# A Framework to Assess the Costs and Benefits of Utilizing Advanced Work Packaging (AWP) in Industrial Construction

By

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## Abstract

The emergence of large mega projects in industrial construction has necessitated the development of more sophisticated construction planning and project control methods. One of the methods developed by the construction industry institute (CII) is advanced work packaging (AWP). The term advanced work packaging refers to a disciplined process for project planning and execution; it was developed to address challenges such as cost and schedule overruns in the industrial construction sector. AWP aims to minimize potential productivity losses stemming from poor coordination and planning by utilizing early project planning, which integrates work packaging with engineering, procurement, construction, and project controls. Furthermore, AWP was designed to reduce the burden of work packaging on field supervision by dealing with constraints as early as possible. Case studies conducted on AWP report a number of benefits in the areas of productivity, cost, safety, and schedule. However, since there is no clear method to assess the costs and benefits of AWP implementation, a significant challenge in AWP adoption is the lack of quantitative evidence to support these reported benefits.

This research presents a structured framework to assess multiple aspects of AWP implementation, which will enable the quantification of both its costs and benefits. Moreover, this framework will allow for projects in which AWP has been implemented to be assessed against those that do not use AWP. The framework provides a systematic approach for measuring AWP maturity, AWP additional costs, workface planner qualifications, foreman and crew characteristics, problem sources, and performance metrics. In addition, the research presents a methodology for the analysis of data collected using the framework in order to help construction organizations assess the costs associated with implementing AWP, and to identify the levels of AWP implementation leading to improved project performance. This research makes a contribution to the industrial construction sector by providing a first-of-its kind framework and methodology to assess various aspects of AWP implementation and to quantify the benefits associated with implementing AWP in practice.

## Preface

This thesis is an original work by Yonas Halala. The research project, of which this dissertation is based on, received research ethics approval from the University of Alberta Research Ethics Board, Project Name “Measuring the Impacts of Advanced Work Packaging on Work Package and Project Performance”, Study ID: Pro00070723, approved on February 07, 2017.

Parts of this thesis’s chapters have been submitted for publication as Halala, Y., and Fayek, A. Robinson. (2017). “A Framework to Assess the Costs and Benefits of Advanced Work Packaging”, in review, submitted January 30, 2018. I was responsible for the major parts of the data collection, analysis and the composition of the manuscript. A. Robinson Fayek was the supervisory author and was involved with concept formation, composition and editing of the manuscript.

## Dedication

This thesis is dedicated to God. I appreciate the good gifts you have given me; a great family, an amazing wife and good friends. I am thankful that I get to know more of you every day. Thanks

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# CHAPTER 1 – INTRODUCTION

## 1.1 Background

Two primary objectives in a construction project are to complete the project on time and within the allocated budget. To achieve these two objectives a plan and a control system to manage the process is necessary. A plan establishes goals for a project's schedule, cost, and resource use and specifies the activities and methods utilized to carry out the work intended. A control system on the other hand collects feedback on the progress of the construction project and compares the progress to the existing plan for informed decision making and to highlight special problem areas needing attention (Rasdorf and Abudayyeh 1992). Many different methods have been used for planning and control systems; these include work package methods (Isaac et al. 2017; Ponticelli et al. 2015), building information modeling (BIM) methods (Cavka et al. 2017; Liu et al. 2015), activity-based job costing methods (Kim and Ballard 2001), lean construction methods (Dave et al. 2016; Ansah et al. 2016), and database framework methods (Batselier and Vanhoucke 2015; Cho et al. 2013).

The Work Packaging Model was developed by the National Aeronautics and Space Administration (NASA) and the Department of Defense (DOD) for design build projects in the aerospace and defense industries (Rasdorf and Abudayyeh 1992). It relies on the work breakdown structure (WBS) for breaking down a project into manageable work packages that have well-defined scopes of work. All construction models aim to address some key issues in construction. Among these key issues some of the prominent ones include cost, schedule, and performance. Thus, it is to be expected that the control of cost, schedule, and performance is an important concern in the construction industry (Rasdorf and Abudayyeh 1992). Initially cost and schedule were considered separately leading to a distributed approach that is characterized by a distributed information system (DIS) which relies on various independent documents (Cho et al. 2013). The documents include bill of quantities (BOQ), budget report, cash flow, detailed cost estimate, and cost breakdown structure (CBS) for cost control; master, bar chart, network, and work breakdown structure (WBS) for schedule control; S-curve, payment report, and earned value methods (EVMs) for performance control; and contractor documents, job specifications, and organization breakdown structure (OBs) for contractor control (Cho et al. 2013). DIS usually leads to inefficient project control, redundant forms and processes, and substantial overhead efforts (Cho et al. 2013). Consequently, DIS is associated with low productivity, conflict, redundancy, and fragmentation (Cho et al. 2013). Thus, the efficient integration of cost and schedule control was proposed as a solution to problems that plague the construction industry characterized by a distributed system (Cho et al. 2013; Rasdorf and Abudayyeh 1992). While the integration of cost and schedule control is not a new concept (Rasdorf and Abudayyeh 1992), attempts at creating an ideal integration system have proved difficult, and a distributed approach has prevailed leaving cost-schedule integration as an unsolved problem (Cho et al. 2013). Cost and schedule integration has remained a major challenge over the past five decades (Cho et al. 2013). With increasing project complexity, development of new methods and improvement of existing methods for planning and control are necessary. This is especially true in industrial construction, where the emergence of mega projects requires the use of more sophisticated levels of planning and control.

The growing size and complexity of construction projects has led to the development of more sophisticated scheduling and planning methods. In 2011, the Construction Industry Institute (CII), along with Construction Owner's Association of Alberta (COAA), chartered research team 272 (RT-272) to review existing work packaging practices, and to develop a project planning and execution model representing industry best practices. The research team developed a lifecycle execution model, which provides work packaging steps and considerations for each project phase, from project definition to project turnover. The model was based upon industry practices from the literature, team experience, case studies, and expert interviews. The model developed by RT-272 came to be known as AWP. AWP, as defined by CII, is "a planned, executable process that encompasses the work on an engineering, procurement and construction project, beginning with initial planning and continuing through detailed design and construction execution" (CII 2013a, CII 2016).

The need for AWP has arisen from the growth in the size of construction projects exemplified by the emergence of large industrial projects and mega projects. These large-scale projects differ from smaller-scale projects in terms of their level of complexity and require a more sophisticated level of planning. As a result, organizations that are stakeholders in such large-scale projects, such as CII and COAA, have been at the forefront in the development of AWP. According to CII, while all construction projects utilized some method of work packaging to divide the scope of a project into manageable portions, AWP provides an organized and structured approach to planning throughout the project lifecycle. Hamdi (2013) stated that before AWP development, a common standard for work packaging was not uniformly implemented within the North American capital projects construction industry. Using AWP, projects are planned early on to integrate work packaging with engineering, procurement, construction, and project control. In AWP, engineering and construction collaborate in pre-project planning, as opposed to construction getting involved after completion of the design phase, thus reducing possible constructability challenges.

One of the challenges AWP was intended to address is the large amount of rework contractors face due to poor field planning and poor coordination between engineering and construction. AWP was proposed to prevent potential productivity losses stemming from poor coordination and planning by utilizing early project planning, which integrates work packaging with engineering, procurement, construction, and project controls. Furthermore, AWP was designed to reduce the burden of work packaging on field supervision by dealing with constraints as early as possible. AWP utilizes workface planning (WFP), which is the process of organizing and delivering all the components necessary for the construction of installation work packages (IWPs) before project commencement. AWP uses engineering work packages (EWPs) to develop construction work packages (CWPs) which are broken down into IWPs for on-site construction. WFP was initially developed to overcome challenges related to cost overruns in front-end planning, design, procurement, and construction in large industrial projects, such as oil sands projects (Hamdi 2013). WFP was one of the top 10 areas for construction productivity improvement on Alberta oil and gas construction projects (Jergeas 2010). Additionally, Jergeas (2010) surveyed industry professionals from owner organizations; engineering, procurement, and construction management (EPC/ EPCM) firms; and construction contractors to identify critical target areas or factors for improving productivity. Addressing the challenges of front-end planning was considered an important component to improve productivity on Alberta oil and gas construction projects. The relationship between AWP and WFP is shown in Figure 1.

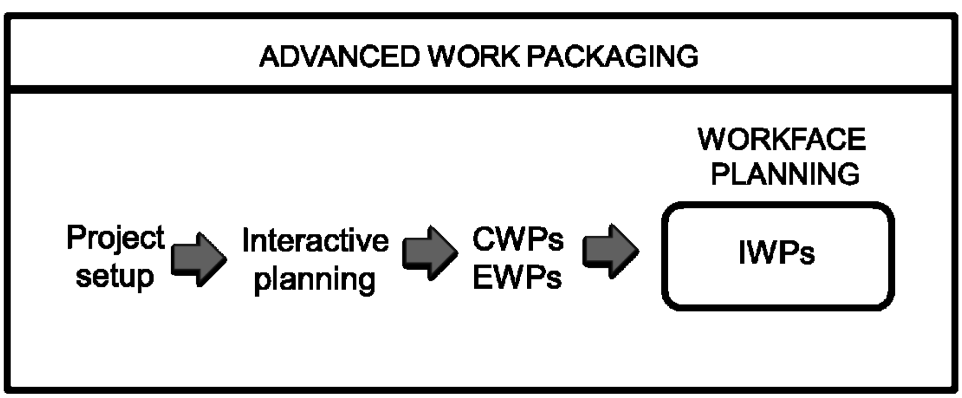


Figure 1. Relationship between AWP and WFP

The benefits attributed to AWP are based on case studies conducted on companies that implemented AWP to different degrees. While the level of implementation of work packaging varied, every company reported multiple benefits that they attributed to AWP. Benefits reported by case study participants included improved labor productivity, increased quality, reduced rework, improved safety performance, and improved client satisfaction. On the other hand, weaknesses of the initial AWP process included risks associated with communication breakdown between construction and engineering, ideal assumptions in developing the model, ideal constraint management, and lack of metrics to measure the effectiveness of AWP implementation. In the literature review portion of this thesis, the research conducted by CII in concert with COAA will be discussed separately from other literature, as this work covers a significant portion of the available literature with respect to AWP. Literature outside of CII is reviewed first and a range of studies carried out by other researchers on the topic of integrated planning and advanced work packaging are discussed.

## 1.2 Problem Statement

Industrial construction is one area where the scope and cost of construction is usually very large as compared to building construction. Almost no two projects are exactly alike, thus challenges encountered during industrial construction are sometimes unique to the project as compared to other industries such as manufacturing or agriculture. Industrial construction is associated with a wide range in size and scope of projects as well as very high cost of construction. The amount of cost involved has necessitated the use of different methods to solve the problems associated with the scope and size increase that occurs in industrial construction. Researchers have developed methods based on tools such as programming and BIM to give a solution to some of the complicated problems faced in planning large industrial mega projects. One of the challenges addressed by these methods was integrating schedule and cost control as opposed to the distributed approach, which was claimed to be the source of the problems that plagued the construction industry (Cho et al. 2013). This desire for integration led to a wide array of methods that were proposed under the umbrella “integrated” planning approaches. One of these methods, Advanced Work Packaging (AWP), was developed by CII as a solution to problems such as cost and schedule overruns. Qualitative data from case studies conducted by CII indicate that AWP significantly improves productivity, cost, safety, and schedule and quality performance (CII 2015). AWP implementation requires additional project costs including hiring AWP dedicated employees, additional man-hours from existing employees to execute AWP specific tasks, and training for personnel on the project. Previous research does not consider these costs directly. However, a quantitative step by step method to asses these reported benefits and the associated costs is necessary to determine whether AWP implementation has a positive return on investment (ROI).

If the costs of AWP outweigh the benefits of AWP it is not practical to implement an AWP program. . Another significant challenge in AWP adoption is the lack of quantitative evidence to support the reported benefits of AWP.

Ponticelli et al. (2015) conducted research on AWP based on two case studies with similar systems constructed in parallel using AWP and non-AWP methods. The results of both case studies showed that the systems constructed using AWP performed better than their non-AWP counterparts in the areas of cost, schedule, and safety. However, the authors did not consider the effect of workface planners, foremen, and crew performance on AWP implementation, and the individuals in the case studies were assumed to be identical. The variation in qualification levels of workface planners, foremen, and crews impacts AWP performance and thus should be considered when assessing AWP benefits. Furthermore, different problems can occur on construction projects, which affect the success of the project, irrespective of the method of planning and scheduling adopted. Considering these problems in evaluating the performance of projects implementing AWP is one component that is lacking in AWP research. The following section discusses the research objectives and steps undertaken to develop the framework in this thesis.

## 1.3 Research Objectives

The hypothesis of this research is that in order to assess the costs and benefits of AWP implementation on industrial construction projects, a structured framework is required to calculate the return on investment (ROI) of AWP implementation. The overall objective of this research is to provide a structured framework to assess various components of AWP that affect its implementation, the associated costs and benefits, and the return on investment (ROI) of AWP implementation on industrial construction projects. The costs and benefits of AWP implementation are determined while considering the impact of workface planner, crew, and foreman performance. In addition, the impact of project problems that influence project success irrespective of planning method is considered. By using the forms provided and following the steps outlined in this research, organizations can analyze their own AWP processes and determine the costs as well as the benefits of implementing AWP. Afterwards the AWP process can be compared to the planning process previously used by the organization, to assess the utility of AWP. To achieve the overall objective, this research has the following sub-objectives:

1. Develop a method to assess the maturity of an AWP/WFP program. The performance of AWP for varying levels of maturity is expected to be different, as such, the maturity of

AWP is calculated and used to study the relationship between AWP maturity and project performance.

2. Develop a method to assess the indirect costs associated with implementing an AWP/WFP program and distinguishing such costs from other project indirect costs.
3. Develop a method to characterise the qualifications of workface planners, crews, and foremen and study their impact on AWP implementation.
4. Develop metrics to assess the impacts of an AWP/WFP program on the performance of individual work packages and/or construction work packages (CWP). The metrics developed are used to compare the performance of AWP programs with varying levels of maturity as well as to compare AWP and non-AWP projects.
5. Develop data collection forms and a systematic data collection methodology to assess the costs and impacts of an AWP/WFP program.
6. Develop a data analysis method to analyze each data collection form. The aggregated values obtained from the data analysis of the forms are used as inputs in the structured framework developed.
7. Test the developed framework to assess the costs and benefits of utilizing an AWP program on an industrial project.

## 1.4 Expected Contributions

This thesis is intended to provide contributions that will positively impact the industrial construction industry in Canada. Some of the contributions will benefit future researchers and are classified under academic contributions, while some contributions will primarily benefit the industrial construction sector and are discussed under industrial contributions.

### 1.4.1 Academic Contributions

The expected academic contributions of this research include:

- Contribute to the body of knowledge related to AWP as a tool for the improvement of productivity, cost and schedule performance in the industrial construction sector.
- Develop a method to identify and calculate the additional costs associated with implementing AWP in construction in comparison to the benefits of AWP. Once the costs and benefits are calculated, the return on investment (ROI) of AWP can be determined. The ROI can be used in future research to compare AWP versus other methods used for construction planning and control.

- Develop metrics to assess the impacts of an AWP program on the performance of work packages and the project as a whole. The metrics developed can be used in future research to compare AWP project performance against non-AWP projects.
- Develop a framework to assess the cost and benefit of implementing AWP. The developed framework will provide a step by step method to analyze the utility of implementing an AWP program.

### 1.4.2 Industrial Contributions

The expected industrial contributions of this research include:

- Provide a quantitative method to measure AWP costs and benefits which can justify the reported qualitative benefits of AWP and present evidence for increased AWP implementation on industrial construction projects.
- Provide industrial construction companies with a tool that can be used to assess the maturity of their AWP process.
- Provide a better understanding of the costs associated with AWP implementation to owners and EPCs.

## 1.5 Research Methodology

The following steps were followed to develop the framework presented in this thesis. First, a literature review of AWP and closely related methods was conducted to identify the status of AWP research and the implementation of AWP in the industrial construction industry. Utilizing the information obtained from the literature review different data collection forms were developed to assess different components of AWP implementation. The data collection forms developed include the (1) AWP maturity assessment; (2) AWP additional costs; (3) workface planner qualification characterization; (4) crew and foreman characterization; (5) problem sources; and (6) key performance indicators (KPIs) forms. For the AWP maturity assessment form criteria and scales for assessing the maturity of AWP on different construction projects was compiled. The AWP maturity form is used to account for the fact that AWP maturity on a construction project will influence the level of AWP implementation, which in turn affects project performance. The AWP additional costs forms are used to calculate the additional costs due to AWP implementation. The costs associated with AWP need to be compared with the saving in cost to accurately quantify the cost benefits of an AWP program. Thus, a method for assessing the costs associated with AWP was developed. The crew and workface planners that are responsible for the implementation of AWP play an important role in the outcome of AWP implementation. To account for this the workface planner, crew and foreman qualification characterization forms were developed to characterize the workface planners, crew, and foreman implementing the AWP program. External factors that affect project performance such as unexpected weather conditions are considered in the problems sources form. To assess the cost and benefit of AWP key performance indicators to assess the impacts of implementing AWP on schedule performance, cost performance, field productivity, predictability, rework, and other performance measures were developed. The data collection forms were developed based on the literature review to collect the data necessary to assess the maturity of AWP, determine the additional costs due to AWP, characterize crews and workface planners, assess problem sources that affect project performance and gather information related to the metrics associated with AWP implementation. Once the data collection forms were developed the data collection methodology was tested on an industrial construction project and data was collected from the project using the forms developed. The collected data from the pilot industrial construction project was analyzed using data analysis methods developed for each data collection form. Using the data collection forms a framework to assess the cost and benefit of implementing AWP was presented.

## 1.6 Thesis Organization

**Chapter 1** provides background information about this thesis. In addition, Chapter 1 discusses the expected contributions and methodology of the research.

**Chapter 2** provides a literature review of cost and schedule control methods. The chapter discusses various types of methods adopted in the construction industry to address construction planning and execution. AWP literature is discussed as one of these methods in-depth.

**Chapter 3** presents the data collection forms developed for the AWP framework. The basis for these data collection forms and the data collection and analysis method is also discussed in this chapter

**Chapter 4** illustrates the framework developed using a case study and demonstrates the data analysis to calculate the cost, benefit, maturity, and performance of AWP. This chapter also presents the framework developed to calculate the costs and benefits of AWP implementation using the results of the data analysis.

**Chapter 5** describes the conclusions, contributions, and the limitations of the study, as well as recommendations for future research.

# CHAPTER 2 – LITERATURE REVIEW[1]

## 2.1 A Literature Review of Integrated Planning Methods for Cost and Schedule Control

Outside of CII literature, the term advanced work packaging (AWP) is not common. However, literature related to identifying the challenges associated with work packages and developing methods to solve them does exist. Several authors have tried to provide solutions to challenges associated with work packaging and workface planning. Tang et al. (2014) hypothesized that minimizing the size of work packages and increasing the frequency of progress monitoring stabilizes workflow variability. This stabilization according to Tang et al. (2014) enables the timely and proactive correction of deviations from the baseline. Tang et al. (2014) discussed the shortcomings of traditional project control approaches such as critical path method (CPM) and earned value management (EVM). According to Tang et al. (2014), CPM and EVM focus mainly on the logical constraints between tasks and showed limited consideration of the use and location of resources during the execution of planned tasks. Tang et al. (2014) mentioned that new planning and project methods are being developed to overcome the limitations of CPM and EVM. One of the methods discussed was the lean construction approach, which was conceived from lean manufacturing. Pre-fabrication, modularization, pull-scheduling, and integrated project delivery techniques were methods mentioned by Tang et al. (2014) and are associated with increased efficiency and more stable workflows. The approach suggested by Tang et al. (2014) is a data-driven planning and control approach for work planning and monitoring. This method works alongside processes for accumulating productivity data in a historical database in order to reveal the most likely production rate of crews. Cost-planning uses the historical database rates to determine the appropriate amount of resources necessary for the quantity of work. Schedule-planning, on the other hand, estimates the duration of activities based on the available resources. Following project execution, the project team works with data analysts to synthesize the productivity data and update the historical database. Tang et al. (2014) stated that continuously updated databases enable more reliable project planning and effective controls in future projects.

[1] Based on Halala, Y., Gerami Seresht, N., and Fayek, A. Robinson. (2016). *"Assessing the Advantages of Advanced Work Packaging (AWP) in Construction: A Literature Review".* Technical Report submitted to Construction Owners Association of Alberta, Edmonton, Alberta, October 5, 2016, 31 pp., NSERC IRC SCMD: Advanced Work Packaging Literature Review_Rev.1/COAA/2016-TD-02.

