University of Alberta

Investigation of the Adaptation of WorkFace Planning at the Organization and Project Levels and the Development of a Mathematical Model to Quantitatively Evaluate the Effectiveness of WorkFace Planning

by

Jing Peng

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This thesis is dedicated to my dear mother, father, and my beautiful wife, who are the inspiration of my every achievement in life.

Abstract

WorkFace Planning (WFP) is an Alberta-based industry best practice aimed at improving productivity on industrial construction projects by eliminating delays caused by excessive onsite planning and inefficient resource coordination. However, no formal study has been conducted to investigate how the industry best practice was applied at the organization and project levels since its debut. To narrow the gap, the current study investigates the adaptation of WFP within an organization and on a case study project, and proposes a mathematical model to evaluate the effectiveness of WFP.

The study found that modifications to the standard WFP procedures were made at both the organization and project levels during implementation, and that most modifications were warranted by certain organization and project characteristics, which were identified in the study. The proposed mathematical model focused on the direct man-hour and monetary savings attributable to WFP, and is capable of assessing the effectiveness of WFP with respect to the mitigation of variance in labour productivity. The documented modifications to the standard procedures, coupled with the relevant organization and project characteristics, are of great value to the future implementation of WFP, especially in companies and projects with characteristics similar to those identified in this study; furthermore, the methodology used in this study to investigate the adaptation of WFP is also useful to study the adaptation of other industry best practices.

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Table of Contents

List of Tables

List of Figures

List of Abbreviations and Acronyms

WFP	WorkFace Planning
COAA	Construction Owners Association of Alberta
FIWP	Field Installation Work Packages
TIC	Total Installed Cost
CII	Construction Industry Institute
BPPII	Best Productivity Practices Implementation Index
SEMAT	Software Engineering Method and Theory
WBS	Work Breakdown Structure
EWP	Engineering Work Package
CWP	Construction Work Package
DBM	Design Basis Memorandum
EDS	Engineering Design Specification
CWA	Construction Work Area
IFC	Issued for Construction
EPC	Engineering-Procurement-Construction
RFI	Request for Information
NCR	Nonconformity Report
FCN	Field Change Notice
AIA	American Institute of Architects
ROI	Return on Investment
VLP	Variance in Labour Productivity

CHAPTER 1: INTRODUCTION

1.1 Background and Problem Statement

As the global economy has come to rely more heavily than ever on fossil fuels in recent decades, and the price of crude oil continues to reach historical levels (NEB 2008; US EIA 2011), the oil sands resources in Canada have drawn tremendous amounts of attention and investment in the past 20 years (NEB 2000). Many large industrial construction projects related to oil sands development were initiated during this period (NEB 2000). The stakes have been, and still are, extremely high for the industrial construction sector of Canada, especially in the province of Alberta, where the majority of Canada's current oil sands development is located (NEB 2004). However, due to the increasing size, complexity, and technological advancement of these construction projects, challenges to meet budget and schedule targets were encountered on a regular basis around the new millennium. A number of mega-projects suffered from significant cost overruns, causing questions in the value of such capital investments (COAA 2012a). As an effort to improve the situation, the Construction Owners Association of Alberta (COAA) developed the concept of WorkFace Planning (WFP). Rooted in the concept of lean construction and existing efforts on work packaging, the main objectives of WFP are:

1. To deliver all the resources necessary to execute construction at the right time, to the right place, and to the right people, in order to avoid delays and cost overruns; and
2. To relieve the onsite supervision team from the time-consuming tasks of onsite planning and resource tracking, thereby allowing them to focus on the supervision and direction of their crews (COAA 2012a).

The objectives of WFP are achieved through appointing dedicated WorkFace planners to:

1. Assist superintendents in dividing large scopes of work into smaller and more manageable pieces of work to form field installation work packages (FIWPs);
2. Sequence the FIWPs and integrate them into the schedule of the project;
3. Align all resources necessary to complete the FIWPs and remove any constraints to completing the FIWPs as planned;
4. Physically put together FIWPs that contain all information necessary for construction in advance; and
5. Provide support to the onsite supervision team to execute and control the FIWPs.

Through implementing WFP, construction projects are expected to experience improved productivity performance as well as lowered total cost. An industry estimate showed that WFP is potentially capable of increasing labour productivity by 25%, and lowering the total installed cost (TIC) by 9% (COAA

2012a). Other expected benefits of WFP include improved constructability, optimized path of construction and project sequencing, as well as improved project communication and more effective supply chain management. Due to the promising estimated potential, WFP was named an industry best practice soon after its debut, and is currently a contractual requirement on most industrial construction projects in Alberta (COAA 2012a).

While the estimated potential of WFP is high, there are conditions to implementing it to its fullest. The original WFP concept was catered to suit the needs of complex mega-projects, and the same mindset was carried through in the development of the industry standard procedure. The current application of WFP, on the other hand, covers industrial projects of all sizes and other characteristics. The adaptation of WFP to companies and projects with different attributes than defined in the industry standard procedure has yet to be investigated and documented.

Besides challenges to effectively adapt WFP, there is also the rising need to evaluate the tangible benefits of WFP and perform a cost-benefit analysis, since the definition of best practice suggests superior results, and the impacts of WFP are yet to be confirmed with a rigorous scientific approach.

The current study attempts to answer to both of the challenges stated above.

1.2 Research Objectives and Expected Contributions

The objectives of this study are:

1. To investigate the adaptation of an industry best practice at the organization and the project levels, illustrated with WFP as an application, as shown in Figure 1, and:
    1. To identify modifications to the industry standard WFP procedure to adapt WFP to a specific organization, as well as the impact of organization characteristics on the adaptation process; and
    2. To identify modifications to the organization-specific WFP procedure to adapt WFP to a specific project, as well as the impact of project characteristics on the adaptation process; and
2. To develop a mathematical model to quantitatively evaluate the effectiveness of WFP.

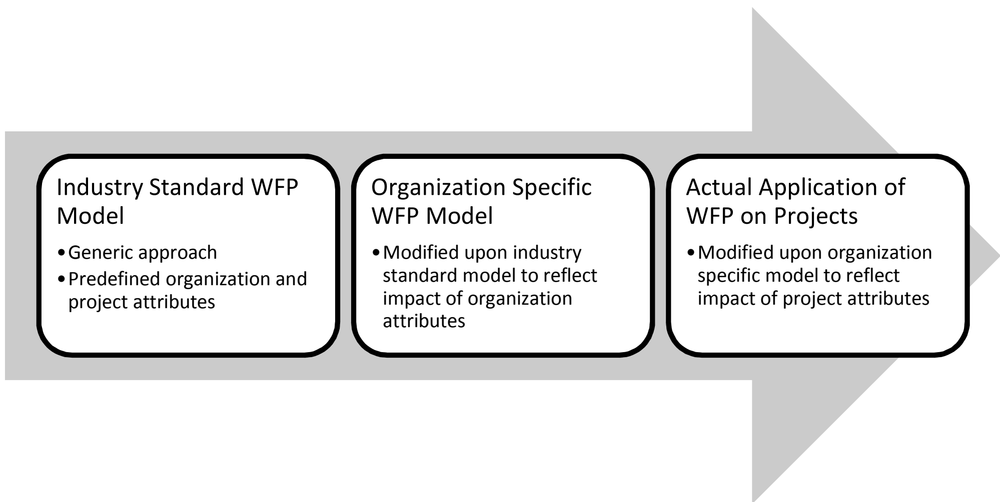

Figure 1.1. Adaptation of the Industry Best Practice of WFP at the Organization and Project Levels

The following are the research contributions of the study:

1. The investigation and documentation of the adaptation of WFP at the organization and project levels contributes to the WFP body of knowledge, and provides reference to assist the future implementation of WFP in the industry;
2. The identification of the impact of various organization and project characteristics on the adaptation of WFP offers a contextual perspective to apply and examine WFP;
3. The methodology used in this study can be generalized to study the adaptation of any industry best practices at the organization and project levels; and
4. The proposed mathematical model sets the theoretical basis for a quantitative evaluation of the effectiveness of WFP.

1.3 Research Methodology

This study was conducted in collaboration with an industrial partner organization. Data collection engaged the staff and a particular project of the partner organization. A semi-structured interview was the primary data collection instrument. The adaptation of WFP was studied in two stages. In the first stage, the industry standard WFP procedure and the partner's in-house WFP procedure were reviewed and compared against each other to identify any modifications, and the corresponding reasons for those modifications. The impact of each organization characteristic on the adaptation process was then investigated by consulting the industrial experts from the partner organization. In the second stage, a case study was conducted to investigate the adaptation of WFP at the project level. A field-level survey form was used to capture the actual procedures used to implement WFP. A comparison was performed between the actual procedures used and the organization-specific procedure, in order to identify any variations and reasons for the variations. The impact of project characteristics was again investigated by consulting the industrial experts from the partner organization.

After the adaptation of WFP at the organization and project levels was studied, a mathematical model was developed to evaluate the benefits of WFP with respect to labour productivity variance mitigation and associated cost reduction.

1.4 Thesis Organization

Chapter 2 of this thesis presents a literature review of concepts relevant to the study. Chapter 3 presents a comparison between the industry standard WFP procedure and the organization-specific WFP procedure, and a comparison between the actual implementation of WFP on a case study project and the organization-specific WFP procedure. Chapter 4 presents a mathematical model for evaluating the effectiveness of WFP with respect to mitigation of variance in labour productivity. Chapter 5 concludes the study by summarizing findings and proposing areas of future research.

