project team material status database	
The project team material status database should consider the following:	
▪ Identify which software system will be used. ▪ If the database will be accessed by different project participants (e.g. owner, designer, and subcontractors), will it be compatible with existing software systems among each participant.	
Level 0	Project team material status database is not applicable
Level 1	No formal paper based system is used to track material status.
Level 2	There is a formal paper based system to track material status.
Level 3	A proprietary internal procurement software tool is used but it is not integrated or used by other contractors.
Level 4	An available software application is used but it is only integrated internally with your company's project control systems.
Level 5	An available software application is used by all contractors that is integrated with your supply chain and other project control systems.

3.5 Validation of the BPPII Industrial

To validate BPPII Industrial, the research team collected BPPII scores and productivity data from a total of 33 projects. The size of these projects varied in construction costs from \$6 million to over \$500 million. Most of the responses came from heavy industrial projects. Their characteristics varied regarding industry group, contract type, project nature, project type, and complexity. Of the 33 responses, 25 were from North America and 8 from other countries. The research team used only the 25 responses from North America for this validation. The responses from the other countries were not homogeneous with those from North America; the project conditions within the other countries differed in regard to labor skills, culture, construction methods, and other factors. These differences were found to be statistically significant when the research team used data from different trades to perform an analysis of variance (ANOVA) between the construction productivity of the North American projects and the construction productivity of the projects from the other countries. Table 3-5 shows the basic statistics of the BPPII Industrial scores' of the 25 North American projects.

Table 3-5. BPPII Score Statistics from North American Projects

Items	Values
Mean	56.52
Variance	2.21
Standard Deviation	14.88
Median	56.16
Minimum	28.95
Maximum	78.28
Sample Size	25

The research confirmed the relationship between the BPPII Industrial score and construction productivity. The construction productivity metric used in this analysis was the Productivity Factor (PF). Productivity Factor is defined as the estimated productivity divided by the actual productivity.

$$\text{Productivity Factor} = \frac{\text{Estimated Productivity (work hours/qty)}}{\text{Actual Productivity (work hours/qty)}}$$

Because it is a relative metric, the PF is a useful metric for our validation work. It can countervail the negative effects stemming from fundamental differences in projects (i.e., industry

group, contract type, nature, size, location, complexity, and so on). In our study, a high PF means a productivity performance higher than estimated.

The hypothesis behind this validation is that projects with higher BPPII Industrial scores perform better. For this validation, the research team divided the responses into two groups—projects with high and low BPPII Industrial scores. The high BPPII Industrial group consists of project BPPII Industrial scores 5% above the median score (67.05%). The low BPPII Industrial group consists of project BPPII Industrial scores 5% below the median score (60.67%). The research team then plotted box-plot diagrams to verify the relationship between BPPII Industrial scores and productivity factors. The team next performed ANOVA to confirm statistically significant differences between the high and low BPPII Industrial groups.

Figure 3-2 shows the box-plots of BPPII Industrial scores and PFs. The horizontal axis represents the high and low BPPII Industrial groups and the vertical axis represents the PFs of projects. The PF of the high BPPII Industrial group can be seen to surpass that of the low BPPII Industrial group.

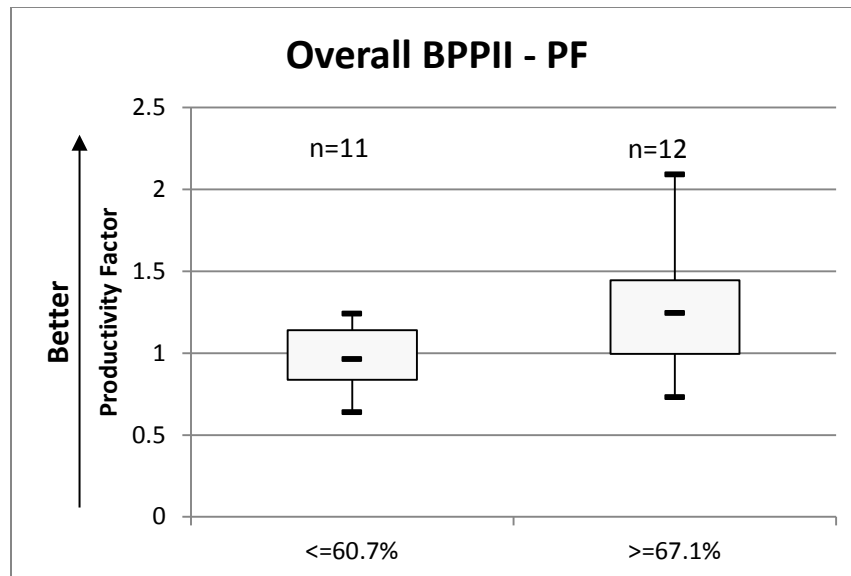


Figure 3-2 Box-plot for Overall BPPII Industrial VS PF

A one-way ANOVA test (Table 3-5) with the same two groups used in the box-plot diagram reveals a good result. This test was performed with a 95% confidence level, and the sample sizes of the low and high BPPII Industrial groups were 11 and 12. Means of the low and high BPPII Industrial groups were 0.9625 and 1.2447 respectively. The p-Value of this test is 0.0414 (< 0.05), meaning that the difference between the two groups is statistically significant. Thus, industrial projects with high BPPII Industrial scores have a significant potential to achieve better construction productivity than was originally estimated for those projects.

Table 3-6 One-Way ANOVA Analysis for BPPII Industrial and PFs

ANOVA Statistics	Low BPPII ($\leq 60.7\%$)	High BPPII ($\geq 67.1\%$)
Sample Size	11	12
Sample Mean of PF	1.2447	0.9625
Sample Standard Deviation of PF	0.4013	0.1962
F-Ratio (Between Variation)	4.72	
p-Value (Between Variation)	0.0414 (<0.05)	

Based on the BPPII Industrial validation, it can be concluded that the BPPII score has a statistically significant relationship with construction productivity. This supports the hypothesis that industrial projects scoring higher on the BPPII also perform better.

With the validation results, it was established that 65% serves as an approximate baseline of BPPII Industrial score to divide high from low BPPII Industrial score groups for industrial projects. In other words, if a certain industrial project has a BPPII Industrial score over 65%, the project can be considered more likely to have the appropriate level of planning and implementation of practices to potentially improve its craft productivity.