Rasdorf and Abudayyeh (1991) discussed using the work-packaging model to integrate the control of cost and schedule. According to the authors, cost and schedule control are two of the most important functions in the construction industry and their integration is a possible solution to problems facing the construction industry. A plan and a control system are discussed as essential components to manage a construction project. The plan establishes goals such as schedule, cost, resource use, and tasks to be achieved along with the work methods to be utilized. The control system collects actual data on the project performance with respect to the goals in the plan and makes decisions based on the analysis of such data. Rasdorf and Abudayyeh (1991) attributed the necessity of an integrated cost and schedule control system to collecting quality data in a timely fashion for decision making and for providing a reliable historical database for the planning of future projects. The authors stated that the integration of cost and schedule is hampered by the differing level of detail adopted by the work breakdown structure (WBS) and the cost breakdown structure (CBS). Rasdorf and Abudayyeh (1991) commented that linking the WBS and CBS using a work-elements concept leads to improved project control, but retaining the WBS and CBS adds to the overhead costs of cost and schedule control. Rasdorf and Abudayyeh (1991) presented the work package model as the model most likely to achieve the desired cost and schedule integration. The work package model relies on the WBS to break the project down into manageable smaller work packages (Rasdorf and Abudayyeh 1991). Cost data are added to the WBS in the work package cost and schedule integration method, which allows for the elimination of the CBS. The authors mentioned that the amount of data needed at a detailed level for the WBS is so large that it has caused resistance in the adoption of the work package model.

Hu and Mohamed (2013) presented a construction planning system that enabled variable resource allocation and variable durations in the execution of work packages for industrial construction projects. The system also accounted for logic relationships and space congestion constraints. The need for such a system was attributed to the complex nature of industrial construction. Work packages often overlap in industrial construction projects, causing interference between work packages. This interference could lead to resource over-allocation and space conflict and was one of the challenges the study tried to address with the developed system. Another challenge tackled by the system was the limited and variable resource availability encountered by industrial projects due to the typical remote locations of such projects. As a result of resource availability and necessity for different kinds of resources, the resource level assigned to work packages is not fixed. Moreover, the duration for a work package is also variable and durations can be shortened or extended as the resource level increases or decreases. The system proposed by Hu and Mohammed (2013) is a congestion-constrained, dynamic resource allocation scheduling framework (CRDASS), which uses time-stepped simulation technology. The system enables variation in resource availability or allocation in every simulation time unit (hour, day, week, etc.). From a case study done on an industrial project, Hu and Mohamed (2013) determined that the system was able to reduce resource idle time as well as shortening the project duration compared to traditional scheduling approaches.

The shortcomings of the traditional methods of scheduling for industrial projects in which spatial factors play a critical role was a basis for Semenov et al. (2010) to develop an advanced visual scheduling method (VSM) for solving the generally constrained project scheduling problem (GCPSP). This method takes into account spatial factors such as product element collisions, missing of supporting neighbouring elements, and workspace congestion. The proposed VSM method is intended to solve the GCPSP problem iteratively by alternating and combing three underlying phases (Semenov et al. 2010):

1. Planning Phase—the user forms a work breakdown structure for the whole project. Precedence relationships, resource utilization limits, and spatial constraints are considered.
2. Scheduling Phase—a resource constrained scheduling problem (RCPSP) posed by the project is solved using existing methods as well as the optimistic assumption that spatial constraints are automatically satisfied.
3. Modelling Phase—the current schedule is visually simulated and checked against spatial constraints. If all the constraints are satisfied, the GCPSP problem has been solved. Otherwise, the method returns to the planning phase and revises iterations until all the constraints have been satisfied.

To validate the proposed VSM method a prototype system was used to conduct a series of computational experiments for industrial projects. A drawback to the developed by Semenov et al. (2010) is the amount of CPU resources required for the simulation and the solution of the GCPSP. The authors stated the developed simulation method needed to be optimized for real world application.

Building Information Modeling (BIM) has been utilized to propose an integrated scheduling approach (Liu et al. 2015). The authors stated that “the extended use of BIM has not reached its full potential” and mentioned that in most cases BIM functions as a database of 3D building components rather than being utilized for automatic generation of project schedules (Liu et al.

2015). Furthermore, according to Liu et al. (2015) resource constraints which must be taken into account for scheduling at the activity level are overlooked in BIM-based scheduling and optimization technology is not integrated with BIM. The method proposed by Liu et al. (2015) facilitates the automatic generation of optimized activity –level construction schedules for building projects under resource constraints. To achieve this goal BIM product models were integrated in-depth with work package information, process simulations and optimization algorithms. The proposed approach can automatically extract rich product information from BIM models and work packaging information from Microsoft (MS) Access Database and use these as inputs to perform simulation based scheduling (Liu et al. 2015). Two capabilities of BIM were mentioned by (Liu et al. 2015) to justify the use of the method for the aforementioned purposes: (1) BIM is able to store all the information pertaining to a facility and (2) BIM can facilitate information exchanges and interoperability between software applications during the project life cycle. These two capabilities enable BIM to allow for structural and schedule planning analysis as well as enhanced communication and collaboration among project participants (Liu et al. 2015). Zhang and Gao (2013) while discussing project time and cost control using BIM indicate that significant changes need to be made to the traditional plan-build-operate lifecycle of a project to make full use of BIM. Additionally, the authors indicated the start of BIM increases a firm’s cost and requires a steep learning curve, which may limit the use of BIM (Zhang and Gao 2013).

Ibrahim et al. (2009) discussed the challenges of traditional data collection on the progress of construction projects such as high costs and lack of sufficient frequency for data control. To address the challenges, Ibrahim et al. (2009) proposed a framework for the automatic generation of work packages as well as a system that employs computer vision (CV) techniques to report on the progress of these work packages. Automating the planning aspect of work packages requires the identification of the appropriate level of detail at which progress is assessed (Ibrahim et al. 2009). Ibrahim et al. (2009) chose the WBS structure as a basis for developing an integrated system that aimed to provide a much more responsive, observation-driven feedback for progress monitoring. There were two objectives to be met: (1) integrating a means of modelling and assigning components two work packages based on precise criteria and (2) automatically interpreting images acquired on site to assess the state of completion of components, and therefore work package progress (Ibrahim et al. 2009). BIM was utilized as part of the research and the researchers planned to constantly enrich the BIM model by automatically feeding it progress information and enabling the state of the project to be captured at any given time. Ibrahim et al. (2009) discussed the challenges in the application of compute vision (CV) and the key problem of recognizing objects and structures in unconstrained site images. The authors alluded to previous work where they employed an iconic image matching algorithm for detection based on the Hausdorff distance between training samples that was able to successfully highlight the presence and locations of components visible in a scene (Ibrahim et al. 2009). Ibrahim et al. (2009) stated while detection of components is a useful first step it does not provide information as to the fundamental change to components or the regions around them. To address this point the authors in the paper focused on developing algorithms for recognizing such changes as key events in a sequence of photographs during construction (Ibrahim et al. 2009). The dynamics of progress assessment hinge on the observance of change defined within CV algorithms either as a departure from a prior model or the difference between images taken at different times. The visual assessment module was intended to interface with the BIM model and provide, for a particular set of images, its assessment of completed components, and the dates at which they underwent significant change (Ibrahim et al. 2009). The collated information can be used to generate on-demand progress reports as feedback to the project manager (Ibrahim et al. 2009). In order to identify the necessary components for the automated work packaging framework Ibrahim et al. (2009) conducted a survey to identify the most frequently used criteria in the formulation of the WBS. The authors chose to use BIM to develop the method for automation generation of work packages due to the ability of BIM to store vast amount of information in computer interpretable format (Ibrahim et al. 2009). The authors proposed a conceptual model that would enable the generation of automatic work packages and developed a pilot prototype to realize the model. The limitations of the framework developed by Ibrahim et al. (2009) include an inability of the framework to represent construction aids such as scaffolding, formwork and tools which may be required in the formulation of the WBS. The identification of these components is a challenge that is difficult to address using the framework due to the arbitrary and complex possibilities in construction. Furthermore, the framework assumes an experienced project manager which poses a challenge to the inexperienced manager.

Cho et al. (2013) proposed a database framework for cost, schedule, and performance data integration. Cho et al. (2013) premised that integration of cost and schedule has been a major challenge in the construction industry over the past five decades. While, a much has been invested in the effort to propose and ideal integration system, a distributed approach is the norm (Cho et al. 2013). Cho et al. (2013) discussed the challenges of integrating cost and schedule data. The main challenge mentioned was the mismatch created in levels of informational hierarchy by the low-level items in traditional BOA representing cost data and the low level items in project schedules (Cho et al. 2013). According to (Cho et al. 2013) previous methods to overcome these data structures compatible focused on distributing the lowest items in BOQ into the lowest schedule item in a network diagram and vice versa. Thus, determining an appropriate level of detail becomes important in integrating cost and schedule information and a number of models have been proposed: (1) WBS- based models, (2) Faceted Classification model, and (3) Work-packaging model (Cho et al. 2013). WBS-based models linking a cost item to a schedule item were proposed by several authors based on the assumption that CBS provides cost functions and WBS provides schedule functions. However, the limited perspectives and level of detail in the hierarchical structure caused a complex data structure, data redundancies, inflexibility in the levels of detail, and a large number of control accounts (Cho et al. 2013). The Faceted classification model proposed was a construction information classification system (CICS) combined with a project coding system (Cho et al. 2013). Based on Uniclass, a classification developed by the Royal Institute of British Architects, Kang and Paulson (1998) proposed a notation system composed of four facets: facility, space, element, and operation. While the proposed CICS addressed a considerable portion of the integration issues associated with WBS-based models, it was appropriate for projects with a relatively small number of zonings and elements and inappropriate for projects that have complex relationships among elemental, organizational, and spatial data (Cho et al. 2013). The last model discussed is the work-packaging model (WPM) which according to the authors has been accepted as the most predominant way to integrate cost and schedule data. To overcome the limitations of a DIS, WPM (1) eliminates CBS, (2) adds cost data in WBS, (3) links WBS items to OBS at the lowest level, and (4) finally formulates a control account (CA) as a common denominator for cost, schedule, and performance data integration (Cho et al. 2013). WPM combines two independent information structures, WBS and OBS, that represent four-dimensional information units, WHERE, WHAT, HOW, and WHO (Cho et al. 2013). Cost Accounts (CA) that are developed include information on WHEN, scope of work, and unit pricings (Cho et al. 2013). While, this method improves on previous efforts it requires a relatively large number of CAs and complex data structure. The method proposed by Cho et al. (2013) was intended to enable the user to access multi-functional, multidimensional, and multiple levels of detail of project execution data with a smaller number of control accounts as compared to the work-packaging model (WPM). The terms for an ideal integration were analyzed and a construction information database framework (CIDF) was proposed. Cho et al. (2013) derived the essential information units, 5W1H (WHAT, WHEN, WHERE< WHO, WHY, and HOW) for a desired integration structure. According to Cho et al. (2013) a simple set of questions are capable of transferring clarified meaning to human communication as opposed to long and meaningless alphanumeric codes. Cho et al. (2013) chose a predefined facet structure having multiple layers of detail based on the essential information units above instead of a single monumental and hierarchical structure. Thus, independent information units can be structured as a facet system and respective independent facets include several levels of detail (Cho et al. 2013). The proposed model named CIDF was explained using examples and compared to the WPM model. A spreadsheet-based OLAP application called cross tabulation was put forward as an aid for implementation of CIDF (Cho et al. 2013).

One of the methods proposed for the scheduling and control of work packages is Advanced Work Packaging (AWP) proposed by the Construction Industry Institute (CII). Ponticelli et al. (2015) conducted a study on AWP based on multiple case studies on two industrial construction projects. The research involved the construction projects with identical scope and one with AWP implementation and the other without. The projects were performed at the same time in neighbouring sites which the author claimed represented a reliable measure of AWP impact. Ponticelli et al. (2015) chose a qualitative methodology for the research conducted utilizing a case based research to investigate the impact of AWP on construction performance. The duration of the first case study project was four months while the duration of the second case study was 12 months. For the first case study the site with AWP was $750,000 below budget, five days early and did not have a recordable incident. The non-AWP site was on budget, on schedule ad had one recordable incident. For the second case study the following results were reported: (1) In terms of cost the site without AWP resulted in budget overruns of $100,000 while the site with AWP was concluded 10% under budget saving $1.5 million, (2) The site with AWP was concluded on schedule while the site without AWP was 3 months behind schedule, (3) The site with AWP reported a lower number of rework while the site without AWP had a higher amount of request for information (RFIs) leading to delay and more rework, (4) While the site with AWP recorded zero safety incidents after one million construction hours the site without AWP reported one recordable injury every month for a total of 12. The study conducted by Ponticelli et al. (2015) does not assess the maturity of the AWP process.

In 2011, the Construction Industry Institute (CII), along with Construction Owner's Association of Alberta (COAA), chartered research team 272 (RT-272) in order to review existing work packaging practices and to develop a model representing industry best practices (CII 2015). After RT-272 completed their work, CII chartered another research team RT-319 under the heading *Making the Case for Advanced Work Packaging as a Standard (Best) Practice*. The purpose of RT-319 was to extend and validate the exploratory findings of RT-272. In the following literature review section, the two-phase research done by RT-272 is discussed, followed by an examination of the research done by RT-319 (CII 2015).

## 2.2 Literature Review of CII and COAA Research in Advanced Work Packaging

RT-272 was originally chartered in 2009 under the heading *Enhanced Work Packaging: Design through Workface Execution*. The second phase of the research was commissioned after CII's annual conference in 2011. The name of the term enhanced work packaging (EWP) was later changed to advanced work packaging (AWP). There were two reasons for this decision: 1) to better characterize the scope of recommendations, and 2) to remove potential confusion with the acronym for engineering work package (EWP) (CII 2015). The research conducted by RT-272 and RT_319 is discussed in detail under separate headings in the following section of this literature review.

### 2.2.1 Definitions

The definitions put forward by CII on AWP in the research summary developed by RT-272 (CII 2013b) are presented below:

*Advanced Work Packaging (AWP)*— "AWP is the overall process flow of all the detailed work packages (EWPs, CWPs and IWPs). It is a planned, executable process that encompasses the work on an engineering, procurement, and construction project, beginning with initial planning and continuing through detailed design and construction execution. AWP provides the framework for productive and progressive construction, and presumes the existence of a construction execution plan."

*Workface Planning (WFP)*— "Workface planning is the process of organizing and delivering all the elements necessary for an installation work package (IWP), before the work is started. This proactive process enables craft workers to perform their work safely, effectively, and efficiently. This is achieved by the breakdown of work into discrete installation work packages that cover the scope of the work completely."

*Engineering Work Package (EWP)*— "An EWP is an engineering and procurement deliverable that is used to create CWPs. The EWP should be aligned with the construction sequence and priorities."

A typical EWP includes the following:

- Scope of work with document list.

- Drawings.
- Installation and material specifications.
- Vendor data.
- Bill of materials.
- Lists (e.g., line lists and equipment lists).

*Construction Work Package (CWP)*— “A construction work package (CWP) defines a logical and manageable division of work within the construction scope. A CWP may be divided by area, system or otherwise, as determined by the project execution plan. CWPs are typically aligned with a bid package and usually contain more than one EWP.”

A typical CWP includes the following:

- Safety requirements.
- At least one EWP.
- Schedule.
- Budget.
- Environmental requirements.
- Quality requirements.
- Special resource requirements.

*Installation Work Package (IWP)*— “An IWP is the deliverable that enables a construction work crew to perform work in a safe, predictable, measurable, and efficient manner. An IWP is typically of limited scope and size such that a crew can complete the work in about a week. All elements necessary to complete the scope of the IWP should be organized and delivered before work is started.”

A typical IWP includes the following:

Work package summary.

- Quantity work sheet.
- Safety hazard analysis.
- Material safety data sheet.
- Drawings.
- Specifications.
- Change documents.

- Manufacturer's installation instructions.
- Model shots.
- Bill of materials.
- Required tools.
- Installation test results forms.
- As-built documentation.
- Inspection checklists.
- Completion verification signatures.

### 2.2.2 Enhanced work packaging: Design through workface execution

According to RT-272, while all construction projects utilized some method of work packaging to divide the scope of a project into manageable portions, EWP provides an organized and structured approach to planning through the project lifecycle (CII 2013a). The burden on field supervisors to plan out the work to be performed within the constraints of the project is reduced by utilizing EWP (CII 2013a). EWP also reduces the burden on field supervision through the packaging of work throughout the project lifecycle and dealing with constraints as early as possible (CII 2013a).

RT-272 noted that, historically, contractors face a large amount of rework; the research team attributed this outcome to poor field planning and poor coordination between engineering and construction (CII 2013a). Low labor productivity was also identified as a serious issue throughout the construction industry. Some of the reasons indicated by RT-272 as contributing to low labor productivity include rework due to poor coordination between engineering and construction and delays resulting from poor planning of material procurement (CII 2013a). The research team indicated that these potential productivity losses stemming from poor coordination and planning can be prevented by utilizing early project planning that integrates work packaging with engineering, procurement, construction, and project controls. From this assessment, RT-272 deduced that the implementation of proper work packaging processes would alleviate the aforementioned problem (CII 2013a). The objectives of the research team were given in six points (CII 2013a):

1. Document the current body of knowledge concerning work packaging and workface planning from academic and industrial literature.
2. Identify and evaluate current work packaging practices, benefits, and barriers in industry.

3. Develop standard definitions for work packaging terminology.
4. Develop an implementation model for effective work packaging throughout the lifecycle of a project.
5. Provide recommendations for the effective implementation of work packaging practices.

The research team developed a lifecycle execution model that provides work packaging steps and considerations for each project phase from project definition to project turnover. The model was based upon industry practices from literature, team experience, case studies, and expert interviews. The research team carried out their research in four phases, as is discussed below (CII 2013a).

#### 2.2.2.1. Phase 1: Exploration

The research team RT-272 consisted of 16 members who were experts in work packaging methods and/ or had extensive knowledge of engineering, procurement, and construction processes. The team was diversified in terms of company type, with four members representing owner companies; eight members representing engineering, procurement, and construction management (EPC/EPCM) firms; one member representing a consulting firm; and three members representing academia. With respect to industry, 50% of the members were from the industrial sector, 12% were from oil and gas, 13% were from power, and 19% were from academia. Cumulatively, the team members possessed 343 years of industry experience, with an average of 26 years in the industry and a cumulative 149 years specifically in workface planning and/or site management. During this phase, the team reviewed the academic and industrial literature and discussed their experiences with work packaging. During the initial meeting, team members shared experiences in areas including approaches used in challenging projects, high-level business practices, as well as practices encountered in seminars, conferences, and literature. The report produced by RT-272 states that the team quickly identified industry needs and trends in best practices following the aforementioned meetings. The literature review done by the research team included contributions from previous CII publications as well as literature from COAA and Lean Construction. In particular, COAA's workface planning committee was utilized as a starting point for the development of definitions, models, and tools. The literature review identified six themes: (1) level of cost benefit, (2) organizational capabilities and roles and responsibilities, (3) new technologies, (4) developing work packages, (5) project lifecycle and turnover, and (6) contract language.

#### 2.2.2.2. Phase 2: Development

Phase two entailed the development of the work package model as well as the case studies and expert interviews. Work packages were evaluated internally by the members of RT-272 and externally through case studies and interviews conducted with experts outside of the research team. The case studies were utilized over other methods, such as surveys, after it was decided they were the best way to acquire a nuanced understanding of the issues related to implementation. The findings from the case studies related to work packaging practices, benefits, and barriers were incorporated into the work packaging model. The development of the work packaging model included the definition of key terms relevant to work packaging, the execution model, and supporting tools. The aim in creating these definitions was to standardize the language related to work packaging, given the wide variation in terms used throughout the construction industry; definitions put forward by COAA, CII, and Lean Construction were considered in the development process.

To develop the work package execution model, the team revisited the high-level trends and recommendations discovered during the exploration phase. This process was undertaken in order to relate the team’s findings to the typical lifecycle of a project, which was divided into four sections: (1) preliminary planning and design, (2) detailed engineering, (3) construction, and (4) installation work packages (IWP) as a focused subset of construction. Team members were assigned to subgroups based on their expertise and interests, and an initial work package execution model was developed by compiling the work of each subgroup. Following an internal review of their findings, narratives, which included scope, assumptions, recommendations, and information requirements, were developed by the subgroups. Next, a finalized combined flowchart was developed by a graphic artist, and the developed narratives were compiled into a single execution model narrative. However, the authors note that the execution model was developed concurrently with the aforementioned case studies and interview questions. RT-272 identified the need for tools to support workface planning, resulting in the development of the following three tools: (1) a project definition assessment tool, (2) an assurance/ audit tool, and (3) an enhanced work packaging scorecard. The assessment tool was developed for companies to enable them to assess their work packaging preparedness and maturity; this tool was developed based on the recommendations made within the execution model. The assurance/ audit tool, which contained 14 discipline-specific checklists, was developed by COAA and included with no modifications by the research team. The scorecard tool was also adapted from a workface planning scorecard published by COAA. The scorecard is a measure of effectiveness in the utilization of workface planning. The academic team members, with the help of the other research team members, developed seven case studies and three expert interviews to explore the various methods of work packaging implementation practices utilized within the industry. A summary of case studies and expert interviews, as well as their areas of contribution to the work package execution model, is shown below in Table 1.