CHAPTER 2: REVIEW OF LITERATURE ON BEST PRACTICES, LEAN CONSTRUCTION, AND WORK PACKAGING

2.1 Best Practices

The phrase "best practice" is defined in the Oxford Dictionary as "commercial or professional procedures that are accepted or prescribed as being correct or most effective" (Oxford Dictionaries 2012). In more general terms, a best practice is a methodology or technique that consistently produces better results than those that could be achieved with its alternatives, and is capable of evolving over time as improvements become available (Wikipedia 2012). The term is used widely by industry authorities and government agencies to establish benchmarks and create standards to regulate and improve current practices (CIHR 2005; IC 2012). The Construction Industry Institute (CII) defines a best practice as "a process or method that, when executed effectively, leads to enhanced project performance" (CII 2012a), and has developed 14 best practices for the construction industry in the United States (CII 2012a). CII has also recently initiated a research program to link the use of CII best practices to labour productivity, the expected product of which is a framework known as the Best Productivity Practices Implementation Index (BPPII) (CII 2012b).

Besides attention from organizations like CII, "best practice" has also been a topic of interest for researchers in the field of construction engineering and management in general. Numerous best practices-related studies have been conducted in the past 10 years.

Andersen et al. (2007) proposed a best practice for establishing project management offices in large organizations through a combination of literature reviews, interview surveys, and benchmarking. The product of Andersen's research was structured to be a set of conceptual guidelines for the development of project management offices (Andersen et al. 2007). Andersen noted that the findings would only be valid for organizations of certain sizes, and that the generalization and application of the research findings to other types of organizations could be potentially risky (Andersen et al. 2007). Muench et al. (2007) developed a set of best practices to guide the development of long-lasting low-volume pavement by performing empirical and historical data analysis. Although the proposed best practices include managerial components, Muench's research focused more on the technical standards for pavement design. The best practices developed from the research were validated using a case study in Hawaii. As a closing remark, Muench et al. stressed that although the proposed best practices are recommended, partial implementation and modification of the practices could also produce success (2007). It is worth noting that the best practices developed by Muench et al. also took the form of a set of guidelines, as opposed to structured stepwise procedures. In comparison to the best practices developed by Andersen, WFP is represented by a series of detailed structured procedures. This allows for more detailed guidance, but at the same time creates more structural rigidity. Lee et al. (2005) investigated the economic value of combined CII best practice use in the US. The researchers analyzed data from the CII Benchmarking and Metrics database, and concluded that both owners and contractors gain from the implementation of best practices, and that greater use of best practices results in better project performance. Lee et al. (2005) also commented that assessment based on combined practice use shows more consistent relationships between practice use and project performance than those based on individual practices. Hastak et al. (2008) analyzed techniques that lead to radical reductions in project cycle time, and identified "implementing CII best practices" as one of the potential techniques. Hastak et al. (2008) tested this hypothesis by performing interview surveys and examining a few case studies. Several CII best practices were identified by industrial respondents as the most important techniques leading to radical reductions in project cycle time (Hastak et al. 2008). More recently, Olumide et al. (2012) investigated the applicability of CII best practices with respect to different construction sectors and project types. The researchers conducted interview surveys with practitioners from four different sectors of the construction industry (Olumide et al. 2012). The applicability of 13 CII best practices was evaluated using four metrics. Olumide et al. (2012) concluded that some of the best practices are more applicable to certain sectors than others, due to the contexts on which the development of the best practices were based.

Despite the dedication and efforts by numerous organizations and individuals to develop and analyze best practices within their respective fields, the concept of best practice has been criticized and questioned by researchers and practitioners. Ambler, in his paper for Software Engineering Method and Theory (SEMAT), states that the concept of best practice is potentially misleading because a different "best practice" exists within every context (2010). The truly *best* practice should be a context-based approach, as opposed to a unified approach. Ambler also stresses that what works the best for one context may not be generally applicable to other contexts (Ambler 2010). In contrast, Bardach (1994) believes that generic solutions such as best practice concepts rarely exist in real life, and in most cases, the existing best practices lack proper validation and verification. The resulting challenge is a conflict between possibilists and sceptics, where the former group believes that the best practices may be working and therefore supports them, and the latter doubts the success of the so-called best practices due to a lack of evidence. Bardach also suggests that solution-seeking in management is very much context-based, and sometimes subjective. Therefore, while one approach may work very well in one case, it may not work in other cases, or even in the same project with a different execution team (Bardach 1994). In both cases, the somewhat context-independent nature of the best practice concept is deemed to be the most significant challenge. Both Ambler (2010) and Bardach (1994) mention the importance of context in solution seeking, and how changes in context could impact the effectiveness of best practices.

The current study investigates the adaptation of the industry best practice of WFP at the organization and project level. The above reviewed studies provided the baseline for the current study.

2.2 Lean Construction and Work Packaging

Since WFP was built upon the concept of lean construction and work packaging, it is necessary to first understand these underlying concepts before studying WFP. The following sections provide a brief review of these concepts and their relationship to WFP.

2.2.1 Lean Construction

Lean construction was developed from the lean principles in the manufacturing industry. The main foci of lean construction are streamlining the construction process and eliminating non-value adding activities and other sources of waste during construction to deliver the most value to the customers at the least resource input (Ballard and Howell 1994). The concept was first brought to attention of academia by lean construction pioneers Lauri Koskela, Glenn Ballard, and Gregory Howell. Koskela pointed out that the conventional managerial practices in construction caused flow problems in the construction process because of the inherent deficiencies in sequential method of design and engineering, traditional approaches to quality, and segmented control. As a result, significant amount of waste and non-value adding activities were introduced and project performance was jeopardized (Koskela 1992). Koskela proposed to, instead of viewing construction as activity, viewing it as flow, and applying what he referred to as “new production philosophy” to the construction industry (Koskela 1992). Koskela’s work set the cornerstone for the early development of lean construction theories. Following the footsteps of Koskela, Glenn Ballard and Gregory Howell conducted further investigation and concluded that the potential for improvement in waste reduction and workflow optimization in construction is huge, and that lean theory is the right tool for the task (Ballard and Howell 1994). Ballard and Howell also proposed ways to implement lean construction theories on actual construction projects and furthered the development of lean construction theories significantly. Lean construction has since gained its popularity and recently CII offered its view of lean construction and the implementation of lean construction at the project level (Diekmann et al. 2004; CII 2007). CII investigated several projects in the eyes of lean principles and concluded that construction efficiency can be improved significantly with the application of lean (CII 2007).

WFP shares the same goals of reducing waste and providing maximal return with lean construction, and conforms to the lean construction philosophy by restructuring project and construction management system to create better flow of work and reduce rework and resource idle. The increased involvement of construction during earlier stages of construction projects promoted by lean construction is also followed by WFP, and is considered one of the key features of WFP (COAA 2012a). Industry's understanding and expectation introduced by lean construction theories have great impact on the development of WFP.

2.2.2 Work Packaging

Work packaging is a project control concept derived from the concept of Work Breakdown Structure (WBS). It is based on the philosophy that the management of any large and complex projects can be made effective only through breaking the scope down to smaller pieces and exercise management at lower and less overwhelming levels (Halpin et al. 1987). CII (1988) issued two reports titled "Work Packaging for Project Control", in which the concept of work packaging was formally structured and presented. The definition of a work package, as stated by CII, is "a well-defined scope of work that terminates in a deliverable product(s) or completion of a service. Each package may vary in size, but it must be a measurable and controllable unit of work to be performed" (Halpin et al. 1987; CII 1988). Consequently, the definition of work packaging is the process to effectively plan, manage and control a project by breaking the global scope of the project into work packages and exercise management on the work package level (Halpin et al. 1987; CII 1988). CII further specified that work packaging is beneficial in all phases of a project, and that consistent use of work packaging through engineering, procurement and construction would create the optimal project results. CII also proposed guidelines to implement work packaging on different management aspects of a project (CII 1988). In today's construction industry, the popularity of various forms of application of the work packaging concept is self-evident. It is standard on heavy industrial projects in Alberta to have engineering companies deliver design documents in engineering work packages (EWPs) and have construction contractor execute the work in EWPs or Construction Work Packages (CWPs).

WFP is in many ways a natural extension of the original work packaging concept. There exist three work packaging concepts in WorkFace Planning. First of all, EWPs containing engineering information are created by engineering to divide the project based on the engineered systems, after which construction management will create CWPs containing engineering information and resource requirements based on the EWPs to facilitate most effective construction, and eventually construction contractor will divide the CWPs down to form FIWPs containing all documents necessary for crews to complete construction. The objectives of WFP are achieved essentially through the construction of FIWPs, which is essentially work packaging applied at the field level. The transformation from EWPs to CWPs and eventually FIWPs proposed by WFP also conforms to the work packaging concept laid out by CII where a consistent packaging system shared between engineering, procurement and construction is recommended.

Both lean construction and work packaging are fundamental principles behind WFP, and the review of these concepts provided necessary theoretical context for the current study.

CHAPTER 3: INVESTIGATION OF THE ADAPTATION OF WFP AT THE ORGANIZATION AND PROJECT LEVELS

3.1 Introduction

While the industry best practice of WFP was originally developed for complex large scale industrial construction projects; it is now being mandated in most industrial construction projects in Alberta. The question therefore exists of how the industry standard procedure is adapted by companies that specialize in different types of projects, and how the adaptation of the industry standard procedure at the organization level is executed in the field. Meanwhile, to understand the adaptation of WFP at the organization and project level, the impact of various organization and project characteristics on the adaptation process also needs to be identified. To find answers to these questions, this chapter presents the investigation of the adaptation of WFP at the organization and project level, and attempts to:

1. Identify modifications to the industry standard procedure to adapt WFP to an organization and the impact of organization characteristics on the adaptation process; and
2. Identify modifications to the organization-specific procedure to adapt WFP to a project and the impact of project characteristics on the adaptation process

3.2 Methodology

The investigation was accomplished in two steps. First, adaptation of WFP at the organization level was studied away from the field. Both the industry standard procedure and the organization-specific procedure were reviewed and compared against each other to document the adaptation status. The comparison focused on key components of the procedures and modifications to the industry standard procedure that the organization has made. A profile of the organization was constructed prior to the comparison to help later identify the impact of organization characteristics on the adaptation process. To support the comparison, semi-structured interviews were conducted with 10 industrial experts from the home office of the partner organization to elicit their perspective on how WFP was adapted in the organization and why. The participating interviewees have an average of 20 and 10 years of experience working in the construction industry and in the organization respectively. The interview also covered interviewees from a variety of positions including senior management, project management, supervision management, project controls, construction planning, and onsite supervision. All interviewees identified themselves as being either familiar with WFP or experienced with WFP. Interview results were treated as a group response and no individuals were identified during analysis. Finally, the impact of organization characteristics on the adaptation process was identified by consulting the industrial experts from the organization.

As the second step of the investigation, a field study was conducted on a case study project of the partner organization. Semi-structured interviews were conducted with the project manager and the WorkFace planner of the project to gain insights on the actual WFP process of the project. Both interviewees have more than 20 years of construction experience. A project profile form was developed to help later identify impact of project characteristics on the adaptation process. Comparison was then performed between the organization-specific procedure and the actual case study procedure to document the field execution of the organization-specific WFP procedure and identify any modifications made. Format of the comparison is similar to that of the previous step. Results of comparison were then analyzed with assistance of the WorkFace planner of the project to identify impact of project characteristics on the adaptation of the organization-specific procedure.

3.3 Investigation of the Adaptation of WFP at the Organization Level

3.3.1 Review of the Industry Standard WFP Procedure

The industry standard WFP procedure was designed to guide the implementation of WFP through all phases of a project from pre-project, design basis memorandum (DBM), engineering design specification (EDS), detailed design, construction execution, to commissioning & start up and project close out. Parties involved in the process include owner, project management, construction management, supply chain management, engineering, and construction contractor (COAA 2012c). For the purpose of this study, only components of the procedure that are relevant to construction management and construction contractor were reviewed to allow for parallel comparison with the organization-specific procedure.

According to the industry standard procedure, the earliest WFP-related involvement of construction management and a construction contractor in a project starts in the DBM phase. In this phase, construction management is required to demonstrate to the owner its capacity to support WFP by including a WFP execution plan as part of the construction execution plan. Construction management shall work with engineering to develop site layout, project sequence, and path of construction, as well as define construction work areas (CWAs) and the scope of CWPs. Around the same time, construction management shall also create early alignment with supply chain management, based on needs identified by project sequence and path of construction. By the end of the DBM phase, the summary master schedule should be reviewed with input from construction management, and should then be approved by the owner.

Entering into the EDS phase of a project, construction management and the construction contractor shall appoint internal leaders or managers to be in charge of WFP and developing staffing plans for WFP. Construction management and the construction contractor shall take part in the constructability reviews and project coordination schedule reviews. Construction management is responsible for reviewing and revising the path of construction, and developing CWPs. After construction management develops and issues the CWP release plan, the engineering team is responsible for generating the EWP release plan by CWPs, and both release plans should be reviewed by the construction contractor before proceeding to detailed design.

The next phase is detailed design. In this phase, construction management and the construction contractor are expected to participate in detailed constructability reviews. Construction management shall continuously feed engineering information into CWPs, and assign WFP coordinators for scaffolding, equipment, and other supporting trades, while the construction contractor develops and issues the FIWP release plan using the CWPs prepared by construction management. The construction contractor is also responsible for building its WFP team and developing the project control level schedule in this phase. At this point, both construction management and the construction contractor should be ready for construction execution.

The industry standard procedure suggests that most WFP-related construction management and construction contractor organization man-hours are used in the construction execution phase. In this phase, construction management shall first feed issued-for-construction (IFC) EWPs into CWPs, and release IFC CWPs to the construction contractor. The construction contractor's WFP team shall then develop FIWPs, sized between 500 to 2000 man-hours, from CWPs before mobilization. Construction management shall keep a database containing constraints relevant to executing the FIWPs. Once all constraints are removed and no RFIs are outstanding, the construction contractor shall issue the FIWPs to the field for execution. As FIWPs are executed in the field, construction management and the construction contractor shall document and report progress to the owner by FIWPs or CWPs. The construction contractor shall also prepare system completion packages and turnover packages as bulk construction approaches completion. At the end of the construction project, construction management and the construction contractor shall collect and document lessons learned, in order to facilitate continuous improvement.

To guide the effective creation and utilization of FIWP, the industry standard procedure has a flowchart sub-procedure named "FIWP Life Cycle" (COAA 2012d). The major components to the procedure are:

1. Electronic Package Creation
    - Superintendents meet regularly to identify task groupings.
    - Planners create electronic FIWPs and FIWP release schedule.
    - Planners monitor constraints and notify support trades when appropriate.

2. Document Control Interface
    - Planners send sequence and contents of FIWP to document control.
    - Document control generates hard copies of the packages.
3. Issuance to the Field
    - Planners issue FIWPs to the field when all constraints are satisfied.
    - Onsite supervision and their crews execute the packages.
4. Control of the FIWP in the Field
    - When a package is completed, onsite supervisors report progress to construction management.
    - When a package is scheduled to be closed but is not completed, either leave it in the field until completion or remove the outstanding items and report as completed.
    - Outstanding items are fed back to construction management and the superintendents for repackaging.
5. FIWP Close Out
    - When a package is reported as completed, close the package out and feed the progress information back to construction management and the superintendents.

To fit the major WFP activities into the project timeframe, the industry standard procedure also includes a FIWP preparation timeline. The timeline covers the 120-day period before construction starts (COAA 2012e):

- 120 days before construction starts, IFC EWPs should be developed and released.
- 90 days before construction starts, IFC CWPs should be developed and released, and preparation of materials, tools, and equipment should start.
- 60 days before construction starts, the electronic creation of FIWPs should begin, and the delivery dates of materials, tools, and equipment should be confirmed.
- 30 days before construction starts, FIWPs should be ready for release, and the availability of materials and equipment onsite should be confirmed.
- 10 days before construction starts, hard copies of FIWPs should be distributed.

With the components of the industry standard WFP procedure related to construction management and construction contractors thoroughly reviewed above, the following section proceeds to describe the organization-specific WFP procedure of the partner organization.

3.3.2 Review of the Organization-specific Procedure

The partner organization is a construction company that typically acts as both construction manager and construction contractor. A brief profile of the organization is shown in Table 3.1. According to the interviewees, their WFP procedure was developed in general alignment with the industry standard procedure, with considerations of roles and responsibilities the organization has experienced historically on projects.

Table 3.1. Profile of the Partner Organization

Field of specialization	Industrial construction in the sectors of oil & gas, petrochemical, pulp & paper, mining, and power generation
Volume of fabrication versus field projects	40% fabrication jobs and 60% field jobs
Scope of service	Construction management/construction contractor
Typical project delivery strategy engaged	Design-bid-build (majority), Design-build, EPC
Typical procurement strategy engaged	Cost reimbursable, lump sum
Typical size of projects	\$50M–\$100M
Labour status	Both union and non-union

The first step in the organization-specific procedure is breaking CWPs down to establish the boundaries of FIWPs. Superintendents of each discipline shall work with a WorkFace planner to perform this task. CWPs are assumed to be engineering deliverables that are issued to the contractor in the procedure. The ideal size of FIWPs is between 500 to 1500 man-hours, or the equivalent workload of one shift (i.e., usually 10 days or 14 days, depending on the context) for one crew. Once CWPs are broken down with FIWP sequencing determined, the designated WFP coordinator shall develop the FIWP release plan and submit it to the construction manager for approval.

The approved FIWP release plan shall then be linked to the project schedule for the creation of the level 4 schedule. The WFP coordinator is responsible for logging the FIWPs into the in-house information management system, and linking all relevant documents to the FIWPs. WorkFace planners shall assemble the FIWPs using a predefined template, and link project documents to the FIWPs. After the FIWPs are assembled, they shall be passed to the superintendents for review. The superintendents shall verify that the contents of the packages are accurate and complete. Once the packages are verified and signed off by the superintendents, the WFP coordinator shall update the status of the packages as ready and add them to the FIWP backlog in sequence, which shall then be incorporated into the three-week look-ahead schedule. Three weeks before the work is scheduled to start, the WFP coordinator shall issue the packages to the responsible general foremen, and the foremen shall verify the readiness of all resources with onsite resource coordinators.