Table 1. Summary of case studies and expert interviews

| ID | Sector & Sub-sector | Construction Duration | Area of Contribution |
|---|---|---|---|
| Case Study 1 | Industrial Power | 24 Months (1M WHours) | Implementation timing |
| Case Study 2 | Industrial Power | 27 Months (1M WHours) | Work packaging systems, Trained planners |
| Case Study 3.1 | Industrial Oil & Gas | 4 Months (80K WHours) | First implementation, Modularized construction |
| Case Study 3.2 | Industrial Oil & Gas | 4 Months (80K WHours) | Poor utilization of work packages, Modularized construction |
| Case Study 3.3 | Industrial Oil & Gas | 4 Months (80K WHours) | Learning curve of work packaging |
| Case Study 3.4 | Industrial Oil & Gas | 4 Months (80K WHours) | Learning curve of work packaging |
| Case Study 4 | Industrial Chemical | 84 months | Evolution of work packaging process |
| Expert Interview 1 | Industrial Many | N/A | Work packaging systems & technology, Formalized procedure |
| Expert Interview 2 | Industrial Many | N/A | Work packaging systems & technology |

| | | | |
|---|---|---|---|
| Expert Interview 3 | Commercial | N/A | Work packaging systems, Lean construction |

The EWP execution model developed by the research team was divided into three stages and was described using a flow chart. These three stages are summarized below:

*Stage I: Preliminary Planning/ Design*

Stage I includes project definition; construction and engineering planning; refining the schedule and WBS development; and CWP and EWP boundary development. Stage I provides an important addition to common practices by detailing several steps in planning for work packaging.

*Stage II: Detailed Engineering*

Stage II includes schedule development, engineering, and detailed construction scheduling. According to the research team, stage II presents a challenge for traditional construction organizations that are not set up to perform EWP. Traditional construction organizations that allow superintendents and foremen to perform detailed planning may be allowing an informal planning process. The EWP model prescribes the use of a workface planner apart from the foreman role to designate and manage IWPs. The workface planner works with field planners to do the work and by doing so, enables them to focus on managing the work and not on detailed planning.

*Stage III: Construction*

Stage III includes IWP development and execution as well as system turn-overs/ start-up and commissioning. The construction process was divided into five steps: (1) IWP creation, (2) document control, (3) issuance to the filed, (4) control in the field, and (5) (at the end) IWP close out.

#### 2.2.2.3. Phase 3: Validation

The validation phase consisted of an external validation of the research findings from the development phase, as well as the validation of the EWP execution model by external industry experts. Eight experts outside of the research team as well as a separate expert group participated in the validation process, which was carried out in an interview format after the experts reviewed the findings from the development phase. Details regarding the backgrounds of the validation experts are given in the report and are summarized below in Table 2.

Table 2. Summary of the background of validation experts

| ID | Area of Expertise | Type of Company | Years of Experience |
|---|---|---|---|
| Expert A | Workface Planning | Consulting | 20 |
| Expert B | Construction | EPC | 22 |
| Expert C | Construction | EPC | 36 |
| Expert D | Workface Planning | Consulting | 19 |
| Expert E | Engineering | EPC | 16 |
| Expert F | Technology | Consulting | 20 |
| Expert G | Construction | EPC | 25 |
| Expert Group H (1) | Construction | Owner | 25 |
| Expert Group H (1) | Construction | Owner | 24 |
| Expert Group H (1) | Construction | Owner | 16 |
| Expert Group H (1) | Construction | Owner | 16 |
| Expert Group H (1) | Construction | Owner | 5 |
| Expert I | Research | Academia | 40 |

The validation experts were asked to identify the strengths and weaknesses of the developed EWP execution model. The strengths of the process emphasized by the experts are listed below:

- Process clearly articulated.
- The model provides guidance, not prescription.
- Work packaging is done through the project lifecycle.
- Accurate cost estimating and tracking.
- Draws workforce around work.
- Constraints are analyzed.
- Proves value of EWP.
- Matches other research efforts of experts in terms of relevance and accuracy.

In contrast, the weaknesses of the process that were identified by the experts are as follows:

- Risks associated with communication breakdown between construction and engineering.

- Ideal assumptions adopted in developing model.
- Current technologies ignored.
- Idealistic constraint management.
- IWP size recommendation idealistic in certain instances.
- Differing levels of authorization were not adopted.
- No metrics to measure the effectiveness and success of EWP implementation such as metrics related to change in cost, productivity, and schedule.
- Broad development of the EWP process model, but not enough depth and details for important aspects of a project such as front-end activities.

The following topics were identified by the study as areas requiring further development in order to enhance the utility of the execution model:

- Evidence—developing quantifiable evidence for a stronger business case in support of EWP.
- Contracting—providing recommendations around contracting strategies.
- Front-end collaboration—provide a more detailed approach to achieve collaboration.
- Organization—provide definitions for different project roles and responsibilities.
- Information Management—provide more details about information management and document control.
- Technologies—provide analysis and recommendations related to current technologies
- Metrics—provide metrics to measure success.
- Tool development—develop additional tools for implementation.

#### 2.2.2.4. Phase 4: Deliverables

The research team delivered four documents at the end of the research effort: the Research Summary (RS) 272-1, the Implementation Resource (IR) 272-2 volume 1 and volume 2, and the Research Report (RR) 272-11. The below list of benefits of EWP was compiled by the research team following a comprehensive review of the literature:

1. Proper work packaging impacts productivity and predictability through enhanced planning.
2. The process of refining construction work packages into crew work packages yields many benefits in the field, including project alignment, communication, control, planning, and productivity.

3. The frontend aspects of workface planning align the construction plans with engineering, procurement, safety, and project controls.
4. When workface planning is utilized, project estimates and progress reports are more accurate due to the small and manageable size of work packages.
5. Work packaging supports proper long-term and short-term planning to occur prior to work being performed.
6. Proper workface planning ensures the resources needed by work crews are available when needed.
7. Removing constraints by planning results in increased productivity due to the availability of material and plans as well as by improving crew motivation.

Using EWP, projects are planned early on to integrate work packaging with engineering, procurement, construction, and project control. Ten case studies were conducted on companies that implemented work packaging to some degree. While the level of implementation of work packaging varied, the research team indicated that every company reported multiple benefits that they attributed to work packaging and workface planning. The benefits reported by each company were documented by the research team. The following list contains the high-level findings and benefits of work packaging and workface planning reported by the companies involved in the case studies:

1. Improved project party alignment and collaboration.
2. Project data stored in one location and site paperwork reduced.
3. Issues identified during planning—increased quality and reduced rework.
4. Improved project predictability—cost and schedule.
5. Improved safety awareness and performance.
6. Drives planning and accountability.
7. Supervisors spend more time supervising.
8. Decreased supervisor and craft turnover.
9. Improved labour productivity.
10. Increased reporting accuracy.
11. Enhanced turnover.
12. Improved client satisfaction.

Based on the information obtained from these case studies and from the expert interviews, the research team reported the following benefits of using EWP:

- The engineering team supports the construction sequence and schedule.
- Vendor-supplied equipment remains on schedule.
- Material are purchased and delivered to support construction.
- Communication of specific tasks is improved at the workface.
- Constraints, such as craft availability, material laydown, scaffolding, and issued for construction (IFC) drawings are better managed.
- Work toward closeout and turnover is better controlled.

As mentioned at the beginning of Section 2, the above process of planning, initially called enhanced work packaging (EWP), was renamed as advanced work packaging (AWP) by RT-272. It was indicated that the actual execution of EWP requires planning and discipline and poses a significant learning curve for practitioners. In addition to the models, tools, and case studies developed, RT-272 discussed the following key findings:

1. Successful implementation of the EWP method requires thought, hard work, buy-in, and consistent execution. Lack of commitment will result in poor results.
2. Pre-requisites to the implementation of a work packaging process include effective material management, document control, and project control systems.
3. The designation of a workface planner/ planning lead as a separate role is strongly recommended.

### 2.2.3. Advanced work packaging: From project definition through site execution

RT-272 was commissioned for a second phase of research under the heading *Advanced Work Packaging: From Project Definition through Site Execution* (CII 2016). The second phase of the research was jointly sponsored by CII and COAA to expand the findings of the first phase and to enhance the guidance provided to member organizations. The work done in phase two focused on extending the execution model for AWP with consideration of the implementation challenges documented through surveys and expert interviews carried out both in North America and globally (CII 2016). It was during the second phase that the relationship between the terms advanced work packaging (AWP) and workface planning (WFP) was clarified (CII 2016). WFP was used by COAA to describe the concept related to productivity improvement at the work front. The research team has defined WFP as a sub-process of AWP to clarify research across phases 1 and 2 (CII 2016).

The main objectives of RT-272 during phase two of the research can be summarized in four points (CII 2016):

1. Elaboration of the AWP process to support implementation.
2. Contractual requirements and contracting strategies to include WFP.
3. Maturity assessment to aid general appraisals of implementation quality and help firms identify where to focus implementation efforts.
4. Continued documentation of the evidence supporting workface planning, as well as documentation of implementation barriers and metrics used to support implementation.

The research team performed the research in three phases: (1) Charter Formation, (2) Development, and (3) Deliverables (CII 2016).

#### 2.2.3.1. Phase 1: Charter Formation

During the first meetings, the experience of the members of the research team was outlined. In addition, the team reviewed feedback from the implementation session for the earlier work of RT-272, which was held during the previous CII conference. The research team also reviewed the documentation that was already available as well as supporting COAA documents. The goals for these meetings were as follows:

1. Aligning CII and COAA members' visions and building a common ground for success.
2. Deciding on which deliverables from the previous research needed to be enhanced.

As a result of these early meetings, the team also decided to focus on implementation.

#### 2.2.3.2. Phase 2: Development

Three areas for further research were identified from the previous work done by RT-272:

1. Process.
2. Contracts.
3. Functional capabilities.

The research team was divided into sub-teams based on their experience and preferences regarding the aforementioned three areas. Expert interviews were conducted as part of the development phase. 19 experts were interviewed, with 79% of these individuals representing the oil and gas sector. From the group of the remaining experts, 16% were from the power sector, and 5% were from the technology sector. Another component of the development process was an invitational workshop, conducted by COAA. The workshop was attended by 35 people and covered discussed topics related to the second phase of research conducted by RT-272. A survey was conducted both online and during an implementation workshop at a COAA best practices conference in May 2012 in Edmonton, AB. Validation of the research deliverables was done through external feedback from six industry experts, following their review of the findings and recommendations put forward by RT-272.

#### 2.2.3.3 Phase 3: Deliverables

During the second phase of their research, RT-272 delivered several documents including two reports, three implementation resource volumes, and one research summary. The research team expanded on the three implementation tools developed during the previous phase of their research and included the following set of tools:

- AWP Maturity Model.
- Contractor Qualification Assessment.
- Project Definition Assessment Tool.
- AWP Audit Tool by Phase.
- AWP Project Integration Flowcharts.
- AWP Functional Role Descriptions.
- CWP Template.
- EWP Template.
- IWP Checklist by Discipline.

The AWP Maturity Model is a qualitative description of the capabilities needed by a company to effectively implement AWP. The model was developed based on the common stages of AWP implementation maturity within the industry that were identified during the case studies carried out by RT-272. The maturity model has three levels, with each level describing both work processes as well as project systems. Each level builds on the capabilities of the previous level. The three levels are as follows: Level 1: AWP Business Efficiency; Level 2: AWP Business Effectiveness; and Level 3: AWP Business Transformation.

For the development of the levels of the AWP maturity model, five aspects of a company were examined: (1) front-end planning, (2) front-end engineering deliverables (FEED), (3) detailed engineering, (4) construction, and (5) start-up.

The below topics were suggested as areas for future development following the completion of the second phase of research conducted by RT-272:

- Validation of benefits—develop quantitative evidence that statistically validates the impact of AWP on metrics such as cost, schedule, quality, predictability, and safety.
- Contracting—provide recommendations and contracting strategies.
- Prerequisites—develop a tool that evaluates the ability of companies to successfully implement AWP.
- Front-end alignment—provide more details on front-end collaboration.
- Organizational implication—develop project roles and responsibilities further.
- Information technology—investigate AWP-related IT technologies.
- Process metrics—provide metrics to measure the success of AWP and WFP.
- Generalizability—provide evidence that AWP is applicable on different project sizes and project conditions.
- Lessons learned—systematically document the lessons learned in overcoming implementation challenges.

### 2.2.4 Making the case for advanced work packaging as a standard (best) practice

RT-319 began their research by recounting the achievements of RT-272. They noted that RT-272 found that AWP delivers significant improvements in performance in field productivity, cost and schedule performance, project predictability, as well as related benefits in safety, quality, and project-team alignment (CII 2015). These results were based on the information reported by a set of industrial construction projects in relation to AWP implementation (CII 2015). The industrial construction companies reported performance improvements in six areas: (1) productivity, (2) cost, (3) schedule, (4) safety, (5) quality, and (6) predictability (CII 2015). RT-319 stated that the due to the exploratory and qualitative nature of these findings they did not provide generalizable evidence in connection to the benefits of AWP implementation (CII 2015). RT-319 identified the following research gaps from the work done by RT-272:

- The impact of AWP on project performance lacks validation and generalizability.
- AWP maturity model is not supported by empirical evidence.
- Process checklists and performance metrics related to AWP are incomplete.

The main objectives of RT-319 were to validate the AWP execution model developed by RT-272. With this in mind, RT-319 set out to achieve two research goals: (1) evaluate the relationships between AWP implementation and various dimensions of projects performance, and (2) identify typical AWP implementation pathways and levels of AWP maturity (CII 2015).

The research team used various qualitative and quantitative research methods, such as case studies, surveys, focus groups, and expert interviews, to collect empirical evidence in validating the causal relationship between AWP implementation and improvement of project performance. According to RT-319, the research involved four main phases: (1) charter formation, (2) development based on previous work, (3) methods, and (4) deliverables (CII 2015). The charter formation discussed the research that had previously been conducted on AWP and lessons learned from RT-272. A literature review of construction planning was also conducted during this phase. In the development phase, three areas were identified as thrust areas that would be the focus of the research: (1) AWP Framework, (2) AWP Maturity, and (3) AWP Tools. The following are the research methods adopted for each thrust area respectively, (1) multiple case studies and survey, (2) multiple case studies and focus group, (3) focus group. The thrust areas are discussed below in order starting from the first which is AWP Framework. The AWP Framework includes a set of AWP prerequisites that were deemed necessary for AWP implementation by RT-272 based on case studies. The set of prerequisites includes process adherence, organizational alignment and contract integration (CII 2015). For the AWP Framework in-depth qualitative data from case studies was combined with quantitative data from surveys to provide statistical evidence of results. An analysis of the survey data was conducted to validate the relationship between AWP implementation and the three aforementioned prerequisites. RT-319 set out to address six hypothesis of research proposed by previous qualitative findings:

- Hypothesis 1-2-3: AWP Implementation (AWP) is specified by AWP Process Adherence (PA), Organizational Alignment to AWP (OA), AWP Contract Integration (CI).
- Hypothesis 4-5: AWP Implementation (AWP) is positively related to the achievement of timely and complete Engineering Deliverables (ED) and Project Predictability (PP).
- Hypothesis 6: Timely and Complete Engineering Deliverable (ED) mediates the relationship between AWP Implementation (AWP) and Project Predictability (PP).

To test the hypothesis surveys were developed to gather data related to each hypothesis. Metrics were developed for each hypothesis in line with the principles that characterize the AWP approach. For instance, for AWP implementation a census was undertaken to cover the full scope of this component. Each item in the survey questionnaire was based on a five-point Likert-type scale that indicates level of agreement. Data were collected during two conferences that were

AWP focused in 2014. The data collected in survey format was analyzed using Partial-Least-Square (PLS) which is one of the Structural Equation Modelling (SEM) techniques. According to the authors, the impact of AWP on project predictability was later selected and analyzed, while the other set of performance indicators were not considered due to practical reasons among which time constraints was mentioned as significant. The survey and analysis are further discussed below:

RT319 indicated that the documented case studies show a 25% improvement in productivity and a 10% reduction in total installed cost (TIC) from the implementation of AWP (CII 2015). These claims made by RT-319 were determined qualitatively and were founded on case studies conducted by RT-272 on companies that had implemented AWP. The benefits stated at the beginning of the section were reported by the companies that participated in the case studies. The basis for these claims was determined qualitatively from case studies conducted on companies that implemented AWP. The benefits above were reported by the companies that participated in the case studies. The research team hoped to gather quantitative evidence through a survey to assess the AWP framework and obtain a statistically valid and generalizable result. The survey was conducted at two AWP practitioners' conferences in Edmonton, Alberta and Houston, Texas. Practitioners were given a hand-held response device by which they answered multiple choice questions. Each device had an identification code, which allowed for the aggregation of data by both question and respondent. The analysis of the survey data focused on the impact of AWP on project predictability performance. The survey results were used as a means for validating the AWP assessment framework, and the research team tested two hypotheses for the analysis: (1) process adherence, organizational alignment, and contract integration specifies AWP assessment; and (2) AWP assessment drives timely/ complete engineering deliverables and causes project predictability. The analysis of the survey focused on the impact of AWP on project predictability performance, and the research team chose to test only this dimension for practical reasons. The team selected the partial least square (PLS) statistical technique to test the causality relationship between AWP and project predictability and to analyze the multiple relationships. Information about the survey respondents is shown below in Table 3 and Table 4 (CII 2015).

Table 3. Experience of survey respondents

| Experience (years) | Number of Respondents | Percentage |
|---|---|---|

| | | |
|---|---|---|
| Less than 10 | 20 | 22% |
| Between 10 and 20 | 26 | 28% |
| Between 20 and 30 | 30 | 33 |
| More than 30 | 16 | 17 |
| Total | 92 | 100% |

Table 4. Roles of survey respondents

| Roles | Percentage |
|---|---|
| Constructor | 45% |
| Engineering | 13% |
| Owner | 24% |
| Supply Chain | 5% |
| Other | 13% |

The analysis of the survey produced the following results (CII 2015):

1. AWP is specified by the three prerequisites of process adherence, organization alignment, and contract integration. The results confirmed that these prerequisites are necessary to achieve consistent implementation of AWP.
2. AWP causes timely and complete engineering deliverables. The results showed that AWP influences 25% of time and engineering deliverables; this was marked as a strong effect in relation to the method used for analysis.
3. AWP causes project predictability, measured in terms of time, schedule, and rework. Among the factors influencing project predictability, AWP was found to be the especially significant. The results showed that AWP influences 25% of project predictability, which indicates a strong effect with respect to the method used for analysis.
4. AWP causes both timely and complete engineering deliverables and project predictability, regardless of project size and role of the company.

The research team stated that after performing more than 10 different statistical tests to analyze the data, they found that they all confirmed the validity of the results. The research team concluded that the results from the methods above show that effective AWP implementation leads to consistent improvements in six dimensions of project performance: (1) productivity, (2) cost, (3) safety, (4) schedule, (5) quality, and (6) predictability. Furthermore, the research team discovered that in relation to AWP maturity, the performance of industrial construction organizations adopting AWP typically follows an S-curve pattern. This finding suggests that organizations experience slow improvements in performance in the initial phase of AWP implementation, followed by fast growth in the middle phase, and moderate advances in the final phase of maturity. However, the researchers also noted that even initial implementations of AWP yielded significant benefits.

The second thrust area was the Maturity Model. To determine the relationship between AWP Maturity and project performance data from multiple case studies was analyzed through individual rating and group discussion by experts. First, focus groups that were composed of RT-319 members proposed an extensive set of project performance metrics which were based on literature and mentioned above as the third category of the assessment framework. Secondly, the focus group scored the multiple case studies based on the metrics proposed in the first step. Experts independently rated 5 different case studies to address potential subjective bias. Thirdly, experts rated the maturity level of companies that were part of the case studies versus the three AWP prerequisites mentioned a using a Likert scale. Finally, the pattern between AWP maturity and project performance was analyzed both in isolation for each maturity component as well as the aggregated effect overall. The ratings for different project performance factors of each case study such as productivity were plotted and interpolated with a polynomial fitting line versus the attributed AWP maturity for each case study. RT-319 stated that each project performance factor increases with AWP maturity which provides further confirmation to the relationship between AWP and project performance. The overall project performance score was determined as the geometric average of the six performance factors. This result was also plotted and interpolated with a polynomial fitting line. Two different shapes from the plotted graphs were depicted (1) square root pattern for factors productivity, cost, safety, and schedule (2) exponential pattern for project quality and predictability According to the authors the square root pattern highlights performance improvements that are achieved at an initial fast rate and that decrease at higher levels of AWP maturity. The research methodology and the case studies are discussed below:

The team conducted expert focus groups and utilized the case studies to identify AWP maturity levels. Independent AWP experts in the focus group were asked to evaluate documented AWP implementations in the case studies to explore and empirically validate the AWP maturity model.

The research methodology and tools adopted to achieve the research objectives of validating AWP benefits and identifying maturity levels is provided below in Table 5 (CII 2015).