As each FIWP is executed in the field, the WorkFace planner and the WFP coordinator shall monitor the progress of the package, update and track all field documents related to the package (e.g., RFIs, NCRs, and FCNs), identify any changes to the package, and identify any conditions that may affect the completion of the package and report them to the construction manager. The general foreman responsible for the project and the superintendent are to ensure that the scope of work is completed as specified. When a FIWP is signed off as complete, the WFP coordinator shall perform a final walkdown (i.e., a construction management process where project controls staff reviews and approves field work) with all responsible parties to confirm the completion of the work. The WFP coordinator is also expected to properly maintain all documents associated with the packages. If minor components of a package are incomplete, the WFP coordinator shall instruct the responsible WorkFace planner to remove the components and develop a new FIWP with a collection of such components from different FIWPs. The current FIWP is then marked and reported as completed. The project schedule and WFP release plan shall also be updated accordingly.

The final step in the organization-specific procedure involves the continuous improvement and auditing components of the procedure. Feedback from the field regarding WFP shall be analyzed by the home office for continuous improvement. Three internal audits are suggested each during the planning, execution, and close-out phases of FIWPs.

In summary, the organization-specific WFP procedure focuses on the respective organization's internal responsibilities related to WFP, and specifies fewer interactions with other parties than in the industry standard procedure. Most of the tasks the organization-specific WFP procedure covers take place after the detailed design phase. The detailed comparison between the industry standard procedure and the organization-specific procedure is presented below.

3.3.3 Industry Standard Procedure versus Organization-specific Procedure

Since the industry standard WFP procedure and the organization-specific WFP procedure are not structured in perfect parallel to each other, the comparison offered here focuses on the key aspects that define the procedures, as opposed to a step-by-step comparison. These aspects include scope of procedure; definition and use of EWP and CWP; staffing and allocation of responsibilities; creation, execution, and control of FIWPs; and timing of activities. A summary of the findings of the comparison is presented in Table 3.2.

Table 3.2. Summary of the Adaptation of the Industry Standard WFP Procedure at the Organization Level in the Partner Organization

Industry Standard Procedure	Organization's Adaptation	Reason for Modification
Scope of Procedure		
Starts in design basis memorandum phase	Starts in construction execution phase	Organization is not typically engaged in design and engineering activities
Definition and Use of EWP and CWP		
Engineering issues EWPs; construction management and construction contractor develop CWPs from EWPs, and then develop FIWPs from CWPs	Owner or engineering issue CWPs or EWPs; construction management and construction contractor develop FIWPs either from CWPs or EWPs	The typical definition and use of CWP and EWP in practice differ from the industry standard procedure
Staffing and Allocation of Responsibilities of WFP		
WFP Champion, WFP coordinator, dedicated WorkFace planners, resource coordinators	Similar organizational structure, but details at the project level are not included in the procedure	Staffing choice and allocation of responsibilities at the project level are context-dependent
Creation, Execution and Control of FIWPs		
Both procedures are similar in the creation, execution, and control of FIWPs		
Timing of Activities		

Five control points cover preparation and issuance of EWPs, CWPs, and FIWPs	One control point for issuance of FIWPs to field	Timing of WFP activities is highly context-dependent; project requirement dictates actual timing

Scope of Procedure

The scope of the industry standard WFP procedure covers the responsibilities of construction management and the construction contractor from the DBM phase until project close out. In comparison, the scope of the organization-specific WFP procedure covers the organization's responsibilities from the construction execution phase until project close out. According to the interviewees, the organization is not typically engaged in design and engineering activities. Therefore, their adaptation of the industry standard WFP procedure did not include the front-end project phases.

Definition and Use of EWP and CWP

In the industry standard procedure, the EWP and the CWP are two distinct entities that serve different functions. An EWP is an engineering deliverable used by construction management and the construction contractor to construct CWPs. A CWP, on the other hand, is a construction deliverable used for the development and assembly of FIWPs. The sequence of events, as defined by the industry standard procedure, is as follows:

1. Construction management develops the scope and release plan of the CWPs, based on the path of construction.
2. Engineering develops a EWP release plan by CWPs.
3. The construction contractor develops a FIWP release plan by CWPs.
4. Engineering issues EWPs to construction management to populate the CWPs, according to the sequence of construction.
5. The construction contractor assembles FIWPs using the CWPs prepared by construction management.

In the organization-specific procedure, on the other hand, the CWP is issued to the contractor by engineering, and FIWPs are sometimes developed directly from EWPs. Feedback from the interviewees showed that adaptation of this component of the industry standard procedure is context-driven. If a contract requires that CWPs be constructed by construction management and the construction contractor, then the industry standard procedure will be followed. However, in more typical situations, the organization is either issued CWPs or issued EWPs, but is not required to develop CWPs. This feedback is also consistent with the feedback from some other contractors using WFP (COAA 2012f; COAA 2012g). The interviewees further indicated that CWP—as defined by the industry standard procedure—serves the purpose of aligning the sequence of EWP issuance. This is a feature the organization has not experienced. The sequence of issuance of EWPs/CWPs has been typically determined by engineering.

Staffing and Allocation of Responsibilities for WFP

The WFP organizational structure recommended by the industry standard procedure includes the following:

- One WFP champion from senior management;
- One dedicated WFP coordinator with sufficient qualification and experience;
- At least one dedicated planner per discipline with substantial experience working as a tradesperson and supervisor; and
- One resource coordinator for each of the materials, tools, equipment, and scaffolds departments.

In this organizational structure, the WFP champion is responsible for providing corporate support for the WFP program and developing skills and standards. The WFP coordinator is responsible for directly managing the implementation of WFP on projects, and performing integration planning. The dedicated planners are responsible for dividing CWPs, assembling the FIWPs, and aligning all necessary resources with the resource coordinators. The resource coordinators are responsible for organizing and delivering all resources on time, according to the requirements set out in the FIWPs.

According to the interviewees, the organization's adaptation of the industry standard procedure suggests a similar organizational structure. However, since staffing for WFP is dependent on the needs of the project, staffing requirements at the project level were not included in the organization-specific procedure.

Creation, Execution, and Control of FIWPs

The industry standard procedure and the organization-specific procedure are very similar with regard to the creation, execution, and control of FIWPs. The industry standard procedure was adapted by the organization with minimal modification.

Timing of Activities

The industry standard procedure specified five control points for the timing of WFP, with one at each of the 120-day, 90-day, 60-day, 30-day, and 10-day marks prior to the field execution of the respective FIWP. The organization-specific procedure has only one control point, which is at three weeks prior to the field execution of the FIWPs, when the assembled FIWPs are to be distributed to the responsible general foremen. According to the interviewees, since the timing of WFP activities in the organization is highly context-dependent, different projects could have very different timing requirements. It is not practical from the organization's perspective to fix a timing guideline that applies to the majority of its projects. Therefore, only one control point was defined in the organization-specific procedure, to ensure the readiness of the FIWPs before scheduled field execution.

In summary, section 3.3.3 documented the adaptation of the industry standard WFP procedure at the organization level in the partner organization. As discussed above, some components of the industry standard procedure were adopted by the organization without any changes, while some other components were modified to reflect the impact of certain organization-specific attributes. To better understand the adaptation of WFP at the organization level, the following section presents an exploration of the impact of various organization characteristics on the adaptation of WFP.

3.3.4 Impact of Organization Characteristics on the Adaptation of the Industry Standard WFP Procedure

After documenting the adaptation of WFP at the organization level, there remains the question of what impact different organization characteristics have on the adaptation process. This section addresses this question by consulting the group of industrial experts from the organization who were previously interviewed. The organization profile form was used as reference material to help elicit knowledge of the experts during consultation. The organization characteristics discussed in this section were identified by the industrial experts from the list of organization characteristics in Table 3.1.

Scope of Operation of the Organization

The scope of operation of the organization was identified by the industrial experts as the first and foremost organization characteristic that warranted modifications to the industry standard procedure. Since the organization specializes in construction and construction management, only the responsibilities of construction management and the construction contractor were considered in the adaptation of the industry standard procedure.

Primary Project Delivery Strategy

The primary project delivery strategy describes the most typical project delivery system the organization works with. Results from consultation with the industrial experts indicated that this is an important characteristic that warrants modifications to the industry standard procedure. While the organization works with various project delivery systems, including design-bid-build, design-build, and EPC, design-bid-build is more frequently encountered than the others. The industrial experts indicated that the early involvement of construction management and the construction contractor, as defined in the industry standard procedure, requires the construction parties to be determined at the same time as engineering, which occurs more often in the design-build and EPC environments than in a design-bid-build environment. The observation of the industrial experts was found to be in agreement with the analysis of project delivery strategies published by the American Institute of Architects (AIA). AIA suggests that the traditional design-bid-build project delivery system offers few opportunities for collaboration between engineering and construction in comparison to the design-build system, and does not allow early involvement of construction parties due to its rigid phasing and the consequences associated with early bidding (AIA 2007). Thomsen's study on project delivery processes also shares similar findings with AIA and the industrial experts (Thomsen 2006). These features of the design-bid-build delivery strategy conflict with the requirements of the industry standard WFP procedure, and since design-bid-build was identified as the primary project delivery strategy the organization works with, front-end activities in the design and engineering phases were excluded in the organization's adaptation of the industry standard procedure.

Another impact the primary project delivery system had is on the timing of WFP activities. According to the industrial experts, since the organization is not involved in design and engineering activities in design-bid-build projects, timing for EWP and CWP preparation is not typically controlled by construction. Therefore, the organization only included timing for the preparation of FIWPs in their adaptation of the industry standard procedure.

Typical Size of Projects

The typical size of projects is the last organization characteristic identified by the industrial experts as relevant to modifications in the adaptation process. According to the industrial experts, the size of a project is a determining factor for staffing and the allocation of responsibilities for WFP. In the industry standard WFP procedure, it was specified that the procedure would be most effective on large industrial construction projects, and defined "large projects" as projects over $300M in value (COAA 2012a). For the partner organization, on the other hand, the typical size of projects is between $50M and $100M. The industrial experts pointed out that engaging the full WFP team on smaller projects may not be efficient and cost effective, and actual staffing for WFP is dependent on the size of the project. As a result, the industry standard procedure was adapted by the organization without a detailed staffing requirement at the project level, to allow more flexibility.

In summary, three organization characteristics were identified by the industrial experts as causes of modifications to the industry standard WFP procedure in section 3.3.4:

1. The scope of operation of the organization warranted modifications to the industry standard procedure, to focus on the responsibilities of construction management and the construction contractor;
2. The primary project delivery strategy warranted modifications to the industry standard procedure in the scope and timing of activities, to adapt to the needs of design-bid-build projects; and
3. The typical size of projects warranted modifications to the industry standard procedure in staffing and allocation of responsibilities, in order to adapt to projects of different sizes.

3.3.5 Summary

In summary, section 3.3 presented an investigation of the adaptation of the industry standard WFP procedure at the organization level in the partner organization. The adaptation status of WFP was documented by reviewing both the industry standard procedure and the organization-specific procedure. Findings of the comparison were summarized in Table 3.2. The impact of organization characteristics on the adaptation process was investigated through consultation with industrial experts. Three organization characteristics were identified as causes to the modifications, and their impacts were assessed and documented. The investigation of the adaptation of WFP at the organization level is complete.

3.4 Investigation of the Execution of WFP at the Project Level

This section presents the adaptation of WFP at the project level by reviewing and comparing the organization-specific WFP procedure with the actual WFP process on a case study project. The format of comparison is similar to that of section 3.3. The project manager and WorkFace planner of the case study project were engaged in the study as interviewees. They both have more than 20 years of experience working in the construction industry, and the WorkFace planner has extensive experience with WFP. A project profile form was used to capture project characteristics potentially relevant to the implementation of WFP. The impact of project characteristics on the adaptation process was assessed by consulting the WorkFace planner of the project.

3.4.1 Review of the Implementation of WFP on the Case Study Project

The case study project is an industrial pipeline project sized between $20M and $30M. The project delivery strategy is design-bid-build. The partner organization was the construction manager and construction contractor of the project, and was not involved in the engineering of the project. Detailed project characteristics are illustrated in Table 3.3.

Table 3.3. Project Characteristics of the Case Study Project

Scope of project	Piping and structural construction of a petrochemical plant
Permit requirement/ safety requirement	General permit
Project delivery strategy	Design-bid-build
Role of organization	Construction management/construction contractor
Bidding strategy	Sole sourced
Contract type	Cost reimbursable
Value of contract	$20M to $30M
Labour status	Union
% Completion of design upon call for bid	>95%
% Completion of design upon award of contract	>95%
% Completion of design upon mobilization	>95%
Current state of project	10 days to mobilization
Estimated duration	10 months

The contract requires the use of WFP, and that all FIWP be prepared and submitted to the owner within 60 days of the contract being awarded. According to the project schedule, the time available between the awarding of the contract and mobilization for the development of FIWPs was 30 days. The WorkFace planner of the project has extensive experience working as a general foreman in the discipline of piping and structural, and was responsible for constructing and controlling all FIWPs for the project and performing integration planning and resource monitoring for the packages. The WorkFace planner started dividing EWPs by area and defining boundaries of the FIWPs by system through consultation with the supervision team approximately 45 days before the contract was officially awarded. The WorkFace planner did not size the FIWPs to fit any standards. Instead, the boundaries of FIWPs were based on the size of the engineered products. The owner provided detailed IFC drawings in batches after the awarding of the contract. The WorkFace planner replaced the original non-IFC drawings with the IFC drawings as they became available, and developed an execution plan for each FIWP. No CWPs were developed in the process, and FIWPs were constructed directly from EWPs. FIWP release plans were developed for both piping and structural, and were incorporated into the project schedule. A scaffolding plan was developed according to the FIWP release plan. Orders for material, equipment, and tools were also placed, according to the needs identified by the FIWPs. As of the cut-off time for data collection for the study (i.e., 10 days to mobilization), all FIWPs had been assembled with IFC drawings.

After the project mobilizes, the WorkFace planner will be responsible for WFP coordination, WFP issuance and control, and WFP resource coordination. A management audit of the execution of WFP is scheduled at the end of the project.

3.4.2 Organization-specific Procedure vs. Implementation on Case Study Project

Similar to the previous comparison, the comparison between the organization-specific procedure and the implementation of WFP on the case study project focused on the scope, definition, and use of EWPs and CWPs; staffing and the allocation of responsibilities; the creation, execution, and control of FIWPs; and the timing of activities. Findings of the comparison are summarized in Table 3.4.

Scope of Procedure

The scope of the organization-specific procedure and the scope of the actual WFP process on the case study are highly consistent. The organization was not involved in any design or engineering activities, and WFP activities started in the construction execution phase.

Definition and Use of EWP and CWP

In the organization-specific procedure, CWPs are issued to the contractor by the owner or engineering as the official design document for the development of FIWPs. In the case study project, the organization was issued EWPs, and FIWPs were constructed from EWPs. The results of the discussion with the WorkFace planner indicated that an EWP was used in place of a CWP on the project. Although the definition and use of EWPs and CWPs on the case study project is different from the organization-specific procedure, it complies with the rationale behind the organization-specific procedure that the organization develops FIWPs directly using documents issued by engineering or the client.

Table 3.4. Summary of the Comparison between the Organization-specific WFP Procedure and the Case Study Project

Organization-specific Procedure	Case Study Project	Reason for Modification
Scope of Procedure		
Scope of WFP on the case study project is consistent with the organization-specific procedure		
Definition and Use of EWP and CWP		
Definition and use of EWP and CWP on the case study project is consistent with the organization-specific procedure		
Staffing and Allocation of Responsibilities of WFP		
Staffing and allocation of responsibilities at the project level is not specified	One WorkFace planner is responsible for most WFP tasks	Staff was assigned based on the demand of the workload
Creation, Execution and Control of FIWPs		
FIWPs are sized for one crew to complete in one shift	Sizing of FIWPs is flexible and not bound by any hard standard, system-based packaging	To facilitate easier integration planning and system turnover
Timing of Activities		
One control point for issuance of FIWPs to the field	Started preparation of FIWPs 45 days before award of contract	To ensure readiness of FIWPs upon mobilization

Staffing and Allocation of Responsibilities for WFP

The organization-specific procedure did not define a detailed staffing requirement and allocation of responsibilities at the project level. In the case study project, one dedicated WorkFace planner is responsible for constructing and controlling all FIWPs, performing integration planning, and performing resource coordination. According to the WorkFace planner, staffing decisions were based on the size and scope of the project. As of the cut-off time for data collection for the study, all scheduled WFP tasks in the project have been completed on time.

Creation, Execution, and Control of FIWPs

The organization-specific procedure specifies that FIWPs should be sized to match the equivalent workload of one shift for one crew. In the case study project, on the other hand, FIWPs are not sized to fit any particular standard. According to the WorkFace planner, the boundaries of FIWPs are system-based in the case study project. If an independent component of the project takes 100 man-hours to construct, then it could be a FIWP by itself. The WorkFace planner indicated that the purpose of building system-based packages is to create natural boundaries for FIWPs, and make integration planning and system turnover easier.

Timing of Activities

The organization-specific procedure specifies one control point for the issuance of FIWPs to the field. In the case study project, the WorkFace planner started dividing the scope of work and building FIWPs with non-IFC drawings approximately 45 days before the contract was awarded. Therefore, although the project schedule allowed only 30 days for the preparation of FIWPs between award of contract and mobilization—much shorter than the 60 days preparation time required by the contract and the 120 days preparation time defined in the industry standard procedure—the WorkFace planner, in fact, had 75 days to prepare the FIWPs. According to the WorkFace planner, the early start of WFP activities was to ensure the readiness of the FIWPs upon mobilization.

3.4.3 Impact of Project Characteristics on the Execution of the Organization-Specific WFP Procedure

As shown in Table 3.4, modifications to the organization-specific procedure on the case study project focused on staffing and the allocation of responsibilities; the creation, execution, and control of FIWPs; and the timing of activities. Through consultation with the WorkFace planner of the project, modifications in staffing and the timing of activities were recognized to be attributable to certain characteristics of the project. This section presents the impact of these project characteristics on the field execution of WFP.

Size of Project

The first relevant project characteristic identified by the WorkFace planner is the size of the project. According to the WorkFace planner, the size of the project had a dominating influence on staffing for WFP on the project because it is an indication of the workload of WFP. Since the project is valued between $20M and $30M, the project management team determined that one dedicated staff member is sufficient to perform WFP-related tasks.