Table 5. Research methodology adopted by RT-319

| Method | Validate AWP Benefits | Method | Identify AWP Maturity Levels |
|---|---|---|---|
| Case Studies | Investigate AWP implementation | Case Studies | Identify AWP maturity traits |
| | Evaluate benefits related to AWP | | Test AWP maturity model |
| Expert Interviews | Support case study analysis | Focus Group | Collect ratings from AWP experts |
| | Analyze specific AWP processes | | Investigate patterns of relationship between AWP maturity and project performance |
| Survey | Validate AWP benefits | | |

The case studies, expert interviews, and surveys were specifically designed to meet the research objective of validating the benefits of AWP. For the purpose of identifying AWP maturity, the research team analyzed a total of 20 case studies. Of the case studies analyzed, 7 were the initial case studies conducted by RT-272. The research team stated that the case study results are strongly supported by the teams' findings from the expert interviews. More information about the case studies is provided below in Table 6 and Table 7 (CII 2015).

Table 6. Case studies by sector

| Sector | Representation |
|---|---|
| Chemical | 15% (3) |
| Infrastructure | 10% (2) |
| Oil & Gas | 50% (10) |
| Power | 25% (5) |

Table 7. Case studies by size of project

| Size of Project | Percentage |
|---|---|
| Small (<5 Mil.) | 25% (5) |
| Medium (5 - 50 Mil.) | 10% (2) |
| Large (>50 – 500 Mil.) | 35% (7) |
| Mega (>500 Mil.) | 30% (6) |

According to RT-319, the AWP model guides the breakdown of project scope into three main deliverables: (1) construction work packages (CWPs), (2) engineering work packages (EWPs), and (3) installation work packages (IWPs). A graphical representation of AWP is given in which project setup is the first entity. The project setup entity is followed by interactive planning, which leads to CWPs and EWPs. Finally, the model culminates in IWPs, which are also named workface planning. According to this representation, front-end planning and detailed engineering encompass the project Setup to CWPs and EWPs, while IWPs fall under construction commissioning and start-up. However, there are slight overlaps between (1) front-end planning and detailed engineering, and (2) construction commissioning and start-up. Measuring AWP implementation consistently to assess performance results posed a challenge for RT-319. To overcome this challenge, the research team developed an assessment framework that would function as a basis for data collection and analysis. The assessment framework was divided into three categories. The first category assessed the prerequisites to AWP implementation. This first component category contained three antecedents or prerequisites that needed to be accomplished for AWP implementation: (1) process adherence, (2) organizational alignment, and (3) contract integration. The second category assessed the practice of AWP implementation within an organization. The third category assessed the project performance of organizations implementing AWP in six areas: (1) productivity, (2) cost, (3) schedule, (4) safety, (5) quality, and (6) predictability.

The third thrust area, AWP tools, identified detailed AWP checklists and performance metrics that were deemed necessary for AWP effectiveness by RT-319. Two deliverables were produced for this thrust area (1) AWP key Performance Indicators (KPIs) and AWP Maturity Checklists. The deliverables were based on focus groups composed of RT-319 members. The focus group identified, reviewed, and approved detailed AWP implementation prerequisites and process metrics. Afterwards, through discussion and repeated meetings metrics were approved.

Finally, the case studies studied by RT-319 reported several project performance improvements. These improvements were presented by RT-319 and are mentioned below (CII 2015):

1. Productivity—every project implementing AWP reported increased field productivity in comparison with estimates and/or previous similar projects. Case studies on average reported productivity increases of 25% for projects with consistent AWP implementation.
2. Cost—consistent cost savings between 5 to 10 percent of TIC for all projects implementing AWP were observed. It was stated by the researchers that these savings were mostly related to productivity improvements. The case studies also showed that on previous projects without AWP the existence of systematic budget overruns.
3. Safety—all the case studies reported zero lost time accident after more than 25 million construction hours. One reason given for the improved safety performance is the focus of AWP in identifying and mitigating safety issues during planning.
4. Schedule—13 out of 20 of the case studies met the scheduled delivery deadlines while 6 projects delivered ahead of schedule. The schedule improvements were mainly attributed to the improved productivity of construction operations.
5. Quality—the organizations consistently implementing AWP showed enhanced quality of field operations with significant rework reduction.
6. Predictability—the high reliability of the cost, schedule, and quantity estimates due to AWP related to high project predictability according to the research team.

### 2.2.5 Effect of Advanced Work Packaging Implementation on Project Performance

Previous research by the Construction Industry Institute (CII) (2013a, 2015) has revealed that advanced work packaging (AWP) can result in consistent improvements on six performance dimensions of construction projects: (1) construction field productivity, (2) cost, (3) safety, (4) schedule, (5) quality, and (6) predictability. The CII (2013a, 2015) evaluated the effect of AWP implementation on construction project performance through a questionnaire survey using face-to-face or phone interviews. According to CII (2015), the interviewees were occupied in managerial positions in various construction industry sectors and were the most knowledgeable members of their designated organizations on AWP procedure. In 2013, CII (2013a) conducted the survey on four construction projects in the power, oil and gas, and chemical sectors; later in 2015, CII (2015) conducted the survey on 11 construction projects from the power, oil and gas, chemical, and infrastructure sectors. The results of the two surveys revealed that there is a direct correlation between the maturity of AWP implementation in the projects and the project performance measures.

The questionnaire survey was organized to achieve the following goals: (1) identify the background and general characteristics of the projects, (2) evaluate the maturity of AWP implementation, and (3) evaluate the performance of the project under study. The background questions included the interviewee's position in the organization and his/ her experience in AWP. Moreover, the general project characteristics, such as the contract type, industry sector, total project cost, were evaluated in the survey. The maturity of AWP implementation was measured based on the different factors such as the total number of resources assigned for AWP in the project. Finally, five different aspects of the project's performance were evaluated in the questionnaire survey: (1) project productivity, which was measured as the field labour productivity; (2) project cost performance, which was measured considering the project cost overruns; (3) project time performance, which was evaluated considering the project schedule overruns; (4) project safety performance, which was measured as the total number of safety incidents that occurred during the project execution; and (5) project quality performance of the construction team, which was measured considering the total amount of field rework that occurred during the execution. Moreover, project predictability was also reported as an additional benefit of AWP implementation in construction projects. Finally, the questionnaire evaluated the project performance measures in comparison to similar projects executed by the organization in which AWP was not implemented.

Referring to the research conducted by CII (2013a, 2015), AWP enhances six aspects of project performance, as discussed earlier. However, there are some research gaps in the survey design and analysis of the responses, which are discussed below:

1. Referring to the questionnaire survey in some of the case studies, AWP was only implemented with some individual trades (e.g., piping). However, the effects of AWP implementation were analyzed on the total project performance measures.
2. The project performance measures used to evaluate the effect of the AWP on construction projects were selected at the project level. Moreover, the performance of the project in each aspect was expressed only by one factor. However, there are numerous factors other than AWP implementation that may affect construction performance at different levels. For

example, Tsehayae and Fayek (2014) identified 168 factors at the activity, project, and higher levels influencing construction labour productivity. Therefore, improvements in project performance measures at the project level (e.g., field labour productivity) cannot be directly correlated to AWP implementation since there are also other factors influencing project performance.

3. The questionnaire survey designed by CII (2013a, 2015) collected information regarding the maturity of AWP implementation using qualitative measures. However, no information was provided regarding the methodology for analyzing the qualitative measures or for the aggregation methodology used to represent AWP implementation maturity on a numerical scale.
4. The project performance measures were compared to similar projects previously carried out by the organization by utilizing a qualitative scale (i.e., better, equal, or worse performance). However, the quantitative measures that can represent the performance of the project (e.g., total installed cost) were not compared to the previous projects.
5. Project predictability was mentioned as one of the benefits of AWP implementation on construction projects. However, no quantitative or qualitative measures to evaluate the predictability of the projects were discussed in the survey.

Previous research conducted by CII introduces the practice of AWP and reports on the benefits of AWP based on qualitative responses from case studies; it also provides a foundation for the research presented in this thesis, which aims to address some of the remaining gaps. The next chapter discusses the data collection forms developed in this research. The aggregated values from the data analysis of the forms are used as inputs in the AWP framework developed.

# CHAPTER 3 – AWP FRAMEWORK: DATA COLLECTION FORMS[2]

This chapter covers the development of the data collection forms that form the basis of the AWP framework. The analysis of these forms is also addressed in this chapter. The framework consists of six components that comprise the AWP process: (1) AWP maturity assessment; (2) AWP additional costs; (3) workface planner qualification characterization; (4) crew and foreman characterization; (5) problem sources; and (6) key performance indicators (KPIs). Figure 1 shows the components of the framework; each component is assessed using a dedicated data collected form.

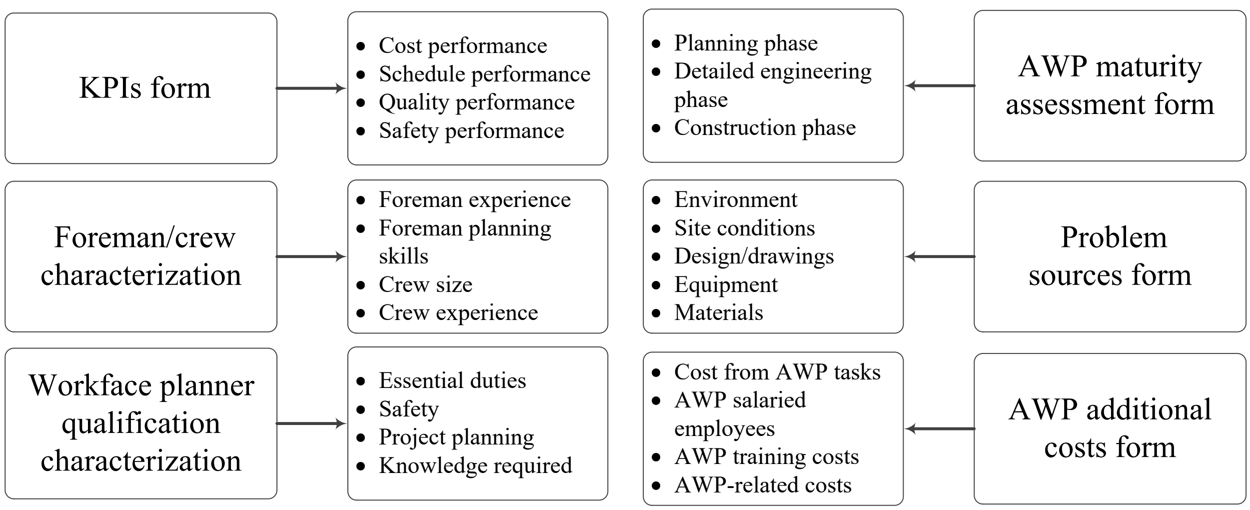


Figure 2. Components of framework to assess AWP costs and benefits

The six data collection forms developed for this research are discussed individually in the following sections.

## 3.1 AWP Maturity Assessment Form

The level of implementation of AWP practices is an important factor when assessing the maturity of AWP on a project. The AWP maturity assessment form was developed based on the AWP Project Integration Flowchart developed by CII (2013b). The AWP Project Integration Flowchart shows AWP and AWP integration practices separately from standard project procedures (CII

[2] Based on Halala, Y., and Fayek, A. Robinson. (2017). *"A Framework to Assess the Costs and Benefits of Advanced Work Packaging".* Manuscript submitted to the *Canadian Journal of Civil Engineering* January 30, 2018.

2013b). These practices were identified, and their level of maturity was assessed. The AWP maturity assessment form evaluates the maturity of AWP in three phases of the project, namely planning, detailed engineering, and construction, which also corresponds to the phases of AWP. The number of criteria assessed in each phase are 50, 24, and 34, respectively.

The data collection form is divided into two sections. The first section gathers general information about the nature of the construction project. In addition, information about the individual responding to the data collection form is collected, including project information, such as name, location, and level of complexity, as well as information describing the respondent, such as duration of employment, age, and experience. The second section presents a list of AWP practices to be evaluated to determine AWP maturity. Two scales, the maturity and importance scales were provided to assess the list of AWP practices. The maturity scale is used to evaluate the extent to which an AWP practice pertaining to a given phase is implemented; implementation can vary within five levels, as shown in Table 8. The importance scale is used to evaluate the level of importance of a particular practice to the overall AWP process, and it can vary within five levels, as shown in Table 9. The importance scale was adopted to reflect the fact that not all practices affect the AWP process to the same extent. A sample of the AWP maturity assessment form is given in Table 10 and the full form is given in Appendix A1.

Table 8. Maturity Scale

| Scale | Scale description |
|---|---|
| Not Applicable | Use of the practice is non-existent on this project |
| Level 1 | Use of the practice is not consistently applied on this project |
| Level 2 | A disciplined process exists for the practice on this project |
| Level 3 | A disciplined process exists for the practice across the different projects within the same organization |
| Level 4 | Quantitative process control is used across the organization to proactively manage the execution of the practice on this project |
| Level 5 | Continuous process improvement is used across the organization to optimize the practice on this project |

Table 9. Importance Scale

| Scale | Scale description |
|---|---|
| 1 | Practice is extremely unimportant to the associated phase |
| 2 | Practice is unimportant to the associated phase |
| 3 | Practice is neither unimportant or important to the associated phase |
| 4 | Practice is important to the associated phase |
| 5 | Practice is extremely important to the associated phase |

Table 10. AWP maturity assessment form sample practices

| No. | AWP practice |
|---|---|
| 1 | Planning phase |
| 1.1 | A documented AWP strategy is in place, and all stakeholders are familiar with the content of the strategy. |
| 1.2 | The contract language includes AWP strategy, plan, procedure, roles and responsibilities. |
| 1.3 | Documented AWP audit protocols have been developed and are being implemented. A process is in place that ensures audit findings are appropriately resolved. |
| 1.4 | An execution plan for detailed engineering and for construction execution has been defined to incorporate AWP. |
| 1.5 | The construction sequencing and contracting plans are identified at the project definition phase. |
| 2 | Detailed engineering phase |
| 2.1 | Prior to the start of detailed engineering, a schedule is developed for all CWPs and EWPs, and it aligns with the agreed upon path of construction. |
| 2.2 | Detailed roles and responsibilities are defined and updated for all stakeholders to support AWP content. |
| 2.3 | Dedicated IWP planner(s) have been identified and a written job description for planners is in place. |
| 2.4 | All planners are on the distribution list for all project documentation or have access to the latest information required for the preparation of IWPs. |

| | |
|---|---|
| 2.5 | The CM appoints dedicated AWP material coordinators. |
| 3 | Construction phase |
| 3.1 | The IWP definition, issuance and control processes are documented and recorded on a regular basis. |
| 3.2 | A process for constraint identification and resolution is in place. |
| 3.3 | Work is always packaged in Installation Work Packages (IWP). |
| 3.4 | IWPs always identify the work to be completed by the team (as indicated by technical data, drawings, and specifications). |
| 3.5 | All IWPs identify the general sequence of the work and the labor necessary to complete the work. |

The data collection process was conducted through a self-completed survey, and potential participants include the AWP manager (at the engineering firm), engineering manager, project manager, construction manager, procurement manager, workface planning lead, superintendent, and foreman/general foreman. This list encompasses participants from all three phases of AWP mentioned above. Participants assessed maturity for their respective phase of involvement. Responses from multiple participants were aggregated to determine an overall maturity score across the three phases of AWP. All responses were weighted equally in the aggregation process.

Once the data were collected, an overall maturity score was determined using a weighted aggregation method. First, the importance score, $R_s^{(h)}$, of each AWP practice $s$ in phase $h$, is obtained according to Equation 1 (Omar and Fayek 2016a).

(1) $$R_s^{(h)} = \frac{\left(A_s^{(h)} * 1 + B_s^{(h)} * 2 + C_s^{(h)} * 3 + D_s^{(h)} * 4 + E_s^{(h)} * 5\right)}{\left(A_s^{(h)} + B_s^{(h)} + C_s^{(h)} + D_s^{(h)} + E_s^{(h)}\right)}, h = 1, \ldots, 3;\ s = 1, \ldots, m_h$$

Where

$A_s^{(h)}$ is the number of respondents rating the AWP practice $s$ in phase $h$ as $1$ (extremely unimportant);

$B_s^{(h)}$ is the number of respondents rating the AWP practice $s$ in phase $h$ as 2 (unimportant);

$C_s^{(h)}$ is the number of respondents rating the AWP practice $s$ in phase $h$ as 3 (neither unimportant nor important);

$D_s^{(h)}$ is the number of respondents rating the AWP practice $s$ in phase $h$ as 4 (important);

$E_s^{(h)}$ is the number of respondents rating the AWP practice $s$ in phase $h$ as 5 (extremely important); and

$m_h$ is the total number of practice in phase $h$.

Second, Equation 2 calculates the mean maturity score, $M_s^{(h)}$, of each AWP practice $s$ in phase $h$, as an average of the maturity scale values assigned by individual respondents (Omar and Fayek 2016a).

(2) $$M_s^{(h)} = \frac{\sum_{i=1}^{n} M_{s,i}^{(h)}}{n^{(h)}},\ h = 1, \dots, 3;\ s = 1, \dots, m_h$$

Where

$n^{(h)}$ number of respondents of AWP maturity assessment form in phase h; and

$M_{s,i}^{(h)}$ is the maturity score value given by the ith respondent to AWP practice s, in phase h

Finally, the aggregated AWP maturity score ($M_{awp}$) that represents the overall AWP maturity of the project is determined, as shown in Equation 3.

(3) $$M_{awp} = \sum_{h=1}^{3} \sum_{s=1}^{m_h} \left( \frac{R_s^{(h)}}{\sum_{z=1}^{3} \sum_{j=1}^{m_z} R_j^{(z)}} \times M_s^{(h)} \right)$$

The AWP maturity assessment form developed is required in the assessment of the correlation between different maturity levels and the resulting AWP performance. Aside from their use in the AWP framework, the results from these forms can be used to assess the level of AWP maturity for an organization that has implemented AWP. The results from the forms can also be used as a tool for improvement by identifying AWP practices with high importance but low maturity.

### 3.2 AWP Additional Costs Form

When AWP is adopted over traditional work packaging approaches, additional costs can be incurred, such as salaries for AWP planners, training for AWP, cost stemming from AWP-specific tasks, and miscellaneous AWP-related costs (e.g., IT costs). The AWP additional cost form contains four components that collect cost information. CII developed AWP project integration flowcharts that show how AWP-specific tasks can be integrated into traditional work packaging tasks (CII 2013b). The AWP integration flowchart depicts tasks common in traditional work packaging separate from AWP tasks. The AWP additional cost form assesses cost incurred from AWP-specific tasks based on this flowchart. If the AWP task was performed by personnel employed for AWP implementation, the salary of the employee was used in determining cost.

The first component gathers information on employees whose responsibilities are dedicated solely to AWP tasks. The second component of the AWP additional cost form is designed to collect the time and cost spent on tasks directly related to AWP by employees with other primary roles on the project (e.g., a project manager). If the AWP task was performed by personnel with responsibilities not dedicated to AWP, the hourly cost was calculated based on time spent on the AWP task. To account for all costs associated with the necessary training for AWP, the third component of the form collects data related to training. In cases where training is specific to the project, additional costs are directly attributed to training. For training provided on an organization level, the cost may be prorated based on the number of projects receiving the training. Finally, the fourth component deals with AWP-related costs, such as recruitment costs, hardware costs, and IT costs, all of which constitute miscellaneous costs accrued as a result of AWP implementation.

The total AWP additional cost ($C_{awp}$) can then be identified as a summation of all these costs over the three phases of AWP, planning, detailed engineering, and construction, as shown by Equation 4.

(4) $C_{awp}$ = Costs from AWP Exclusive Tasks + AWP Salaried Employees + AWP Training Costs + AWP Related Costs

The data collection process was conducted through a survey, which was completed by the owner, project manager, engineering firm, construction manager, supply chain manager, and construction contractor. Costs can be incurred across different phases of a project; therefore, the data collection form requires participation from different stakeholders involved in the various project phases. Data obtained from the AWP additional cost form enables calculation of the total additional costs associated with implementing AWP. The AWP additional costs form gathers costs from 116 AWP-specific tasks, and provides a comprehensive list of costs that can be attributed to AWP implementation. The ideal data collection context for this form is during the construction of a project, and not after the project has been completed. The form requires the determination of duration spent on AWP tasks, which would be more accurate if recorded at the time they are executed.

## 3.3 Workface Planner Qualification Characterization

Workface planners are responsible for issuing the installation work packages (IWP) that form the basis for AWP implementation. The workface planner qualification characterization form assesses the qualities of workface planners using predetermined criteria developed based on the COAA workface planner characterizations (COAA 2016). A total of 44 evaluation criteria for general, material, equipment, and scaffold workface planners was developed using the COAA characterizations. The criteria category is shown in Table 11. The data collection form is divided into two sections. The first section collects general information about the workface planner or supervisor participating in the data collection; this includes information, such as age of the respondent, duration of involvement in the project, and years of experience in workface planning. The second section lists the criteria of a workface planner that are used for evaluation. Two scales of measure are presented: the importance scale and the agreement scale. The importance scale differentiates between criteria used for evaluation by assigning different levels of importance, while the agreement scale measures the level to which the workface planner being evaluated possesses the qualification criteria. The two scales are adopted to reflect the varying importance of different tasks in assessing the characterization of a workface planner. The two scales used are shown in Table 12 and Table 13. A sample of the workface planner qualification characterization form criteria is given in Table 14 and the full form is given in Appendix A3.

Table 11. Workface planner assessment category

| Workface planner assessment category | Number of criteria |
|---|---|
| Essential duties | 9 |
| Safety | 4 |
| Project planning | 9 |
| Knowledge required | 7 |
| Skills required | 8 |
| Other desirable characteristics | 7 |
| Total | 27 |

Table 12. Importance Scale

| Scale | Scale description |
|---|---|
| 1 | Criterion is extremely unimportant for the workface planner qualification characterization |
| 2 | Criterion is unimportant for the workface planner qualification characterization |
| 3 | Criterion is neither unimportant or important for the workface planner qualification characterization |
| 4 | Criterion is important for the workface planner qualification characterization |
| 5 | Criterion is extremely important for the workface planner qualification characterization |

Table 13. Agreement Scale

| Scale | Scale description |
|---|---|
| 1 | Strongly disagree |
| 2 | Disagree |
| 3 | Neither disagree nor agree |
| 4 | Agree |
| 5 | Strongly agree |

Table 14. Workface qualification characterization form sample criteria

| No | Evaluation criteria |
|---|---|
| 1 | Essential duties |
| 1.1 | Ensures that safety, quality and efficiency at the WorkFace are considered in the planning process |
| 1.2 | Uses his/her hands-on construction expertise to develop IWP |

| | |
|---|---|
| 1.3 | Coordinates with and provides WorkFace construction knowledge to project schedulers, engineers, superintendents and managers |
| 1.4 | Acts as liaison between the project controls department and workforce supervision |
| 2 | Safety |
| 2.1 | Knows, understands and communicates the safety regulations (Occupational Health and Safety Act) and project specific safety policies and procedures. |
| 2.2 | Identifies specific risks associated with executing the planned activities |
| 2.3 | Provides or arranges for inclusion of safety compliance in IWP to mitigate specific risks |
| 2.4 | Ensures intended safety requirements are properly conveyed to workforce supervision |
| 3 | Project planning |
| 3.1 | Develops IWP templates |
| 3.2 | Prepares required project IWP, which includes determining required activities, resources, special conditions, quality control, risk planning, interdependencies |
| 3.3 | Determines and coordinates resource requirements and works well with resource coordinators |
| 3.4 | Reviews IWP for completeness and accuracy |
| 4 | Knowledge required |
| 4.1 | Has knowledge of health, safety and environmental programs |
| 4.2 | Knows the company and project environment |
| 4.3 | Is a member of at least one specific construction trade discipline (at a minimum journeyman level), construction specialty, or engineering discipline |
| 4.4 | Knows general construction and materials systems and procedures |
| 5 | Skills required |
| 5.1 | Has good problem solving skills |
| 5.2 | Is able to resolve conflicts |
| 5.3 | Has strong leadership skills |
| 5.4 | Has effective oral and written communication skills |
| 6 | Other desirable characteristics |
| 6.1 | Is willing to accept challenges |
| 6.2 | Is willing to learn |
| 6.3 | Is responsible and accountable |
| 6.4 | Has good work ethic |

The data collection process was conducted through a survey. The workface planner was assessed by his/her direct supervisor(s), such as construction superintendents and workface planning leads. Additionally, the workface planner completed the same survey, but did so as a self-assessment. The responses from the workface planner and the corresponding supervisor were then weighted equally and combined to determine an aggregated score for the workface planner. The aggregated scores of all workface planners were combined to determine the final aggregation score representing all workface planners involved in the project.

In the first step, the importance scale shown in Table 12 is used to determine the importance score, $Y_{l,i}$, for each individual *i* and each qualification criterion $l, l = 1, \dots, k$, where $k$ stands for the total number of qualification criterion, in this case $k$ is equal to 44. Second, the agreement scale shown in Table 13 is used to evaluate the extent to which participants satisfy the criteria being assessed; this is done by assigning an agreement score $P_{l,i}$ for each evaluation criterion $l$ and each individual $i = 1, \dots, n_I$, where $n_I$ is the number of respondents. Third, the characterization score of each workface planner is determined. This score represents the extent to which the evaluated individual possesses the required qualifications based on the criteria provided. The characterization score of individual *i*, denoted by $V_i$, is calculated as a weighted average summation of the agreement score ($P_{l,i}$) weighted by the importance score ($Y_{l,i}$), as shown in Equation 5.

(5) $$V_i = \sum_{l=1}^{k} \left( \frac{Y_{l,i}}{\sum_{j=1}^{k} Y_{j,i}} \ x \ P_{l,i} \right)$$

The characterization scores are determined both for the workface planner self-evaluation and for the evaluation from the supervisor, denoted by $V_i$ and $V_i^{(s)}$, respectively. Once the characterization scores $V_i$ and $V_i^{(s)}$ are calculated, an aggregated characterization score for each of the $n_I$ workface planners, $AV_i, i = 1, \dots, n_I,$ is obtained using Equation 6.

(6) $$AV_i = \frac{\left( V_i + V_i^{(s)} \right)}{2}$$

Finally, all the aggregated characterization scores ($AV$) of the workface planners are aggregated using Equation 7 in order to calculate the final characterization score ($FC$) of all workface planners on a construction project.

(7) $$FC = \frac{1}{n_I} \sum_{i=1}^{n_I} AV_i$$

Workface planners develop IWPs, which are the end product of the AWP process. Since the performance of IWPs directly impacts the AWP process, the performance of workface planners has a direct impact on the performance of AWP. In this research, the FC is one component used in the comparison of construction projects with different levels of AWP implementation.

## 3.4 Crew and Foreman Characterization

Similar to the workface planner, the construction crew and foreman executing IWPs have a direct impact on the performance of IWPs. Twenty-six criteria were used for crew characterization, including crew size, composition, experience, team spirit, skill level, and level of absenteeism (Tsehayae and Fayek 2014). Moreover, 12 criteria were used for foreman characterization, including foreman experience, training, leadership skills, and supervisory skills. Due to the nature of the criteria in the crew and foreman characterization form, some of the criteria have been assigned unique predetermined ratings. Some criteria, such as number of crew members, required numerical responses, while others, such as the fairness of job assignment by the foreman, were measured on a predetermined (1–5) rating scale with a corresponding description for each scale. A sample of the crew and foreman characterization form criteria is given in Table 15 and the full form is given in Appendix A4.

Table 15. Crew and foreman characterization form sample criteria

| Crew characterization criteria | |
|---|---|
| Criteria | Scale of measure |
| Crew size | Integer number (crew size) |
| Adequacy of crew size | 1-5 Predetermined rating (1. very poor, 2. poor, 3. fair, 4. good, 5. very good) |
| Craftsperson education | Categorical (elementary school, secondary school, technical or apprentice, college, university) |
| Craftsperson on job training | Real number (No. of training sessions attended x Duration of training, hrs) |
| Craftsperson technical training | Real number (No. training sessions attended x Duration of Training, hrs) |
| Crew composition | Integer numbers (no. journeymen, no. apprentices) |
| Crew experience | Integer number (years of experience) |
| Craftsperson age | Integer number (Age) |
| Foreman characterization criteria | |
| Criteria | Scale of measure |
| Foreman Experience | Integer number (years of experience) |
| Foreman training | Real number (No. training sessions attended x Duration of training, hrs) |

| | |
|---|---|
| Foreman leadership style | Categorical (Autocratic, Democratic, Participative, Goal-oriented, Situational) |
| Foreman supervisory skills | 1-5 Predetermined rating scale (1. very poor, 2. poor, 3. fair, 4. good, 5. very good) |
| Change of foreman (supervisor) | Integer number (no. changes of foreman [supervisor] per month) |
| Foreman skill in proper resource allocation | 1 - 5 Predetermined rating scale (1. very poor, 2. poor, 3. fair, 4. good, 5. very good) |

The data collection process was conducted through a survey, with respondents comprising crew members, the foreman, and the direct supervisor of the foreman. Once data were collected, the crew and foreman scores for each criterion were used to compare the performance of IWPs done by different crews and foremen.

### 3.5 Problem Sources Form

Several different problems can occur on construction projects, which affect the success of the project. Some of these problems have a significant impact on project success, irrespective of the method of planning and scheduling adopted. The problem sources form was developed to account for various problems from multiple sources that can occur on a construction project, such as unexpected harsh weather. The form identifies common problems that can affect construction projects in areas such as environment, site, owner/consultant, design/drawing, schedule, workforce, work, supplies/equipment, utilities/city, and other miscellaneous problems, based on a list compiled by Russell and Fayek (1994), Bassioni et al. (2004), and Olawale and Sun (2013). The form uses the compiled list as criteria to assess the extent to which a project was impacted by different construction problems. The data collection form has two sections. The first section collects general information about the project being evaluated, while the second section has a list of criteria used for evaluation. The criteria are evaluated using two scales of measurement, the agreement scale and the level of impact scale. The agreement scale measures the level of agreement with respect to the existence of a criterion, and the level of impact scale is used to identify the level of impact the particular criterion has on the project. The description for the agreement scale is shown in Table 13. The level of impact scale is shown in Table 16. A sample of the problem sources form criteria is given in Table 17 and the full form is given in Appendix A5.

Table 16. Level of Impact Scale

| Scale | Scale description |
|---|---|
| 1 | No impact |
| 2 | Slightly Negative |
| 3 | Negative |
| 4 | Strongly Negative |

Table 17. Problem sources form sample criteria

| No | Evaluation criteria | No | Evaluation criteria |
|---|---|---|---|
| 1 | Environment | 6 | Workforce |
| 1.1 | Temperature too high | 6.1 | Under manning |
| 1.2 | Wind too high | 6.2 | Overmanning |
| 1.3 | Too much precipitation | 6.3 | Low skill level |
| 2 | Site conditions | 7 | Work |
| 2.1 | Insufficient storage space | 7.1 | Estimating error |
| 2.2 | Inadequate external access | 7.2 | Error in construction |
| 2.3 | Inadequate internal access | 7.3 | Layout error |
| 3 | Owner and consultants | 8 | Supplies and Equipment |
| 3.1 | Delay in decisions required | 8.1 | Insufficient materials |
| 3.2 | Large amount of change requested | 8.2 | Insufficient transportation equipment (cranes, forklifts) |
| 3.3 | Interference or stop work orders | 8.3 | Insufficient hand tools |
| 4 | Design/ Drawings | 9 | Utilities/City |
| 4.1 | Drawing errors | 9.1 | Awaiting permits |
| 4.2 | Design changes/ additions | 9.2 | Awaiting connection |
| 4.3 | Drawings insufficient/incomplete | 9.3 | Awaiting inspections/tests |
| 5 | Schedule | 10 | Miscellaneous |
| 5.1 | Delay of activity predecessors | 10.1 | Theft |
| 5.2 | Work done out of sequence | 10.2 | Strikes |
| 5.3 | Improper sequencing of activities | 10.3 | Vandalism |

The data collection process was conducted using a survey, with respondents comprising the project manager, construction manager, superintendent, and foreman/general foreman. Data from the respondents was aggregated to determine a level of impact score for the project.

To analyze the collected data, Equation 8 is used to calculate the level of agreement score $T_r$ for each criterion *r, r is 1, …, f,* where *f* is the total number of criteria; in this case $f$ is equal to 83.

(8) $$T_r = \frac{(A_r * 1 + B_r * 2 + C_r * 3 + D_r * 4 + E_r * 5)}{(A_r + B_r + C_r + D_r + E_r)} \text{ , } r = 1, \dots, f$$

Where

$A_r$ is the number of respondents rating the criterion r as 1 (“strongly disagree”)

$B_r$ is the number of respondents rating the criterion r as 2 (“disagree”)

$C_r$ is the number of respondents rating the criterion r as 3 (“neither disagree nor agree”)

$D_r$ is the number of respondents rating the criterion r as 4 (“agree”)

$E_r$ is the number of respondents rating the criterion r as 5 (“strongly agree”)

Second, the level of impact scale, described in this section, is used to evaluate the different levels of impact of the specified criteria on the performance of the project; this is achieved by assigning a level of impact score for each criterion. A mean level of impact score $(L_r)$ is calculated based on the value assigned by each respondent to each criterion *r*, as shown in Equation 9.

(9) $$L_r = \frac{\sum_{i=1}^{n} L_{r,i}}{n}, r = 1. \dots, f$$

Where

$n$ is the number of respondents of the AWP source form

$L_{r,i}$ is the level of impact scores given by the $i$th respondent for a given criterion $r$

Finally, the level of impact score $(LOI)$ is determined as shown in Equation 10.

(10) $$LOI = \sum_{r=1}^{f} \left( \frac{T_r}{\sum_{j=1}^{f} T_j} \; x \; L_r \right)$$

The level of impact score is used to characterize the project with respect to the level of impact of project problems encountered during the construction process, and it enables comparison among different projects with different levels of AWP implementation.

## 3.6 Key Performance Indicators (KPIs)

The KPIs form was used to collect data to compare the performance of projects with different levels of AWP implementation. The KPIs form collects information on work package and project performance. Twenty-seven work package-level KPIs were divided into the following performance metric categories: cost (7), schedule (4), quality (4), safety (5), productivity (5), and predictability (2) (Omar and Fayek 2016b). Moreover, 13 project-level KPIs for the detailed design (6) and construction phases (7) of a construction project were included in the KPIs form (Omar and Fayek 2016b). The data collection process was conducted using a survey, with respondents comprising the EPC firm AWP manager, project manager, construction manager, project controls, and foreman. Using data from the respondents, the KPIs were calculated using the equations shown in Table 18 and 19. A sample of the work package and project KPI forms is given in Table 18 and 19 respectively. The full forms for the work package KPIs and the project KPIs are given in Appendix A6.

Table 18. Work Package Performance Indicators Sample Metrics

| KPI No. | KPI Name | KPI Definition | KPI Formula |
|---|---|---|---|
| 1. Work Package Cost Performance Indicators | | | |
| 1.1 | Work Package Cost Growth | The variance between the actual total work package cost and total work package estimated cost at tender stage, expressed as a ratio of total work package estimated cost at tender stage. | $\dfrac{\textit{(actual total work package cost − total work package estimate cost at tender stage)}}{\textit{total work package estimate cost at tender stage}}$ |
| 1.2 | Work Package Budget Factor | The ratio between the actual total work package cost, and total work package estimated cost at tender stage and cost of approved changes to work package. | $\dfrac{\textit{actual total work package cost}}{\textit{(total work package estimate at tender stage + approved changes to work package)}}$ |
| 2. Schedule Performance Metrics | | | |

| KPI No. | KPI Name | KPI Definition | KPI Formula |
|---|---|---|---|
| 2.1 | Work Package Schedule Factor | The ratio between the actual work package duration and the sum of the estimated work package duration at tender stage and approved changes to work package duration. | *actual work package duration* / *(estimated work package duration at tender stage + approved changes to work package)* |
| 2.2 | Work Package Schedule Growth | The variance between the actual work package duration and the estimated work package duration at tender stage, expressed as a ratio of the estimated work package duration at tender stage. | *(actual work package duration – estimated work package duration at tender stage)* / *Estimated work package duration at tender stage* |
| 3. | Work Package Quality Performance Metrics | | |
| 3.1 | Work Package Rework Cost Factor | The ratio between the total direct cost of work package rework, and the actual work package direct cost | *total direct cost of work package rework* / *actual work package direct cost* |
| 3.2 | Work Package Rework Time Factor | The ratio between total duration of work package rework, and the actual work package duration | *Total duration of work package rework* / *actual work package duration* |
| 4. | Safety Performance Indicators | | |
| 4.1 | Lost Time Rate | The ratio between the total time lost to incidents in work package and the total hours worked on the work package. | *amount of lost time to incidents in work package(hr.)* / *total hours worked* |
| 4.2 | Lost Time Frequency | The ratio between the total number of lost time cases reported in work package and the total hours worked on the work package | *amount of lost time to incidents in work package(hr.)* / *total hours worked* |
| 5. | Work Package Productivity Metrics | | |

| KPI No. | KPI Name | KPI Definition | KPI Formula |
|---|---|---|---|
| 5.1 | Construction Productivity Factor (Physical Work | The actual direct work man-hours required to install a unit quantity of the work package output | $\frac{\textit{Actual direct man-hours of work package}}{\textit{total installed quantity}}$ |
| 5.2 | Construction Productivity Factor (Cost) | The ratio between the total installed work cost and the total actual man-hours | $\frac{\textit{total installed cost of work package}}{\textit{actual direct man-hours of work package}}$ |
| 6. Work Package Predictability Performance Indicators | | | |
| 6.1 | Cost Predictability | The variance between the actual work package cost and estimated work package cost at tender stage, expressed as a ratio of the estimated construction cost. | $\frac{\textit{(actual work package cost – estimated work package cost at tender stage)}}{\textit{Estimated work package cost at tender stage}}$ |
| 6.2 | Time Predictability | The variance between the actual work package duration and the estimated work package duration at tender stage, expressed as a ratio of the estimated work package duration. | $\frac{\textit{(actual work package duration – estimated work package duration at tender stage)}}{\textit{Estimated work package duration at tender stage}}$ |

Table 19. Project Performance Indicators Sample Metrics

| KPI No. | KPI Name | KPI Definition | KPI Formula |
|---|---|---|---|
| 1. Project Detailed Design Performance Metrics | | | |

| KPI No. | KPI Name | KPI Definition | KPI Formula |
|---|---|---|---|
| 1.1 | EWPs Issue Rate | The number of EWPs issued on schedule divided by the total number of EWPs of the project. | *number of EWPs issued on schedule* / *total number of project EWPs* |
| 1.2 | Vendor Data Incompleteness | The number of EWPs delayed due to the vendor data incompleteness divided by the total number of EWPs of the project. | *number of EWPs delayed due to incomplete vendor data* / *total number of project EWPs* |
| 1.3 | Project Scope Data Incompleteness | The number of EWPs delayed due to the project scope freeze/change divided by the total number of EWPs of the project. | *number of EWPs delayed due to project scope freeze/change* / *total number of project EWPs* |
| 2. Project Construction Performance Metrics | | | |
| 2.1 | Project Schedule Factor | The number of IWPs completed on schedule divided by the total number of IWPs of the project. | *Number of IWPs completed on schedule* / *total number of project IWPs* |
| 2.2 | Material Related Delay Factor | The number of the IWPs delayed due to the late delivery of material divided by the total number of IWPs of the project. | *number of IWPs delayed due to late material delivery* / *total number of project IWPs* |
| 2.3 | Equipment Related Delay Factor | The number of the IWPs delayed due to unavailability of equipment divided by the total number of IWPs of the project. | *number of IWPs delayed due to equipment unavailability* / *total number of project IWPs* |

The development and analysis of the six data collection forms was discussed in this chapter. The data collection forms are used to collect data and the results of their analysis are used in the AWP framework.

### 3.6.1 Utilizing KPIs in AWP framework

The KPI forms serve two purposes in the AWP framework: (1) to calculate the benefit of AWP ($B_{awp}$) for a single project, and (2) to compare the performance of AWP on projects with different AWP maturity levels. The benefit of AWP ($B_{awp}$) and the cost of AWP ($C_{awp}$) are used to calculate the ROI of AWP implementation. To calculate the $B_{awp}$, KPIs that can be used to assess AWP benefit in terms of dollar value are used. KPIs that are not used in ROI calculation are used to compare performance of AWP for projects with different AWP maturity levels. One of the KPIs used for ROI calculation is a cost KPI, cost per unit at completion ($CC$). The cost per unit at completion ($CC$) KPI, which can be found in Appendix A.6, is used as an example to demonstrate the calculation steps to determine $B_{awp}$ using KPIs. The first step in determining $B_{awp}$ using this KPI is to calculate $CC$ for each work package that utilizes AWP denoted $CC^{awp}$ to distinguish from work packages without AWP implementation. The $CC^{awp}$ values are calculated for each AWP work package using the equation for $CC$ given in the KPI forms and shown in Equation 11 below.

(11) $$CC^{awp} = \frac{actual\ total\ work\ package\ cost}{quantity\ of\ completed\ work}$$

The second step is to collect the cost per unit at completion values($CC$) from the similar work packages that did not use AWP (non-AWP) based on historical data. In step 3, the difference between $CC$ values from non-AWP work packages and $CC^{awp}$ values from AWP work packages is multiplied by the quantity of work completed ($Q$) to determine the $B_{awp}$ for each work package $w$, $w$=1,…,$n$, where $n$ stands for the total number of work packages. The results from all work packages are added to determine the $B_{awp}$ using the cost per unit at completion KPI as shown in Equation 12.

(12) $$B_{awp} = \sum_{w=1}^{n}[(CC_w - CC_w^{awp}) \times Q_w]$$

A similar process is used to determine $B_{awp}$ for other KPIs in different categories, such as schedule and productivity KPIs. For instance, the schedule KPI, time per unit at completion($TC$), which can be found in Appendix A.6, is another KPI that can be used to determine $B_{awp}$ and the equation for this KPI when AWP is used for the work package is shown in Equation 13 below.