Scope of Project

The scope of the project was another project characteristic identified by the WorkFace planner as relevant to staffing for WFP. Since the scope of the project included only two major disciplines and the WorkFace planner had extensive experience in both, no extra staffing was assigned to cover each discipline.

Bidding Strategy

According to the WorkFace planner, the bidding strategy of the project greatly impacted the timing of WFP activities. Since the organization was the only contractor candidate, the WorkFace planner was able to start WFP tasks 45 days before the construction contract was officially awarded, without risking wasting man-hours if the project was bid competitively.

Percentage Completion of Design upon Call for Bid

The last relevant project characteristic identified by the WorkFace planner is the percent of design completion upon the call for bids. According to the WorkFace planner, since 95% of the engineering for the project had been completed upon the call for bids, sufficient design documents could be and were provided to the contractor to start WFP early.

In summary, section 3.4.3 presents four project characteristics that were identified by the WorkFace planner as causes of modifications to the organization-specific WFP procedure:

1. The size of the project determined the anticipated workload of WFP, which supported the project management team's decision on staffing for WFP;
2. The scope of the project contained two major disciplines. Since the WorkFace planner is experienced in both disciplines, no extra staffing was assigned to cover each discipline;
3. The bidding strategy of the project facilitated an early start of WFP activities. Since the project is sole-sourced, the organization was able to start WFP activities before a contract was awarded, without taking excessive risks; and
4. The high percentage of design completion upon the call for bids provided the organization with materials that enabled it to start WFP activities early.

3.4.4 Summary

Section 3.4 documented the field execution of the organization-specific WFP procedure on a case study project. The findings of the comparison were summarized in Table 3.4. Four project characteristics that impacted the adaptation process were recognized by consulting the WorkFace planner of the project, and the impacts of the project characteristics were documented in section 3.4.3.

3.5 Conclusion

In conclusion, chapter 3 investigated the adaptation of the industry best practice of WFP at the organization level and then at the project level. The adaptation statuses were documented by performing comparisons, first between the industry standard WFP procedure and the organization-specific procedure, and then between the organization-specific procedure and the actual WFP process on a case study project. Organization and project characteristics that led to modifications during the adaptation processes were identified, and their impacts were documented. While the current study only covered the adaptation of WFP in one organization and one case study project, the methodology used for the investigation could be generalized to study the adaptation of WFP in other companies and projects, and the adaptation of other industry best practices.

CHAPTER 4: DEVELOPMENT OF A MATHEMATICAL MODEL TO ASSESS THE EFFECTIVENESS OF WFP[1]

4.1 Introduction

Similar to other initiatives that aim to improve project performance, the cost-benefit analysis of WFP is of great interest to both academia and the industry. An empirical estimate by the industry showed that a potential improvement of 25% in labour productivity can be achieved with the implementation of WFP. Assuming labour costs constitute 40% of TIC and WFP adds 2% to labour cost, the potential net savings resulting from the use of WFP is 9.2% of TIC, which gives a return on investment (ROI) ratio of over 1000% (COAA 2012a). However, there have been no mathematical models with reasonable rigor developed to confirm the estimate by the industry. To demonstrate the effectiveness of WFP and confirm the industry's estimate, this chapter presents a mathematical model that quantitatively evaluates the impact of WFP on the reduction of variance in labour productivity (VLP) and its associated costs. The focus of this chapter is on the mathematical formulation of the model, and an overview of the next steps in model development is included in the discussion section of the chapter.

[1] Parts of this chapter have been published in Peng, J., Fayek, A.R., Mohamed A., Kennett, C. (2012). "Exploring the Impact of WorkFace Planning on Labour Productivity Variance Mitigation on Industrial Construction Projects." *Proc. Construction Research Congress 2012*, ASCE, 2376-2385.

4.2 Literature Review

4.2.1 Measurement of Productivity and Variance in Productivity

Measurements of productivity and variance in productivity are fundamental to the proposed model. Neil (1982) suggested that ideal, or potential, productivity can be calculated by taking the product of the actual productivity with one plus the sum of a series of adjustment factors divided by the area productivity index, or:

$$\text{Potential Productivity} = \text{Actual Productivity} * \left(\frac{1 + \sum \text{adjustment factors}}{\text{area productivity index}}\right)$$

[Equation 4.1]

The adjustment factors are estimated based on ratings of different aspects of the project, and the area productivity index reflects the impact of the geographic location and footprint of the project on productivity (Neil 1982).

In contrast to Neil, Thomas and Kramer (1987) proposed a factor based model where:

$$\begin{aligned}\text{Actual Productivity} & \\ &= \text{Ideal Productivity} + \text{Variance from Factor 1} \\ &+ \text{Variance from Factor 2} + \cdots + \text{Variance from Factor n}\end{aligned}$$

[Equation 4.2]

Thomas and Kramer's model considers the impact on productivity of each factor individually to determine the variance in productivity from each factor. The actual productivity is then calculated as the summation of ideal productivity and the variance in productivity from each factor. This concept of a factor based productivity model is adopted in the proposed model to calculate the consequences of VLP.

4.2.2 Factors Affecting Labour Productivity

Labour productivity and the factors that affect it have been studied extensively in the field of construction research. A number of studies have contributed to a list of causes of VLP. Liberda et al. (2003) identified 49 factors that affect construction productivity, and categorized and prioritized them into human, external, and management factors. Through meetings with craft workers and their immediate supervisors, Dai et al. (2009) identified 83 factors that affect labour productivity, and then prioritized the factors via surveys. As a result, they identified 10 latent factors that affect labour productivity. Rivas et al. (2011) performed an analysis of the 38 factors identified by Borcherding and Alarcón (1991) to determine their relative importance.

Besides studies that focus on the comprehensive list of factors, several studies have focused on the impact of isolated factors on labour productivity:

1. Hanna et al. (2005) studied the impact of extended overtime on construction labour productivity.
2. Moselhi et al. (2005) studied the impact of change orders on labour productivity.
3. Ibbs (2005) studied the impact of change's timing on labour productivity.

4. Horman and Thomas (2005) studied the impact of inventory buffers on labour productivity.
5. Hanna et al. (2007) studied the impact of overmanning on mechanical and sheet metal labour productivity.
6. Chang et al. (2007) studied the impact of schedule compression on labour productivity for mechanical and sheet metal contractors.
7. Hanna et al. (2008) studied the impact of shift work on labour productivity for labour intensive contractors.
8. Zhai et al. (2009) studied the impact of automation and integration of construction information systems on labour productivity.

Since the proposed model seeks to link the implementation of WFP to mitigating VLP by examining the factors affecting labour productivity, factors and ranking of the factors identified from the above studies will be considered in the implementation of the model.

4.3 Mathematical Formulation of the Model

The model has been structured to document the individual occurrences of VLP, and group their consequences according to their causes (factors affecting labour productivity). The conceptual basis of this model is the factor-based productivity model developed by Thomas and Kramer (1987).

4.3.1 Definition of Variables

Table 4.1 contains the definition of all the variables used in the model.

Table 4.1. Definition of Variables

Variable	Unit	Description
$V_{i,j}$	N/A	Consequence of a specific occurrence j of VLP caused by i
$X_{i,j}$	mhrs	Man-hour variance of VLP of a specific occurrence j of VLP caused by i
$Y_{i,j}$	$	Monetary variance associated with VLP of a specific occurrence j of VLP caused by i
V_T	N/A	Total consequence of VLP for a project
X_T	mhrs	Man-hour component of V_T
Y_T	$	Cost component of V_T
V_W	N/A	Total amount of mitigated consequence of VLP from the implementation of WFP
X_W	mhrs	Man-hour component of V_W
Y_W	$	Cost component of V_W
V_P	N/A	Total potential consequence of VLP for a project without WFP
X_P	mhrs	Man-hour component of V_P
Y_P	$	Cost component of V_P
VLP	mhrs	Variance in labour productivity, difference between actual man-hours spent and budgeted man-hours for the same amount of output

4.3.2 Definition of Labour Productivity, Variance in Labour Productivity, and the Consequence of Variance in Labour Productivity

Historically, productivity has been measured either as the ratio of input over output, or the inverse of it (Thomas et al. 1990). In this model, labour productivity is measured as the amount of man-hour input required to produce a unit amount of output. Subsequently, variance in labour productivity (VLP) is defined as the difference between actual man-hours (mhrs) spent and budgeted man-hours for the same amount of output.

$$VLP = Actual\ Manhours\ Spent - Budgeted\ Manhours$$

[Equation 4.3]

There are two components to the consequence of VLP: direct variance in man-hours (represented in mhrs), and extra costs associated with such variance (represented in dollars). In the case when extra costs are spent to prevent the loss of labour productivity, the costs will also be included in the consequence of VLP, although the man-hour component of such consequence could be 0. In other words, although the man-hour component and the monetary component are related, they are different entities. An example is when required materials are not ordered on time, and in order to save labour costs and maintain productivity levels, a rush material order is made and incurs $4000 of extra cost. The consequence of VLP can be symbolized as:

$$V_{i,j} = (X_{i,j}, Y_{i,j})$$

[Equation 4.4]

where V is the consequence of VLP; X is the man-hour component of the consequence; and Y is the monetary component of the consequence. Subscript i identifies the cause of VLP and subscript *j* identifies the specific occurrence of VLP with respect to cause *i*. A positive X value indicates overspent man-hours, and a positive Y value indicates monetary losses.