(13) $$TC^{awp} = \frac{actual\ work\ package\ duration}{quantity\ of\ completed\ work}$$

The difference in time per unit at completion KPI value for AWP ($TC^{awp}$) and non-AWP ($TC$) work packages is multiplied by the quantity of completed work ($Q$) for each work package $w$, $w$=1,…,$n$, where $n$ stands for the total number of work packages. The sum from all work packages is multiplied by the project overhead cost ($OC$) per unit of time to determine the $B_{awp}$ as shown in Equation 14.

(14) $$B_{awp} = \left(\sum_{w=1}^{n}(TC_w - TC_w^{awp}) \times Q_w\right) \times OC$$

The next chapter presents the AWP framework developed and a case study illustrating the application of the data collection and analysis methodology used in the AWP framework.

# CHAPTER 4 – APPLICATION OF AWP FRAMEWORK[3]

This chapter discusses the AWP framework developed and the application of the framework using partial data from a case study to illustrate the analysis of the forms. The first section describes the framework development and the second section discusses the case study used to pilot the data collection forms and the corresponding analysis.

## 4.1 Proposed Methodology to Calculate Cost-Benefit of AWP Implementation Using Framework

Once data are collected and analyzed from each data collection form, the results from the forms are used in the AWP framework. The AWP framework assesses AWP implementation by determining the ROI of AWP implementation for a given project and comparing the performance of projects with varying levels of AWP maturity.

### 4.1.1 Calculation of ROI for a given project

To determine ROI the cost of AWP ($C_{awp}$) is calculated from the additional costs form and the benefit of AWP ($B_{awp}$) is calculated using KPIs such as cost, schedule, and productivity from the KPIs form, as discussed in section 3.6.1. The following steps are followed to determine ROI.

Step 1: The cost of AWP implementation ($C_{awp}$) is obtained using the Additional Cost Form.

Step 2: The benefit of AWP implementation ($B_{awp}$) is calculated using the KPIs form developed as shown in section 3.6.

Step 3: The ROI of AWP is calculated using Equation 15 (Pearce 2015).

(15) $$ROI = \frac{B_{awp} - C_{awp}}{C_{awp}}$$

[3] Based on Halala, Y., and Fayek, A. Robinson. (2017). *"A Framework to Assess the Costs and Benefits of Advanced Work Packaging".* Manuscript submitted to the *Canadian Journal of Civil Engineering* January 30, 2018.

The following figure demonstrates the framework used to calculate ROI.

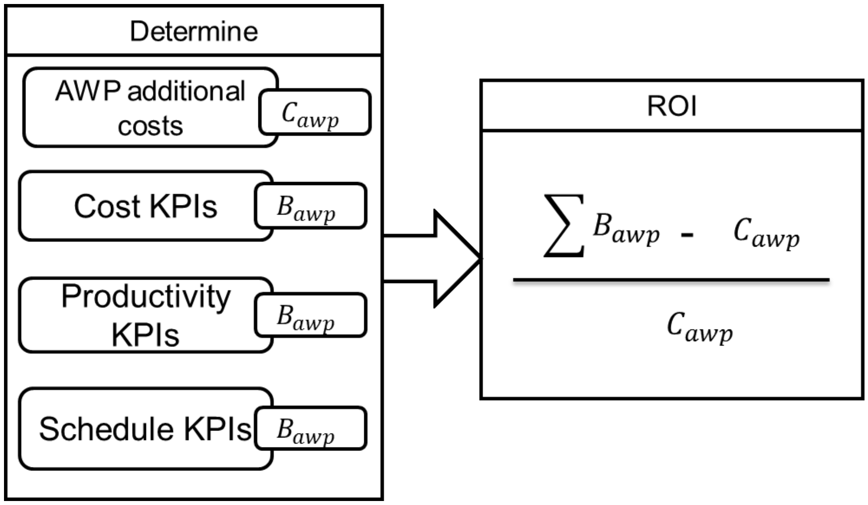


Figure 3. ROI calculation framework

The calculation of ROI is demonstrated using hypothetical data for three projects using a cost KPI, cost per unit at completion $(CC)$, to determine $B_{awp}$. For practical application of the framework, other KPIs from different categories are used in addition to $CC$ to determine $B_{awp}$. KPI values for AWP work packages $CC^{awp}$ and KPI values for non-AWP work packages $(CC)$ from historical data are given in Table 20. The cost of AWP $(C_{awp})$ is assumed to be calculated using the AWP additional costs form and has a value of $100,000 for all three projects. Table 20 shows the data used to calculate the $B_{awp}$.

Table 20. Cost per unit at completion and quantity of work data for AWP and non-AWP work packages for hypothetical projects

| Project | Work Package | Cost per unit at completion [$/unit] | | Quantity of work completed$(Q)$ [unit] |
|---|---|---|---|---|
| | | AWP $(CC^{awp})$ | Non AWP $(CC)$ | |
| A | Steel | 300/tonne | 350/tonne | 1000 tonnes |
| | Pipe | 50/ft | 75/ft | 1000 ft |
| | Lighting | 100/ft | 120/ft | 500 ft |
| B | Steel | 310/tonne | 300/tonne | 1000 tonnes |
| | Pipe | 55/ft | 50/ft | 1000 ft |

| | | | | |
|---|---|---|---|---|
| | Lighting | 105/ft | 100/ft | 500 ft |
| C | Steel | 300/tonne | 300/tonne | 1000 tonnes |
| | Pipe | 50/ft | 50/ft | 1000 ft |
| | Lighting | 100/ft | 100/ft | 500 ft |

The benefit of AWP for the three projects is calculated as follows using Equation 12 respectively.

For A, $B_{awp} = (\$350/tonne - \$300/tonne) \times 1000tonnes + (\$75/ft - \$50/ft) \times 1000ft + (\$120/ft - \$100/ft) \times 500ft = \$125{,}000$

For B, $B_{awp} = (\$300/tonne - \$310/tonne) \times 1000tonnes + (\$50/ft - \$55/ft) \times 1000ft + (\$100/ft - \$110/ft) \times 500ft = -\$20{,}000$

For C, $B_{awp} = (\$300/tonne - \$300/tonne) \times 1000tonnes + (\$50/ft - \$50/ft) \times 1000ft + (\$100/ft - \$100/ft) \times 500ft = \$0$

Based on these values the $ROI$ of each project is:

For project A, $ROI = \frac{\$125{,}000 - \$100{,}000}{\$100{,}000}$ = 0.25 or 25%

For project B, $ROI = \frac{-\$20{,}000 - \$100{,}000}{\$100{,}000}$ = -1.2 or -12%

For project C, $ROI = \frac{\$0 - \$100{,}000}{\$100{,}000}$ = -1 or -100%

From the hypothetical cases above, it is evident that in order to for AWP to be acceptable in terms of ROI the benefits from AWP implementation should, at a minimum, cover the additional costs of AWP implementation. If AWP does not improve upon the alternative method for project planning and execution, the result is negative ROI, as in the case of projects B and C.

**4.1.2 Comparison of performance between projects implementing AWP**

In the second component of the AWP framework, a method to evaluate the relationship between AWP maturity and project performance is developed. To achieve this goal, projects with different maturity levels are compared in terms of performance based on ROI and KPIs. However, projects with different maturity levels cannot be directly compared without accounting for the context of the projects. Thus, before comparing the performance of projects with different maturity levels, projects with similar contexts must be identified for comparison. To identify projects with similar contexts, the FC, LOI, crew, and foreman values determined from the analysis of the data collection forms shown in Figure 4 are used to define context. These four values address different components that influence project performance. Projects with similar FC, LOI, crew, and foreman values are classified as projects with similar context and used to compare AWP maturity versus project performance. Figure 4 shows the data collection forms and the results of their analysis in the framework used to compare AWP maturity with project performance. To compare AWP maturity versus project performance, a method such as correlation analysis can be used. For correlation analysis, $M_{awp}$ is the independent variable and ROI as well as individual KPIs from several categories, as shown in Figure 4, are the dependent variable. By using this approach the relationship between different levels of AWP maturity and project performance can be evaluated.

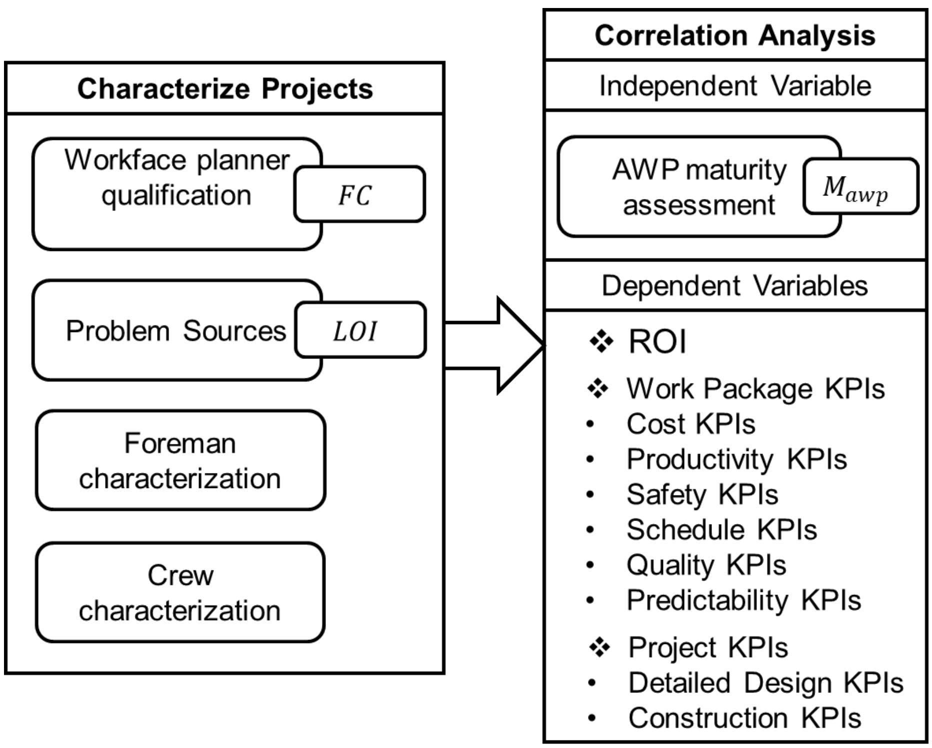


Figure 4.Context characterization and correlation analysis framework

The steps in the AWP framework to assess the relationship between AWP maturity and project performance are discussed next.

Step 1: The $FC$ (final workface planner characterization score) from the workface planner form, the $LOI$ (level of impact) from the problem sources form, and the crew and foreman characterization values from the crew and foreman characteristics form are used to determine projects that have similar characteristics or context for comparison.

Step 2: Determine ROI using the framework developed for each project.

Step 3: The ROI and the KPIs of projects with different AWP maturity levels but similar characteristics identified in Step 1 are compared using a method such as correlation analysis. Using correlation analysis, observations such as positive, negative or no correlation are made between AWP maturity and individual KPIs and the overall ROI value determined in Step 2.

Positive correlation between AWP maturity and ROI or KPIs would indicate that AWP maturity increases simultaneously with an increase in ROI or KPIs. Negative correlation would indicate that either AWP maturity or ROI/KPIs increase while the other decreases. No correlation indicates the possible lack of association between AWP maturity and ROI or KPIs. Through the implementation of the AWP framework developed in this section the possible association between AWP maturity and ROI or KPIs can be evaluated.

To implement the framework, additional data from multiple projects is required. Construction companies can use the framework on different projects on which they implement AWP. Once data are collected from several different projects, the steps outlined can be used to assess the relationship between AWP maturity and performance as well as the ROI of AWP for each project. A similar process can be adopted by researchers to assess ROI for projects from different organizations implementing AWP. Furthermore, future research can compare the ROI of AWP versus the ROI of other recent project planning and control methods developed for industrial construction.

## 4.2 Case Study Analysis

A case study was conducted to test the data collection forms and data analysis methodology on an industrial construction project. The industrial project was an oil sands project, the latter of which requires modules to be constructed in a module yard and transported for installation on site. At the time of data collection, the percentage of project completion, in terms of engineering and construction works, was 100% complete. Stakeholder organizations in the project include an owner, design consultant, and construction contractor. Some of the data collection forms require input from all stakeholders. However, for this case study, data was only obtained from the construction contractor, and as a result, some of the required data was not acquired. From the construction contractor, data collection forms were completed by three workface planners, a supervisor of the workforce planners, a business and project controls manager, and the construction manager in charge of supervising the project. Results from the forms showed that 70% of respondents classified the complexity of the project as average, while the remaining 30% classified the project complexity as somewhat high. This section illustrates the data collected using each form and the subsequent analysis of the data, using partial sets of actual data to maintain confidentiality of the final results for the case study.

The AWP maturity assessment form for the case study project was completed by the construction manager in charge of the project. The maturity assessment form analysis is demonstrated using data for the first five AWP practices in Phase 1 of AWP or planning phase, as shown in Table 10. The importance values, given by the construction manager based on the importance scale shown in Table 9, for the first five AWP practices are 4, 4, 3, 4, and 5 respectively; the maturity values, given based on the maturity scale shown Table 8, are 5, 3, 2, 3 and 5 respectively.

To illustrate the calculation steps, the importance score *($R_s^{(h)}$)* is calculated using Equation 1 for the first AWP practice *s*, where *s* is equal to 1, in phase *h*, where *h is equal to* 1, resulting in a value of 4:

$$R_1^{(1)} = \frac{(0 * 1 + 0 * 2 + 0 * 3 + 1 * 4 + 0 * 5)}{(0 + 0 + 0 + 1 + 0)} = 4$$

Next, the mean maturity score *($M_s^{(h)}$)* is calculated using Equation 2 for the first AWP practice *s*, where *s* is equal to 1, of phase *h,* where *h* is equal to 1, resulting in a value of 5:

$$M_1^{(1)} = \frac{5}{1} = 5$$

The $R_s^{(h)}$ and $M_s^{(h)}$ values for the remaining five AWP practices are calculated similarly. Next, the aggregated maturity score ($M_{awp}$) for these five AWP practices can be calculated using Equation 3, where $\sum_{j=1}^{5} R_j^{(1)}$ is equal to 20.

$$M_{awp} = \frac{4}{20} x\, 5 + \frac{4}{20} x\, 3 + \frac{3}{20} x\, 2 + \frac{4}{20} x\, 3 + \frac{5}{20} x\, 5$$

$$M_{awp} = 3.75$$

The $M_{awp}$ for the first five AWP practices is 3.75, indicating that the level of maturity is between Level 3 (“A disciplined process exists for the practice across the different projects within the same organization") and Level 4 ("Quantitative process control is used across the organization to proactively manage the execution of the practice on this project"). The maturity scores for the case study were determined across two phases of AWP, phase 1 (planning) and phase 3 (construction), as well as the overall maturity score across the two phases. Phase 2 (detailed engineering) was not considered, since the construction contractor that provided the data was not directly involved in this phase.

For the case study project, the AWP additional costs form was completed by the operations manager. Information was collected for four different sources of costs that can be attributed to AWP, namely costs from AWP-exclusive tasks, AWP-salaried employees, AWP training costs, and AWP-related costs. Additional costs resulting from AWP are incurred across the three phases of AWP implementation, and by the corresponding stakeholder/stakeholders involved in the AWP phase. The data collected for the case study represents the additional costs resulting from AWP implementation, which were incurred by the construction contractor involved in Phase 1 and Phase 3. It should be noted that no costs were incurred for AWP training in the case study project.

Next, the AWP workface planner qualification characterization was completed by three workface planners involved with the project and by their supervisor. The self and supervisor evaluations were used independently in the first step to calculate the aggregated characterization score $(AV_i)$ using the data analysis methodology discussed in Section 3.3. Table 21 shows the data used for the analysis performed on the workface planner qualification characterization form using self-assessment data for workface planner 1, as well as data from the corresponding evaluation by the supervisor for the first five workface planner qualification criteria.

Table 21. Data for five qualification criteria for workface planner 1

| No. | Evaluation criteria | Workface planner 1 assessment | | Supervisor assessment | |
|---|---|---|---|---|---|
| | | Importance | Agreement | Importance | Agreement |
| 1 | Ensures that safety, quality, and efficiency at the Workface are considered in the planning process. | 5 | 4 | 5 | 5 |

| | | | | | |
|---|---|---|---|---|---|
| 2 | Uses his/her hands-on construction expertise to develop IWP. | 4 | 3 | 5 | 4 |
| 3 | Coordinates with and provides Workface construction knowledge to project schedulers, engineers, superintendents, and managers. | 3 | 4 | 4 | 5 |
| 4 | Acts as liaison between the project controls department and workforce supervision. | 4 | 4 | 4 | 5 |
| 5 | Identifies risks and opportunities associated with implementing IWPs. | 4 | 4 | 4 | 4 |

The importance score ($Y_{l,1}$) is 5.00 for both the self-assessment by workface planner 1 and the assessment by the supervisor for criteria $l$, where *l* is equal to 1.

The agreement score ($P_{l,1}$) is 5.00 for the self-assessment for workface planner 1 and 4.00 for supervisor assessment for criteria $l$, where *l* is equal to 1.

The remaining values for $Y_{l,1}$ and $P_{l,1}$ are shown in Table 21. The characterization score for these five evaluation criteria can now be calculated for the self-assessment of workface planner 1 ($V_1$) or for the supervisor assessment $V_1^{(s)}$ using Equation 5, as shown below.

$\sum_{l=1}^{5} Y_{l,1}$= 5 + 4 + 3 + 4 + 4 = 20

$$V_1 = \frac{5}{20} x\, 4 + \frac{4}{20} x\, 3 + \frac{3}{20} x\, 4 + \frac{4}{20} x\, 4 + \frac{4}{20} x\, 4$$

$$V_1 = 3.8$$

$\sum_{l=1}^{5} Y_{l,i}^{(s)}$ = 5 + 5 + 4 + 4 + 4 = 22

$$V_1^{(s)} = \frac{5}{22} x\, 5 + \frac{5}{22} x\, 4 + \frac{4}{22} x\, 5 + \frac{4}{22} x\, 5 + \frac{4}{22} x\, 4$$

$$V_1^{s} = 4.59$$

The aggregated characterization score for workface planner 1 ($AV_1$) for the five sample criteria is calculated using Equation 6, resulting in an agreement score between 4 ("agree") and 5 ("strongly agree"):

$$AV_1 = \frac{3.8 + 4.59}{2} = 4.20$$

The final characterization ($FC$) value for the case study was determined by averaging the aggregated characterizations scores ($AV$) for three workface planners that participated in the study.

For the case study project, the AWP problem sources form was completed by the construction manager in charge of the project. The level of impact score ($LOI$) was calculated following the data analysis methodology discussed in Section 3.5 and demonstrated using data for the first five problem sources. The agreement values, given by the construction manager based on the agreement scale shown in Table 13, for the first five problem sources are 1, 2, 3, 4, and 1 respectively; the level of impact values, given based on Table 16, are 1, 2, 1, 2, and 1 respectively.

The agreement score ($T_r$) is calculated using Equation 8 for criteria $r$, where *r* is equal to 1.

$$T_1 = \frac{(1 * 1 + 0 * 2 + 0 * 3 + 0 * 4 + 0 * 5)}{(1 + 0 + 0 + 0 + 0)} = 1$$

The mean level of impact score ($L_r$) for each problem code criterion is calculated using Equation 9 for problem code criteria $r$, where *r* is equal to 1.

$$L_1 = \frac{1}{1} = 1$$

The level of impact score ($LOI$) for these five problems sources can now be calculated using Equation 10.

$\sum_{j=1}^{5} T_j$ = 1 + 2 + 3 + 4 + 1 = 11

$$LOI = \frac{1}{11} x\ 1 + \frac{2}{11} x\ 2 + \frac{3}{11} x\ 1 + \frac{4}{11} x\ 2 + \frac{1}{11} x\ 1$$

$$LOI = 1.54$$

The analysis for the level of impact of these five project problem sources is 1.54 or between "no impact" and "slightly negative impact".

KPIs were calculated based on the formulae given in the forms. KPIs from projects with different levels of AWP maturity will be determined using a similar process. The resulting KPIs can be used in the framework described in section 4.1. The KPI forms require multiple sets of data for meaningful analysis.

# CHAPTER 5 – CONCLUSIONS AND FUTURE RESEARCH

This chapter presents a review of the research conducted for this thesis, summarizes the contributions and limitations of the research, and discusses recommendations for future research.

## 5.1 Research Summary

This research aimed to fill the gap in construction research on Advanced Work Packaging (AWP), as well as, helping the industry to not only assess the maturity of their AWP process but also the cost and benefits associated to implementing AWP. AWP was developed by CII to address challenges faced by construction companies such as cost and schedule overruns. While the reported benefits of AWP state that savings in schedule and cost can be achieved through AWP implementation, a quantitative process to assess an AWP program is not available in literature. This thesis presents a structured framework developed to address this gap in AWP research. The framework assesses multiple aspects of AWP implementation, in an effort to quantify both costs and benefits so that projects implementing AWP can be assessed against those that do not use AWP. The framework provides a systematic approach to measure AWP maturity, AWP additional costs, workface planner qualifications, foreman and crew characteristics, problem sources, and performance metrics. In addition, this thesis presents a methodology for the analysis of data collected using the framework to help construction organizations assess the costs associated with implementing AWP, and to identify the levels of AWP implementation leading to improved project performance. The results from the AWP framework will facilitate improved decision making for construction practitioners regarding AWP implementation.