For instance, if a project took 5000 extra man-hours to complete, and incurred \$1,000,000 extra cost due to the VLP, then $V = (5000,\ 1000000)$. Within the total consequence of VLP, if delayed material orders (*i*) caused 500 overspent man-hours and \$125,000 of subsequent extra cost; then V_i for material delay is $(500, 125000)$. Furthermore, if one specific material order (*j*) was delayed, and caused 70 overspent man-hours and \$20,000 of extra cost, then $V_{i,j}$ for this specific occurrence is $(70,\ 20000)$. Another example would be when a rush material order (*j*) was made to avoid wasting man-hours and incurred \$4,000 of extra cost with no overspent man-hours, then $V_{i,j} = (0, 4000)$. With the above equation, the consequence of VLP with respect to a specific cause *i* can be represented as:

$$V_i = \sum_{1}^{j} V_{i,j} = (\sum_{1}^{j} X_{i,j}, \sum_{1}^{j} Y_{i,j})$$

[Equation 4.5]

The total consequence of VLP of the entire project is then:

$$V_T = \sum_{1}^{i} V_i = \sum_{1}^{i} \sum_{1}^{j} V_{i,j}$$

[Equation 4.6]

For any project, $(X_T \leq 0, Y_T \leq 0)$ is the most desirable consequence. For any occurrence of VLP, $(x_{i,j} \leq 0, y_{i,j} \leq 0)$ is desirable.

Similar to the calculation of V_T, the total amount of consequence mitigated by the implementation of WFP, V_W, is calculated as:

$$V_W = \sum_1^i V_{Wi} = \sum_1^i \sum_1^j V_{Wi,j}$$

[Equation 4.7]

where V_{Wi} is the consequence mitigated by WFP with respect to specific causes of VLP. For instance, if through "identifying new methods of construction" WFP saved 800 man-hours and $50,000 for the project, then $V_{W1} = (-800, -50000)$; and if through "identifying opportunities to place material orders in advance and in bulk" WFP saved 20 man-hours and $40,000, then $V_{W2} = (-20, -40000)$.

If the above-mentioned aspects are the only contributions of WFP to mitigating VLP, then: $V_W = V_{W1} + V_{W2} = (-820, -90000)$, and the total amount of consequence mitigated by WFP is 820 man-hours and $90,000.

4.3.3 Mechanism for Evaluation

To evaluate the impact of WFP on VLP mitigation, both V_T and V_W will be calculated for a targeted project, or components of a project, depending on the scope of the evaluation. V_T provides the project benchmark for actual consequence of VLP, and V_W is a measure of the effectiveness of the WFP program with respect to VLP mitigation. Each occurrence of mitigated VLP that can be credited to V_W and each occurrence of VLP that contributes to V_T will be captured individually. For instance, if the consequence of the VLP mitigated by "WFP identifying material shortages in advance and placing orders on time" is (X_1, Y_1), then it can be broken down to $\left(\left(X_{1,1} + X_{1,2} + X_{1,3} + \cdots + X_{1,j_1}\right), \left(Y_{1,1} + Y_{1,2} + Y_{1,3} + \cdots + Y_{1,j_1}\right)\right)$.

There exist two types of VLP mitigation associated with V_W. The first type is when WFP identifies a confirmed threat or challenge to completing construction as planned and solves the challenge. In this case the variance mitigated by WFP is $(-X_{i,j}, -Y_{i,j})$, where $(X_{i,j}, Y_{i,j})$ represents the potential labour productivity loss and associated cost if WFP does not identify and solve the challenge. However, this type of variance mitigation may not be reflected in V_T, because the project may not have experienced any variances. The second type of VLP mitigation is when WFP identifies an opportunity and takes advantage of the opportunity to improve labour productivity, in which case the improvements in labour productivity and cost will be included in V_T as well as in V_W. In the end, V_T and V_W can be combined in the following equation:

$$V_P = V_T - V_W = Total\ Potential\ Consequence\ of\ VLP\ without\ WFP$$

[Equation 4.8]

The ratio of $\left(\frac{V_W}{V_P}\right)$ is the effectiveness ratio of WFP. For example, if $\left\{\left(\frac{X_W}{X_P}\right), \left(\frac{Y_W}{Y_P}\right)\right\} = (-0.3, -0.4)$, then during construction, the WFP program has potentially mitigated 30% of total VLP and 40% of subsequent cost variances.

The last component to the mathematical formulation is the cost benefit analysis. Both the man-hour component and cost component of V_W will be compared against the total cost of implementing WFP (*C*), which includes all direct cost (such as wage of WorkFace planners) and indirect cost (such as office and camp space for the WFP team) items associated with the implementation of WFP. The cost-benefit performance of the WFP program will be measured as

$$\left(\frac{\mathrm{V}_W}{\mathrm{C}}\right) = \left(\left(\frac{\mathrm{X}_W}{\mathrm{C}}\right), \left(\frac{\mathrm{Y}_W}{\mathrm{C}}\right)\right).$$

[Equation 4.9]

If $\left(\frac{\mathrm{Y}_W}{\mathrm{C}}\right) \leq -1$, the direct monetary benefit associated with mitigated VLP alone pays off the cost of implementing WFP. The ratio $\left(\frac{\mathrm{X}_W}{\mathrm{C}}\right)$ on the other hand, indicates how many man-hours the WFP program is saving per unit cost. An example would be if the total cost of implementing WFP is $100000, and $V_W = (-2000, -180000)$, then $\left(\frac{\mathrm{V}_W}{\mathrm{C}}\right) = (-0.02, -1.8\,)$. The direct ROI of WFP with respect to VLP mitigation is 80%, and the man-hours saved per dollar of cost is 0.02 mhrs.

4.4 Discussion

The proposed model captures the impact of WFP on VLP mitigation by quantifying the consequences of WFP-related VLP mitigation by occurrence and grouping them by causes of VLP. The strengths of the model include: (1) it is logical and quantitative, and therefore, is potentially capable of providing an accurate estimate of the impact of WFP on project performance; (2) the impact of WFP on VLP mitigation can be quantified within a project, thus eliminating the need to perform comparative case studies to prove the effectiveness of WFP; (3)

it treats the benefits of WFP in labour productivity and costs as related but separate entities, and therefore considers more than only savings in labour cost as presented in the industry's estimate.

Similar to any mathematical models, the strategy for data collection is crucial to the success of the proposed model. The next steps in model development following the mathematical formulation are also just as important. As such, they both warrant brief discussion in this chapter.

4.4.1 Data Collection Requirements

Data on V_T and V_W can be collected from the industrial partners' projects through a combination of reviewing project files, cost reports, and time sheets generated by the construction management team. Additional data collection instruments to extract project information can be utilized as necessary, including direct observation of the WFP process; conducting field interviews and surveys with crews, onsite supervision staff, construction management staff and WFP staff; and embedding a log system into the WFP process to document WFP activities.

4.4.2 Next Steps in Model Development

While the mathematical formulation is core to the model, it can only be applied to construction projects when its supporting elements are completed. This section provides a brief overview of the next steps in the development of the model. The steps include: identification of causes of VLP, establishment of connections between WFP and causes of VLP, and establishment of qualification criteria for project selection.

Identification of Causes of VLP

This step of the model shall build upon the work of Liberda et al. (2003), Dai et al. (2009), and Rivas et al. (2011) to identify a list of factors affecting labour productivity that are most relevant to industrial construction projects. Once the list is constructed, it shall be assessed through surveys and discussions with industrial experts, and condensed or expanded as necessary.

Establishment of Connections between WFP and Causes of VLP

To assess the impact of WFP on VLP mitigation, it is necessary to define in advance the logical connection between WFP and causes of VLP. The list of factors shall be filtered and verified by interviewing construction experts and practitioners of WFP. A list of factors (causes of VLP) that could be improved with the implementation of WFP shall then be generated and ranked based on the strength of the connections. The rationale of the connections between WFP and the factors shall be documented. A predefined rating threshold shall be used to eliminate weak and unconfirmed connections.

Establishment of Qualification Criteria for Project Selection

Before evaluating the impact of WFP on VLP mitigation, the quality of the candidate projects' WFP programs shall be assessed and documented by being audited against the industry standard WFP model as well as the contractor's own WFP model. A scorecard shall be used to document the results of the audits. Only the highest-scoring projects with scores no lower than a predefined threshold shall qualify for quantitative evaluation. If modifications to the standard models were made to accommodate specific project conditions, the impact and justification of the modifications shall be assessed and documented. This step shall make sure that the projects conform reasonably to the established procedures and that the impact of "poorly executed WFP" on the quantitative results is mitigated. During project execution, the implementation of WFP on the projects shall be constantly observed and documented for future reference.

4.5 Conclusion

Studying the quantitative impact of WFP on project performance of industrial construction projects is crucial to revealing the potential of WFP and establishing a benchmark for the evaluation of WFP practices on future projects. This chapter presented a mathematical model that quantitatively estimates the impact of WFP on VLP mitigation, which is critical to improving the productivity performance of industrial construction projects. The model is also capable of performing cost-benefit analyses of the WFP programs with respect to VLP mitigation.

Future work on the model includes the following steps: (1) identify causes of VLP in industrial projects; (2) establish the connections between WFP and causes of VLP; (3) establish the criteria for the selection of projects to study; (4) perform pilot studies using the model and make adjustments accordingly; (5) validate the model; and (6) conduct case studies on actual construction projects using the model.

Based on the findings of the proposed model, future research could address the following potential topics: (1) comparison of the labour productivity performance of projects that implement varying levels of WFP, including those that do not use WFP at all; (2) construction of a WFP assessment database and establishment of benchmarks to assess the performance of WFP under different circumstances; (3) exploration of the optimal application of WFP, and exploration of other benefits of WFP on industrial construction projects.

CHAPTER 5: CONCLUSIONS AND FUTURE RESEARCH

5.1 Conclusions

Effective planning is crucial to all industrial construction projects, but is not always easy to achieve due to the complexity and uncertainties inherent to the projects. As such, WorkFace Planning was developed to promote and facilitate effective construction planning and resource coordination. However, since different organization and project contexts demand slightly different planning strategies, the adaptation of WFP at the organization and project levels needs to be investigated. Also, being a productivity improvement initiative, the economic effectiveness of WFP needs to be investigated to accurately estimate its potential and evaluate the quality of implementation on actual projects.

The current study addressed both problems stated above. The study investigated the adaptation of WFP at the organization and project levels by first comparing the industry standard WFP procedure with an organization-specific WFP procedure to identify any variations and any organization attributes that caused the variations. Then, with the same methodology, the study investigated the adaptation of WFP at the project level on a case study project. Findings of the study showed that modifications were made to the standard procedures at both the organization and project levels to incorporate the impacts of context variables, such as “scope of operation,” “primary project delivery strategy” and "typical size of project" at the organization level; and "size of project," "scope of project," and "bidding strategy" at the project level. A mathematical model was then proposed to quantitatively estimate the benefits of WFP associated with VLP mitigation, and subsequently facilitate cost-benefit analyses of WFP.

5.2 Contributions and Limitations of the Study

This study has made several contributions to both academia and the industry, and these contributions are concentrated mainly in four areas:

1. The methodology developed here to study the adaptation of WFP at the organization and project levels can be used to research the adaptation of any industry best practices;
2. The investigation and documentation of the adaptation of WFP at the organization and project levels contributed to the WFP body of knowledge, and provided reference to assist in the future implementation of WFP in the industry;
3. The identification of the impact of various organization and project characteristics on the adaptation of WFP offered a contextual perspective to apply and examine WFP; and
4. The proposed mathematical model set the theoretical basis for the quantitative evaluation of the effectiveness of WFP.

However, as the study was conducted, limitations of the study were also identified. Since findings of the study were based on a single organization and a single case study project, generalizability of the findings has not been verified. Therefore, more case studies need to be conducted with companies and projects that have different attributes than the ones studied here, in order to validate and add to the findings of the current study, and to generalize the findings to aid future applications of WFP.

5.3 Recommendations for Future Work

Following the successful completion of the current study, the following topics could be pursued in the future:

1. Investigation of the adaptation of WFP in various companies and projects, and in companies that hold various project management roles (e.g., owner, engineering, EPC organization);
2. Construction of a database containing organization and project characteristics that impact the adaptation of WFP, and documentation of any warranted modifications;
3. Modularization of WFP procedure at each step of WFP for different contexts; adaptation of WFP on different projects through different module assemblies;
4. Inclusion of WFP performance data in industry-wide benchmarking systems;
5. Investigation of the adaptation of other industry best practices at the organization and project levels, using methodologies developed in the current study; and

6. Further development and validation of the model to quantitatively evaluate the impact of WFP on project performance, which includes:
    a) Identifying causes of VLP, establishing connections between WFP and causes of VLP, and establishing qualification criteria for project selection;
    b) Performing pilot studies using the model, and making adjustments accordingly;
    c) Validating the model by performing case studies and collecting feedback from industrial experts; and
    d) Applying the mathematical model, once it has been validated, to industrial construction projects to evaluate the effectiveness of WFP and to conduct cost-benefit analyses.
7. After the model is fully developed and validated, research challenges that can be addressed using the model include:
    a) Comparison of the labour productivity performance of projects that implement varying levels of WFP, including those that do not use WFP at all; and
    b) Construction of a WFP assessment database and establishment of benchmarks to assess the performance of WFP under different circumstances.

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Appendix A: Generic Interview Form Used to Study the Adaptation of WFP at the Organization Level

SECTION 1: Basic Information	
Name:	
Current position:	
Contact information:	Email:
	Cell Phone:
	Work Phone:
YOE* in the industry:	
YOE current position:	
YOE with the Organization:	
Responsibilities associated with your current position:	
SECTION 2: General Understanding of WFP	
What is WFP?	What's the rationale and components of WFP?
What is your understanding of the industry standard approach to implementing WFP?	

What is a FIWP and who is responsible for building FIWPs?	
What is a CWP and who is responsible for defining the scope of CWPs? Who is responsible for building the CWPs?	
How do you relate the responsibility of your position to WFP?	
SECTION 3: Personal Experience with WFP	
What formal training have you received on WFP?	Name of the program, provider, duration, contents, and certificate?
What experience have you had with WFP (both planning and execution)?	
How do you like the idea of WFP?	Do you believe in the idea of WFP? Why or why not?
SECTION 4: The Organization's WFP Program	

What is your understanding of the organization's established WFP procedure?	
Is the established procedure being followed in practice? If not, what is the actual procedure?	
What is your role in WFP under the current organizational structure?	
How do you think the current procedure is performing?	What are the KPIs? Any Data available?
What do you see as the advantages of the current procedure?	What benefits have you realized?
What do you see as the shortfalls of the current procedure?	What difficulties have you experienced?
What do you envision as the ideal WFP in terms of process and result?	

Open Ended Questions:	
Researcher's Comments	

*YOE – Years of Experience

Appendix B: Project Specific Interview Form Used to Study the Adaptation of WFP at the Project Level

1. Have you been provided the organization's standard WFP procedure to perform WFP? (If not, why? What is the reference material used for WFP?)
2. Have you been provided any formal training either from within the company or outside to perform WFP? (If not, why?)
3. What is your current position and what are the WFP related responsibilities associated with your position on the current project? (If inconsistent with the organization standard procedure, why?)
4. Are there dedicated WorkFace planners on the current project? (If not, why?)
5. Who defines the scope of CWPs on your current project?
6. Who divides the scope of CWPs/EWPs into FIWPs? (If inconsistent with the organization standard procedure, why?)
7. Who packages the FIWPs? (If inconsistent with the organization standard procedure, why?)

8. Are there designated resource coordinators (materials, equipment, scaffolding, etc.) that are responsible for coordinating and securing resources for WFP (or the FIWPs)?
9. Who is directly in charge of the WFP program on the current project?
10. How big are the FIWPs on the current project? What are the deciding criteria?
11. Who is coordinating all the FIWPs on the current project, including developing FIWP release plan (If inconsistent with the organization standard procedure, why?)
12. Who approves the FIWP release plan?
13. Is the FIWP release plan linked to the project schedule?
14. When are FIWPs ready for release (with respect to the schedule start time of the work)?
15. Are all CWPs from all disciplines broken down to FIWPs for execution? (If not, why?)

16. Are the standard templates used for the construction and management of FIWPs? (If not, why?)
17. Who manages all the FIWPs prior to start of the work and who are the FIWPs issued to?
18. When are the FIWPs released to the field? (How long before physical work starts?)
19. How are the FIWPs maintained after issue to the field? (progress report, RFIs, NCRs, FCNs, QC documents, package recycle upon completion)
20. How are FIWPs closed?
21. What happens if a package is partially completed by the time it is scheduled to be closed?
22. How are documents maintained after FIWPs are completed?
23. How are lessons learned documented? Are there any feedback log or documentation mechanism?

24. Has there been any internal audits on the implementation of WFP on the current project?
25. Has the procedure used on the current project been approved by home office prior to implementation?
26. Overall, Is WFP effective on the current project? Please justify your answer.

Appendix C: Project Profile Form Used to Study the Adaptation of WFP at the Project Level

Project Name:	
Scope of Project:	
Owner:	
EP/EPC Firm:	
Construction Contractor:	
Labour Status:	
Permit Requirement/Safety Requirement:	
Location and Area Footprint:	
Current Value of Project:	
Budget for Direct Cost:	
Budget for Indirect Cost:	
Contract Type:	
Procurement Strategy:	
Bidding Strategy:	
Date of Contract Award:	
Date of Mobilization:	
Estimated Duration:	
Completion of Design when Budget if Fixed:	
Completion of Design when Schedule is Fixed:	
Completion of Design at the Time of bid:	
Completion of Design upon Mobilization:	
Current Progress:	

Current Manpower:	
Peak Manpower:	
*Design Complexity of Project:	Very Low/Low/Medium/High/Very High
Construction Complexity of Project:	Very Low/Low/Medium/High/Very High
Construction's involvement in Design:	None/Low/Medium/High/Extensive
Repetitiveness of Work:	Very Low/Low/Medium/High/Very High
Schedule Criticality:	Very Low/Low/Medium/High/Very High
Budget Criticality:	Very Low/Low/Medium/High/Very High
Volume of Work Available in the Market:	Very Low/Low/Medium/High/Very High
Competitiveness of the Market:	Very Low/Low/Medium/High/Very High
Competency of Workforce:	Low/Below Average/Average/Above Average/High
Competency of PM Team:	Low/Below Average/Average/Above Average/High

*Qualitative Responses require further justification