The research in this thesis was carried out in three main stages: (1) a literature review of AWP was conducted to identify the processes and implementation of AWP within the construction industry; (2) six data collection forms were developed for the proposed framework addressing different aspects of AWP implementation; and (3) the data collection forms were pilot tested on an industrial construction project and the forms were analysed using data analysis methods developed for each form. The proposed framework and the steps followed to implement it were also outlined in this third stage.

**First Stage**

In the first stage, a literature review of different construction project planning and control practices was conducted. Different methods developed to address the challenges faced by the construction industry in project planning and control were identified. The AWP process was researched and reported benefits and challenges of utilizing AWP were discovered.

**Second Stage**

In the second stage, the information gathered during the literature review was used to develop data collection forms that form the basis of the AWP framework developed in the third stage. The data collection forms addressed different aspects of AWP implementation including (1) AWP maturity; (2) additional costs due to AWP implementation; (3) workface planner characterization; (4) crew and foreman characterization; (5) external problems sources that impact AWP performance; and (6) metrics to measure AWP performance. The forms developed are designed to address different components of AWP implementation in the AWP framework. At the end of this stage, data collection forms as well a method to analyze each form were developed.

**Third Stage**

An AWP framework was proposed in the third stage. The data collection forms were pilot tested on an industrial case study project. Each data collection form was analyzed using methods developed for each corresponding form. After data collection, the aggregated values from the data collection forms were used as inputs in the AWP framework developed. The framework proposed is used to assess the relationship between AWP maturity and project performance as well as to determine the return on investment of AWP by calculating the costs and benefits of AWP implementation. At the end of this stage, it was shown that the data collection forms developed for the implementation of the proposed framework in the assessment of the maturity of AWP process are applicable to real construction cases. Further data collection is necessary to fully implement the proposed framework.

## 5.2 Research Contributions

### 5.2.1 Academic Contributions

1. Contributed to the body of knowledge related to AWP as a tool for the improvement of productivity, cost and schedule performance in the industrial construction sector. While, qualitative evidence to indicate AWP improves productivity, cost, and schedule performance is available quantitative methods are lacking in AWP research. This thesis

proposes a framework to assess these improvements quantitatively to address this research gap and contribute to the AWP body of knowledge.

2. Developed a method to identify and calculate the additional costs associated with implementing AWP in construction. One question raised in AWP research is what additional costs are incurred by an organization implementing AWP as opposed to the control or planning method used before AWP implementation. While qualitative estimates of the cost of AWP implementation were given in previous research, a method to assess these costs was not available. Thus, to address this gap, a method to quantitatively calculate these costs is proposed in this thesis.
3. Developed metrics to assess the impacts of an AWP program on the performance of work packages and the project as a whole. The development of metrics to measure the performance of AWP was a gap in AWP literature, which has been addressed in this thesis.
4. Developed a framework to assess the costs and benefits of implementing AWP. The developed framework provides a step by step method to determine the return on investment (ROI) of AWP and to examine the relationship between AWP maturity and project performance. The developed framework contributes a quantitative approach to assess the utility of AWP implementation, which was lacking in previous AWP research.

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### 5.2.2 Industrial Contributions

1. Provided a quantitative framework to measure AWP costs and benefits, which can justify the reported qualitative benefits of AWP and present evidence for increased AWP implementation on industrial construction projects. Further data collection is required to implement the framework developed. Once this requirement is met, the ROI of AWP can be determined enabling organizations to assess the utility of implementing AWP as compared to the project control and planning method utilized before AWP implementation. The framework developed is the first of its kind to quantitatively assess the ROI of AWP in a step by step process.

2. Provided industrial construction companies with a tool that can be used to assess the maturity of their AWP process. Previous research assigned maturity levels to AWP

projects using a qualitative description of three different AWP maturity levels; Level 1: AWP business efficiency; Level 2: AWP business effectiveness; and Level 3: AWP business transformation. The maturity of projects was classified based on how closely the project process fulfilled the AWP maturity level definition. This research presents a different approach in which 108 AWP activities across the three stages of planning, design, and construction are used to determine an aggregated value for the level of AWP maturity. In addition, the AWP maturity assessment tool can be used to assess overall AWP maturity for each of the three stages of planning, design and construction individually. The approach adopted in this research enables organizations to determine areas for improvement by directly identifying AWP activities with high importance scores and low maturity scores.

3. Provided a better understanding of the costs associated with AWP implementation to owners and EPCs. Past research presented high level qualitative cost estimates of AWP implementation. The method provided in this research can be used to calculate the cost of implementing AWP on a project by determining the direct cost of AWP activities, the salary of AWP dedicated employees, and other costs such as training costs.

## 5.3 Research Limitations and Recommendations for Future Research

The following limitations were encountered in the course of this research:

1. Data for the AWP additional costs forms should ideally be collected across the lifecycle of the project and not after project completion. Furthermore, the data to be collected requires detailed information about different AWP activities. The length of the data collection cycle and level of detail required for this form can be a limitation faced by organizations using this form to determine AWP costs. Possible solutions include electronic data collection methods and breaking up the data collection form to correspond to project milestones.
2. The process to prorate the cost of AWP training given on an organizational level when assessing the cost of AWP on a project is not addressed. Prorating the cost by multiplying the cost of AWP training by the cost of the project under study divided by the total cost of all the projects within the organization is one option that can be used.
3. The analysis of the crew and foreman forms were not designed to result in a single aggregated value as compared to the workface planner forms. Thus, these forms are analyzed by comparing the evaluation criteria of different crews and foremen as

opposed to a single aggregated value that represents overall performance. Future research can change the format of these forms and develop forms that can provide an aggregate value and enable these forms to be analyzed individually.

4. While external project problems are considered, unexpected favourable conditions that are not accounted for during project planning such as new technology that positively impact project performance are not considered. Unexpected but favourable conditions can impact the performance of a project irrespective of the project control or planning method used. In addition to considering project problems that influence projects negatively, unexpected favourable conditions that affect projects positively can also be added.
5. The AWP process is conducted by all stakeholders involved in a construction project. Data were not collected from the owner and design team. Obtaining participation from multiple stakeholders can be a limitation in implementing the data collection forms developed. One possible solution is to change the format of the forms such that data can be gathered and analyzed for the three stages of planning, design, and construction separately, which correspond to stages of AWP.
6. Sufficient data were not available to fully implement the AWP framework developed. Further data collection is required to apply the AWP framework in practice and to draw conclusions about the benefit and cost of AWP implementation based on multiple projects.

Future research can explore the following topics:

1. The relationship between AWP maturity and performance can be studied using the AWP maturity and KPI forms developed. Future research can collect and analyze data from multiple projects to relate their aggregated maturity value with different KPIs. Based on such analysis, the impact of different maturity levels on AWP performance can be assessed and observations corresponding to the five levels of AWP maturity can be made.
2. Different organizational structures exist in industrial construction. Future research can compare the ROI of an AWP program for different organizational structures to assess the type of organizational structure most suited to AWP implementation.
3. Different project planning and execution methodologies, in addition to AWP, exist to address the challenges of industrial construction. Future research can compare the ROI of AWP with other project planning and execution methodologies.

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## APPENDIX

# Appendix A. Data Collection Forms

### A.1. AWP Maturity Assessment Form

STUDY TO ASSESS THE ADVANTAGES OF UTILIZING ADVANCED WORK PACKAGING (AWP) ON CONSTRUCTION PROJECTS

AWP Maturity Assessment

Dear Participant,

The University of Alberta under the Natural Sciences and Engineering Research Council of Canada (NSERC), Industrial Research Chair in Strategic Construction Modeling and Delivery would like to thank you for agreeing to participate in this survey. This study is intended to assess the advantages of utilizing Advanced Work Packaging (AWP) for the improvement of project performance. This interview survey is intended to assess the maturity of AWP within your organization and on this project.

Background:
Advanced Work Packaging (AWP) was announced as a best practice by the Construction Industry Institute (CII) in 2015 and has been adopted by the Construction Owners Association of Alberta (COAA). This study aims to quantify the costs and benefits of implementing an Advanced Work Packaging/Workface Planning (AWP/WFP) program on construction projects by measuring the impacts of such a program on schedule performance, cost performance, predictability, field productivity, rework, safety, and indirect costs. The maturity of AWP within an organization and on a project is one of the factors that need to be considered when studying the impacts of AWP.

Your participation in this survey is purely voluntary. You do not have to participate, and there are no consequences if you do not. All answers will remain confidential, and only the aggregated results will be made public in the form of reports and publications.

Your participation will be limited to completing the survey, which will take approximately twenty to thirty minutes to complete.

This survey consists of two main sections. The first section is designed to collect general information about the organization you work for and your position in this organization. The second section includes a list of AWP practices, which you are asked to rate in terms of relative importance and maturity within your organization and on this project.

SECTION 1: GENERAL INFORMATION

*1.1.* Please select the industry of your organization: (please specify ALL that applies)

□ New Home Building and Renovation - building, remodelling or renovating houses and apartment buildings

□ Civil Engineering Construction engineering projects - highways, dams, water and sewer lines, power and communication lines, and bridges

□ Institutional and Commercial Construction - building commercial and institutional buildings and structures such as stadiums, schools, hospitals, grain elevators and indoor swimming pools

□ Heavy Industrial Construction - building industrial facilities such as cement, automotive, chemical or power plants, refineries and oil-sands installations

□ Other (please specify): ______________________

*1.2.* Please select your organization type in this project: (please specify ALL that apply)

□ Owner

□ Consultant and/or project management services

□ Engineering Firm

□ Engineering and Procurement

□ EPC firm

□ Main Contractor

□ Construction Contractor

□ Fabrication Contractor

□ Other (please specify): ______________________

*1. 3.* Please indicate the name of your current employer (Company you work for):

______________________________

*1. 4.* Approximately, how long have you been employed by your current employer?

________ Year(s) ________Month(s)

*1.5.* Please select your current occupation:

□ Advanced Work Packaging Manager

□ Engineering Manager

□ Project Manager

□ Construction Manager

□ Procurement Manager

□ WFP Lead

□ Superintendent

□ General Foreman

□ Foreman

□ Other (please specify):

______________

*1. 6.* Approximately, how long have you worked in the stated occupation?

________ Year(s) ________Month(s)

*1.7.* Please specify your highest educational degree: (please specify ALL that applies)

□ Professional designation/degree

□ Master's degree or above

□ Bachelor's degree

□ Some university credit (no degree)

□ College Diploma

□ Some college credit (no degree)

□ Technical, vocational, or trade school

□ Other (please specify): ___________

*1.8.* Please select the industry that this project belongs to:

□ New Home Building and Renovation - building, remodelling or renovating houses and apartment buildings

□ Civil Engineering Construction engineering projects - highways, dams, water and sewer lines, power and communication lines, and bridges

□ Institutional and Commercial Construction - building commercial and institutional buildings and structures such as stadiums, schools, hospitals, grain elevators and indoor swimming pools

□ Heavy Industrial Construction - building industrial facilities such as cement, automotive, chemical or power plants, refineries and oil-sands installations

□ Other (please specify): ______________________

*1.9.* Please specify the project delivery system for this project from those listed below:

□ EPC

□ EPCM

□ Traditional Design-Bid-Build

□ CM at Risk

□ Design-Build

□ Parallel Prime

□ EP and C

□ Other (please specify): ____________

*1.10.* Please specify the project contract type from the listed below:

□ Unit Rate

□ Lump Sum

□ Cost Plus (Reimbursable)

□ Other (please specify): ____________

*1.11.* Please rate the project complexity based on the following questions:

*1.11a.* Please indicate the type of project?

□ Greenfield

□ Brownfield

□ Combination of greenfield and brownfield

□ Other (please specify): ____________

*1.11b.* Please choose one option in each row to evaluate the level of project complexity:

| | |
|---|---|
| □ Project is characterized by the use of no unproven technology | □ Project is characterized by the use of unproven technology |
| □ Project has a small number of process steps | □ Project has an unusually large number of process steps |
| □ Project has small facility size or process capacity | □ Project has large facility size or process capacity |
| □ Project has previously used facility configuration or geometry | □ Project has new facility configuration or geometry |

□ Project utilized proven construction methods

□ Project utilizes new construction methods

*1.11c.* Please indicate the ratio of the height of the work to the footprint of the work for the project overall (e.g., a ratio of 2:1 would indicate that the height of the work is two times the footprint of the work, i.e., 2 m of height per square metre of footprint): ____________________

*1.11d.* Please rate the level of complexity with respect to the number of contractual parties:

□ Low □ Somewhat Low □ Average

□ Somewhat High □ High

*1.11e.* Please rate the level of complexity with respect to the number of project teams:

□ Low □ Somewhat Low □ Average

□ Somewhat High □ High

*1.11f.* Please rate the level of complexity with respect to the work scope:

□ Low □ Somewhat Low □ Average

□ Somewhat High □ High

*1.11g.* Please rate the level of complexity with respect to the number of work scope interfaces:

□ Low □ Somewhat Low □ Average

□ Somewhat High □ High

*1.11h.* Please rate the level of complexity with respect to the number of work packages:

□ Low □ Somewhat Low □ Average

□ Somewhat High □ High

*1.11i.* Please rate the level of complexity with respect to the construction methods:

□ Low □ Somewhat Low □ Average

□ Somewhat High □ High

*1.11j.* Please rate the level of difficulty with regards to the constructability:

□ Low □ Somewhat Low □ Average

□ Somewhat High □ High

*1.12.* Please indicate the current project location: ______________________________

*1.13a.* Please specify the total contract value for the current project: ____________________

*1.13b.* Please specify the contract value for your organization's scope of work:_______________

*1.14a.* Please specify the contract duration for the current project: __________________

*1.14b.* Please specify the contract duration for your organization's scope of work: ___________

*1.15a.* Please specify the current project start date (for construction work):_______________

*1.15b.* Please specify the project start date for your organization's scope of work (for construction work):_______________

*1.16a.* How many construction-related personnel (e.g., project management, supervision, project controls, foreman, and tradespeople) are employed on this project?

□ Less than 100 □ 101 – 200 □ 201– 300

| | | |
|---|---|---|
| □ 301– 400 | □ 401– 500 | □ Above 500 |

*1.16b.* How many personnel (e.g., project management, supervision, project controls, foreman, and tradespeople) are employed on this project from your organization?

| | | |
|---|---|---|
| □ Less than 100 | □ 101 – 200 | □ 201– 300 |
| □ 301– 400 | □ 401– 500 | □ Above 500 |

*1.17.* Please specify which labour group is involved in this project? (Please specify ALL that apply)

| | | |
|---|---|---|
| □ Merit | □ CLAC | □ Building Trades |
| □ United Association | □ United Brotherhood of Carpenters and Joiners of America | □ United Steelworkers |
| □ International Brotherhood of Electrical | □ International Association of Bridge, Structural, Ornamental, and Reinforcing Iron | □ Other (please specify): |

*1.18.* Please specify the approximate percent complete to date in the *Engineering Work* for this project:

____________

*1.19.* Please specify the approximate percent complete to date in the *Construction Work* for this project:

____________

*1.20.* Please specify the approximate overall percent (*Engineering and Construction*) complete to date for this project:

____________

*1.21.* Please specify the approximate percent of construction work for this project executed by your own company:

________

SECTION 2: AWP PRACTICES

This section of the survey presents AWP practices associated with three different phases of AWP namely, (1) preliminary planning/design, (2) detailed engineering, and (3) construction. The importance of each practice as well as the maturity is assessed using the measurement scales provided as follows:

1. Importance Measurement: is to measure how important a practice is to the phase it is associated with (e.g., preliminary planning/design), which can vary within five levels as shown below:

| Scale value | Scale description |
|---|---|
| 1 | Practice is extremely unimportant to the associated phase |
| 2 | Practice is unimportant to the associated phase |
| 3 | Practice is neither unimportant or important to the associated phase |
| 4 | Practice is important to the associated phase |
| 5 | Practice is extremely important to the associated phase |

2. Maturity Measurement: is to measure the extent to which an AWP practice pertaining to a given phase of AWP exists, which can vary within five levels (in addition to Not Applicable) as shown below:

| Scale value | Scale description |
|---|---|
| Not Applicable | Use of the practice is non-existent on this project |
| Level 1 | Use of the practice is not consistently applied on this project |
| Level 2 | A disciplined process exists for the practice on this project |
| Level 3 | A disciplined process exists for the practice across the different projects within the same organization |
| Level 4 | Quantitative process control is used across the organization to proactively manage the execution of the practice on this project |
| Level 5 | Continuous process improvement is used across the organization to optimise the practice on this project |

Please provide your evaluation for the various AWP practices, pertaining to each AWP phase, by providing a value for each of the measurement scales (Importance and Maturity measurements) as identified above. Blank rows are provided for you to add additional practices that you feel are critical in the assessment of AWP. The project phases in which AWP is implemented are described in more detail below.

Note: Provide the title of the employee who is primarily responsible for the task in the "Primary Responsible for Task" column. If you are unsure whose primary responsibility the task is please indicate by an "X" mark. If you are unfamiliar with the AWP practice being evaluated, please check the "Not able to Evaluate" column and proceed to the next practice. If the AWP practice is not applicable to your organization, please choose "Not applicable" in the maturity section.

## 1) Phase I - Preliminary Planning/ Design

| **Importance** | | | | | **Maturity** | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| *Level 1* | *Level 2* | *Level 3* | *Level 4* | *Level 5* | *Level 0* | *Level 1* | *Level 2* | *Level 3* | *Level 4* | *Level 5* |
| *Extremely Unimportant* | *Unimportant* | *Neither Unimportant or Important* | *Important* | *Extremely Important* | *Not Applicable* | *(Not Consistently Applied)* | *(Disciplined Practice for Project )* | *(Disciplined Practice Across All Project)* | *(Quantitative Practice Control)* | *(Continuous Process Improvement)* |

| No. | **Evaluation Criteria** | **Primary Responsibility for Task** | **Not able to Evaluate** | **Importance** | | | | | **Maturity** | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *1.1* | A documented advanced work packaging strategy is in place, and all stakeholders are familiar with the content of the strategy. | | | 1 | 2 | 3 | 4 | 5 | 0 | 1 | 2 | 3 | 4 | 5 |
| *1.2* | The contract language includes AWP strategy, plan, procedure, roles and responsibilities. | | | 1 | 2 | 3 | 4 | 5 | 0 | 1 | 2 | 3 | 4 | 5 |
| *1.3* | Documented AWP audit protocols have been developed and are being implemented. A process is in place that ensures audit findings are appropriately resolved. | | | 1 | 2 | 3 | 4 | 5 | 0 | 1 | 2 | 3 | 4 | 5 |
| *1.4* | An execution plan for detailed engineering and for construction execution has been defined to incorporate AWP. | | | 1 | 2 | 3 | 4 | 5 | 0 | 1 | 2 | 3 | 4 | 5 |

| | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *1.5* | The construction sequencing and contracting plans are identified at the project definition phase. | | | 1 | 2 | 3 | 4 | 5 | 0 | 1 | 2 | 3 | 4 | 5 |
| *1.6* | Designated AWP Champions are chosen from managerial positions with appropriate training and authority for every key project participants. | | | 1 | 2 | 3 | 4 | 5 | 0 | 1 | 2 | 3 | 4 | 5 |
| *1.7* | High-level roles and responsibilities are defined and updated for all stakeholders to support AWP content. | | | 1 | 2 | 3 | 4 | 5 | 0 | 1 | 2 | 3 | 4 | 5 |

| Importance | | | | | Maturity | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| *Level 1* | *Level 2* | *Level 3* | *Level 4* | *Level 5* | *Level 0* | *Level 1* | *Level 2* | *Level 3* | *Level 4* | *Level 5* |
| *Extremely Unimportant* | *Unimportant* | *Neither Unimportant or Important* | *Important* | *Extremely Important* | *Not Applicable* | *(Not Consistently Applied)* | *(Disciplined Practice for Project )* | *(Disciplined Practice Across All Project)* | *(Quantitative Practice Control)* | *(Continuous Process Improvement)* |

| No. | **Evaluation Criteria** | **Primary Responsibility for Task** | **Not able to Evaluate** | **Importance** | | | | | **Maturity** | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *1.8* | In the early planning stage, project execution planning documents included construction sequence, phases and boundaries to support AWP. | | | 1 | 2 | 3 | 4 | 5 | 0 | 1 | 2 | 3 | 4 | 5 |
| *1.9* | The WBS is aligned with AWP execution and associated with work package deliverables (CWP/EWP/IWP). | | | 1 | 2 | 3 | 4 | 5 | 0 | 1 | 2 | 3 | 4 | 5 |
| *1.10* | A project database is developed by the PMT and maintained by a data coordination manager to retain lessons learned, EWP/CWP release plans, WBS structure, and IWPs information. | | | 1 | 2 | 3 | 4 | 5 | 0 | 1 | 2 | 3 | 4 | 5 |
| *1.11* | AWP project data interface requirements are documented and consistent across the project. | | | 1 | 2 | 3 | 4 | 5 | 0 | 1 | 2 | 3 | 4 | 5 |
| *1.12* | Project-wide naming and numbering convention are consistent with the WBS | | | 1 | 2 | 3 | 4 | 5 | 0 | 1 | 2 | 3 | 4 | 5 |

| | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *1.13* | An ongoing feedback loop exists between the construction planning and engineering planning teams so that both are proceeding in alignment with work packaging planning. | | | 1 | 2 | 3 | 4 | 5 | 0 | 1 | 2 | 3 | 4 | 5 |
| *1.14* | Construction staffing plans for AWP have been developed. | | | 1 | 2 | 3 | 4 | 5 | 0 | 1 | 2 | 3 | 4 | 5 |
| *1.15* | Physical site constraints, procurement constraints, environmental constraints, permitting constraints, and any other type of restraints are incorporated into the CWP and EWP plan. | | | 1 | 2 | 3 | 4 | 5 | 0 | 1 | 2 | 3 | 4 | 5 |

| Importance | | | | | Maturity | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| *Level 1* | *Level 2* | *Level 3* | *Level 4* | *Level 5* | *Level 0* | *Level 1* | *Level 2* | *Level 3* | *Level 4* | *Level 5* |
| *Extremely Unimportant* | *Unimportant* | *Neither Unimportant or Important* | *Important* | *Extremely Important* | *Not Applicable* | *(Not Consistently Applied)* | *(Disciplined Practice for Project )* | *(Disciplined Practice Across All Project)* | *(Quantitative Practice Control)* | *(Continuous Process Improvement)* |

| No. | **Evaluation Criteria** | **Primary Responsibility for Task** | **Not able to Evaluate** | **Importance** | | | | | **Maturity** | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *1.16* | A Level 2 schedule grouped by CWPs has been developed, and it reflects the construction execution plan, engineering plan, established boundaries, and constraints. | | | 1 | 2 | 3 | 4 | 5 | 0 | 1 | 2 | 3 | 4 | 5 |
| *1.17* | Experienced construction personnel approve the schedule, scope, sequence, and timing of EWPs/CWPs. | | | 1 | 2 | 3 | 4 | 5 | 0 | 1 | 2 | 3 | 4 | 5 |
| *1.18* | A Level 3 schedule for EWPs and CWPs has been developed, and it reflects the path of construction, construction execution plan, engineering plan, established boundaries, and constraints. | | | 1 | 2 | 3 | 4 | 5 | 0 | 1 | 2 | 3 | 4 | 5 |
| *1.19* | Procurement processes are aligned with AWP. CWPs, EWPs and purchase orders are aligned and consistent. | | | 1 | 2 | 3 | 4 | 5 | 0 | 1 | 2 | 3 | 4 | 5 |
| *1.20* | The schedule plan reflects the work packaging plan. | | | 1 | 2 | 3 | 4 | 5 | 0 | 1 | 2 | 3 | 4 | 5 |
| *1.21* | The CWP boundary development process is formalized. | | | 1 | 2 | 3 | 4 | 5 | 0 | 1 | 2 | 3 | 4 | 5 |
| *1.22* | The work-packaging process is integrated with project procedures. | | | 1 | 2 | 3 | 4 | 5 | 0 | 1 | 2 | 3 | 4 | 5 |

| | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *1.23* | The transitions from area-based construction to systems-based completion have been included for the various systems. | | | 1 | 2 | 3 | 4 | 5 | 0 | 1 | 2 | 3 | 4 | 5 |
| *1.24* | Major equipment and associated vendor data requirements have been identified and aligned with AWP schedules. | | | 1 | 2 | 3 | 4 | 5 | 0 | 1 | 2 | 3 | 4 | 5 |
| *1.25* | The materials management process and system are integrated and consistent with work packaging process and system. | | | 1 | 2 | 3 | 4 | 5 | 0 | 1 | 2 | 3 | 4 | 5 |
| *1.26* | The EWP execution sequence is compatible with the CWP sequence. | | | 1 | 2 | 3 | 4 | 5 | 0 | 1 | 2 | 3 | 4 | 5 |

| Importance | | | | | Maturity | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| *Level 1* | *Level 2* | *Level 3* | *Level 4* | *Level 5* | *Level 0* | *Level 1* | *Level 2* | *Level 3* | *Level 4* | *Level 5* |
| *Extremely Unimportant* | *Unimportant* | *Neither Unimportant or Important* | *Important* | *Extremely Important* | *Not Applicable* | *(Not Consistently Applied)* | *(Disciplined Practice for Project )* | *(Disciplined Practice Across All Project)* | *(Quantitative Practice Control)* | *(Continuous Process Improvement)* |

| No. | Evaluation Criteria | Primary Responsibility for Task | Not able to Evaluate | Importance | | | | | Maturity | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *1.27* | The CWP/EWP release plan is properly reflected in the project schedule. | | | 1 | 2 | 3 | 4 | 5 | 0 | 1 | 2 | 3 | 4 | 5 |
| *1.28* | Regularly scheduled control metrics are oriented at AWP deliverables. | | | 1 | 2 | 3 | 4 | 5 | 0 | 1 | 2 | 3 | 4 | 5 |
| *1.29* | The PMT leads the integrated planning sessions and maintains the project database, ensuring that all stakeholders provide the data in the established format and schedule. | | | 1 | 2 | 3 | 4 | 5 | 0 | 1 | 2 | 3 | 4 | 5 |
| *1.30* | Path of Construction meetings minutes are reported and followed by action items. | | | 1 | 2 | 3 | 4 | 5 | 0 | 1 | 2 | 3 | 4 | 5 |
| *1.31* | Information sharing procedures define data format and frequency of communication in order to ensure that data is handled systematically. | | | 1 | 2 | 3 | 4 | 5 | 0 | 1 | 2 | 3 | 4 | 5 |
| *1.32* | CWP/EWP changes are communicated in a timely and effective manner amongst project members. | | | 1 | 2 | 3 | 4 | 5 | 0 | 1 | 2 | 3 | 4 | 5 |

| | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *1.33* | A data integration plan has been put in place to assure compatibility between systems and minimize the need for data re-entry. | | | 1 | 2 | 3 | 4 | 5 | 0 | 1 | 2 | 3 | 4 | 5 |
| *1.34* | All appropriate stakeholders attend Path of Construction meetings. | | | 1 | 2 | 3 | 4 | 5 | 0 | 1 | 2 | 3 | 4 | 5 |
| *1.35* | Project participants are pre-qualified to support AWP implementation. | | | 1 | 2 | 3 | 4 | 5 | 0 | 1 | 2 | 3 | 4 | 5 |
| *1.36* | CWP and EWP development is based on pre-defined templates (i.e. table of contents, format). | | | 1 | 2 | 3 | 4 | 5 | 0 | 1 | 2 | 3 | 4 | 5 |
| *1.37* | Formal constructability reviews are performed before developing EWP and CWP release plans. | | | 1 | 2 | 3 | 4 | 5 | 0 | 1 | 2 | 3 | 4 | 5 |

| Importance | | | | | Maturity | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| *Level 1* | *Level 2* | *Level 3* | *Level 4* | *Level 5* | *Level 0* | *Level 1* | *Level 2* | *Level 3* | *Level 4* | *Level 5* |
| *Extremely Unimportant* | *Unimportant* | *Neither Unimportant or Important* | *Important* | *Extremely Important* | *Not Applicable* | *(Not Consistently Applied)* | *(Disciplined Practice for Project )* | *(Disciplined Practice Across All Project)* | *(Quantitative Practice Control)* | *(Continuous Process Improvement)* |

| No. | Evaluation Criteria | Primary Responsibility for Task | Not able to Evaluate | Importance | | | | | Maturity | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *1.38* | The PMT finalizes and agree on the issuing, signing, and distribution process for CWP/EWP/IWP. | | | 1 | 2 | 3 | 4 | 5 | 0 | 1 | 2 | 3 | 4 | 5 |
| *1.39* | The AWP plan includes considerations for site logistics and support services. | | | 1 | 2 | 3 | 4 | 5 | 0 | 1 | 2 | 3 | 4 | 5 |
| *1.40* | The AWP plan includes long-lead items assessment. | | | 1 | 2 | 3 | 4 | 5 | 0 | 1 | 2 | 3 | 4 | 5 |
| *1.41* | The information that is shared across disciplines and functions is understood and applied in the systems and tools to be deployed on the project. | | | 1 | 2 | 3 | 4 | 5 | 0 | 1 | 2 | 3 | 4 | 5 |
| *1.42* | Information sharing between project participants are set up to meet AWP requirements. | | | 1 | 2 | 3 | 4 | 5 | 0 | 1 | 2 | 3 | 4 | 5 |
| *1.43* | Business processes are integrated with the IT systems to support AWP. | | | 1 | 2 | 3 | 4 | 5 | 0 | 1 | 2 | 3 | 4 | 5 |
| *1.44* | Cost and payment milestones reflect the work packaging plan. | | | 1 | 2 | 3 | 4 | 5 | 0 | 1 | 2 | 3 | 4 | 5 |

| | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *1.45* | Commissioning and Start-Up considerations have been integrated into the early planning process. | | | 1 | 2 | 3 | 4 | 5 | 0 | 1 | 2 | 3 | 4 | 5 |
| *1.46* | The PMT had sufficient resources to complete the scope definition phase. | | | 1 | 2 | 3 | 4 | 5 | 0 | 1 | 2 | 3 | 4 | 5 |
| *1.47* | A training matrix is established in regards to AWP strategy. | | | 1 | 2 | 3 | 4 | 5 | 0 | 1 | 2 | 3 | 4 | 5 |
| *1.48* | The owner is responsible for program compliance and process discipline definitions. | | | 1 | 2 | 3 | 4 | 5 | 0 | 1 | 2 | 3 | 4 | 5 |
| *1.49* | AWP champion reviews the major systems and support functions for AWP execution (e.g. staffing, budgets, templates, engineering design systems). | | | 1 | 2 | 3 | 4 | 5 | 0 | 1 | 2 | 3 | 4 | 5 |

**Other (Please list and evaluate):**

| No. | **Evaluation Criteria** | **Primary Responsibility for Task** | **Not able to Evaluate** | **Importance** | | | | | **Maturity** | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *1.50* | | | | 1 | 2 | 3 | 4 | 5 | 0 | 1 | 2 | 3 | 4 | 5 |
| *1.51* | | | | 1 | 2 | 3 | 4 | 5 | 0 | 1 | 2 | 3 | 4 | 5 |
| *1.52* | | | | 1 | 2 | 3 | 4 | 5 | 0 | 1 | 2 | 3 | 4 | 5 |
| *1.53* | | | | 1 | 2 | 3 | 4 | 5 | 0 | 1 | 2 | 3 | 4 | 5 |

## 2) Phase II – Detailed Engineering

| Importance | | | | | Maturity | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| *Level 1* | *Level 2* | *Level 3* | *Level 4* | *Level 5* | *Level 0* | *Level 1* | *Level 2* | *Level 3* | *Level 4* | *Level 5* |
| *Extremely Unimportant* | *Unimportant* | *Neither Unimportant or Important* | *Important* | *Extremely Important* | *Not Applicable* | *(Not Consistently Applied)* | *(Disciplined Practice for Project )* | *(Disciplined Practice Across All Project)* | *(Quantitative Practice Control)* | *(Continuous Process Improvement)* |

| No. | **Evaluation Criteria** | **Primary Responsibility for Task** | **Not able to Evaluate** | **Importance** | | | | | **Maturity** | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *2.1* | Prior to the start of detailed engineering, a schedule is developed for all CWPs and EWPs, and it aligns with the agreed upon path of construction. | | | 1 | 2 | 3 | 4 | 5 | 0 | 1 | 2 | 3 | 4 | 5 |
| *2.2* | Detailed roles and responsibilities are defined and updated for all stakeholders to support AWP content. | | | 1 | 2 | 3 | 4 | 5 | 0 | 1 | 2 | 3 | 4 | 5 |
| *2.3* | Dedicated IWP planner(s) have been identified and a written job description for planners is in place. | | | 1 | 2 | 3 | 4 | 5 | 0 | 1 | 2 | 3 | 4 | 5 |
| *2.4* | All planners are on the distribution list for all project documentation or have access to the latest information required for the preparation of IWPs. | | | 1 | 2 | 3 | 4 | 5 | 0 | 1 | 2 | 3 | 4 | 5 |

| | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *2.5* | The CM appoints dedicated AWP material coordinators. | | | 1 | 2 | 3 | 4 | 5 | 0 | 1 | 2 | 3 | 4 | 5 |
| *2.6* | The tracking levels and coordination procedures are established for the planners, general foremen, construction superintendent, and resource coordinators to drive the performance during the construction phase. | | | 1 | 2 | 3 | 4 | 5 | 0 | 1 | 2 | 3 | 4 | 5 |
| *2.7* | Adequate audits for AWP implementation are undertaken. | | | 1 | 2 | 3 | 4 | 5 | 0 | 1 | 2 | 3 | 4 | 5 |
| *2.8* | EWPs are associated with CWPs with appropriate lag time to allow CWP/IWP development. | | | 1 | 2 | 3 | 4 | 5 | 0 | 1 | 2 | 3 | 4 | 5 |
| *2.9* | The attributes of all portions of the model have been associated with the EWPs and the systems. | | | 1 | 2 | 3 | 4 | 5 | 0 | 1 | 2 | 3 | 4 | 5 |

| Importance | | | | | Maturity | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| *Level 1* | *Level 2* | *Level 3* | *Level 4* | *Level 5* | *Level 0* | *Level 1* | *Level 2* | *Level 3* | *Level 4* | *Level 5* |
| *Extremely Unimportant* | *Unimportant* | *Neither Unimportant or Important* | *Important* | *Extremely Important* | *Not Applicable* | *(Not Consistently Applied)* | *(Disciplined Practice for Project )* | *(Disciplined Practice Across All Project)* | *(Quantitative Practice Control)* | *(Continuous Process Improvement)* |

| No. | **Evaluation Criteria** | **Primary Responsibility for Task** | **Not able to Evaluate** | **Importance** | | | | | **Maturity** | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *2.10* | A formal process or procedure for EWPs has been established with input from the planning and document control teams to forecast accurate completion dates and to consistently progress EWPs. | | | 1 | 2 | 3 | 4 | 5 | 0 | 1 | 2 | 3 | 4 | 5 |
| *2.11* | A detailed bill of material is developed for each EWP. | | | 1 | 2 | 3 | 4 | 5 | 0 | 1 | 2 | 3 | 4 | 5 |
| *2.12* | Systems have been identified and incorporated into the planning process at this phase. | | | 1 | 2 | 3 | 4 | 5 | 0 | 1 | 2 | 3 | 4 | 5 |
| *2.13* | Engineering progress is tracked by EWP. | | | 1 | 2 | 3 | 4 | 5 | 0 | 1 | 2 | 3 | 4 | 5 |
| *2.14* | Detailed Constructability reviews are performed after AWP Planners have been appointed. | | | 1 | 2 | 3 | 4 | 5 | 0 | 1 | 2 | 3 | 4 | 5 |
| *2.15* | Detailed design is completed and released through EWPs. | | | 1 | 2 | 3 | 4 | 5 | 0 | 1 | 2 | 3 | 4 | 5 |
| *2.16* | An ongoing feedback loop exists between the construction planning and engineering planning teams so that both are proceeding in alignment with work packaging planning. | | | 1 | 2 | 3 | 4 | 5 | 0 | 1 | 2 | 3 | 4 | 5 |

| | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *2.17* | Regular reports are developed for AWP integrated systems by CM, Engineering, and Construction Constructor. | | | 1 | 2 | 3 | 4 | 5 | 0 | 1 | 2 | 3 | 4 | 5 |
| *2.18* | Commissioning and Start Up activities and sequencing have been identified and included into detailed engineering. | | | 1 | 2 | 3 | 4 | 5 | 0 | 1 | 2 | 3 | 4 | 5 |
| *2.19* | The owner assures that reporting requirements and document control are defined and support AWP. | | | 1 | 2 | 3 | 4 | 5 | 0 | 1 | 2 | 3 | 4 | 5 |

| Importance | | | | | Maturity | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| *Level 1* | *Level 2* | *Level 3* | *Level 4* | *Level 5* | *Level 0* | *Level 1* | *Level 2* | *Level 3* | *Level 4* | *Level 5* |
| *Extremely Unimportant* | *Unimportant* | *Neither Unimportant or Important* | *Important* | *Extremely Important* | *Not Applicable* | *(Not Consistently Applied)* | *(Disciplined Practice for Project )* | *(Disciplined Practice Across All Project)* | *(Quantitative Practice Control)* | *(Continuous Process Improvement)* |

| No. | Evaluation Criteria | Primary Responsibility for Task | Not able to Evaluate | Importance | | | | | Maturity | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *2.20* | The owner is actively involved and plays an oversight role to assure continued alignment according to AWP plan. | | | 1 | 2 | 3 | 4 | 5 | 0 | 1 | 2 | 3 | 4 | 5 |
| *2.21* | Vendor’s data are mapped for each EWP and included within the Purchase Order. | | | 1 | 2 | 3 | 4 | 5 | 0 | 1 | 2 | 3 | 4 | 5 |
| *2.22* | The PMT establishes defined document and control processes before AWP information are issued for construction. | | | 1 | 2 | 3 | 4 | 5 | 0 | 1 | 2 | 3 | 4 | 5 |
| *2.23* | Engineering Deliverables were issued on schedule in accordance with the EWP plan. | | | 1 | 2 | 3 | 4 | 5 | 0 | 1 | 2 | 3 | 4 | 5 |
| *2.24* | Engineering deliverables were complete (in terms of required documentation) when they were first issued. | | | 1 | 2 | 3 | 4 | 5 | 0 | 1 | 2 | 3 | 4 | 5 |

**Other (Please list and evaluate):**

| No. | Evaluation Criteria | Primary Responsibility for Task | Not able to Evaluate | Importance | | | | | Maturity | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *2.25* | | | | 1 | 2 | 3 | 4 | 5 | 0 | 1 | 2 | 3 | 4 | 5 |
| *2.26* | | | | 1 | 2 | 3 | 4 | 5 | 0 | 1 | 2 | 3 | 4 | 5 |
| *2.27* | | | | 1 | 2 | 3 | 4 | 5 | 0 | 1 | 2 | 3 | 4 | 5 |

## 3) Phase III – Construction

| Importance | | | | | Maturity | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| *Level 1* | *Level 2* | *Level 3* | *Level 4* | *Level 5* | *Level 0* | *Level 1* | *Level 2* | *Level 3* | *Level 4* | *Level 5* |
| *Extremely Unimportant* | *Unimportant* | *Neither Unimportant or Important* | *Important* | *Extremely Important* | *Not Applicable* | *(Not Consistently Applied)* | *(Disciplined Practice for Project )* | *(Disciplined Practice Across All Project)* | *(Quantitative Practice Control)* | *(Continuous Process Improvement)* |

| No. | Evaluation Criteria | Primary Responsibility for Task | Not able to Evaluate | Importance | | | | | Maturity | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *3.1* | The IWP definition, issuance and control processes are documented and recorded on a regular basis. | | | 1 | 2 | 3 | 4 | 5 | 0 | 1 | 2 | 3 | 4 | 5 |
| *3.2* | A process for constraint identification and resolution is in place. | | | 1 | 2 | 3 | 4 | 5 | 0 | 1 | 2 | 3 | 4 | 5 |
| *3.3* | Work is always packaged in Installation Work Packages (IWP). | | | 1 | 2 | 3 | 4 | 5 | 0 | 1 | 2 | 3 | 4 | 5 |
| *3.4* | IWPs always identify the work to be completed by the team (as indicated by technical data, drawings, and specifications). | | | 1 | 2 | 3 | 4 | 5 | 0 | 1 | 2 | 3 | 4 | 5 |
| *3.5* | All IWPs identify the general sequence of the work and the labor necessary to complete the work. | | | 1 | 2 | 3 | 4 | 5 | 0 | 1 | 2 | 3 | 4 | 5 |
| *3.6* | All IWPs identify all required material necessary to complete the work. | | | 1 | 2 | 3 | 4 | 5 | 0 | 1 | 2 | 3 | 4 | 5 |
| *3.7* | Materials are bagged and tagged by IWP. | | | 1 | 2 | 3 | 4 | 5 | 0 | 1 | 2 | 3 | 4 | 5 |
| *3.8* | All IWPs identify all relevant special conditions. | | | 1 | 2 | 3 | 4 | 5 | 0 | 1 | 2 | 3 | 4 | 5 |

| | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *3.9* | All IWPs include or reference all quality control and non-destructive examination requirements. | | | 1 | 2 | 3 | 4 | 5 | 0 | 1 | 2 | 3 | 4 | 5 |
| *3.10* | IWPs include or reference all major execution risk response plans. | | | 1 | 2 | 3 | 4 | 5 | 0 | 1 | 2 | 3 | 4 | 5 |
| *3.11* | All IWPs identify their interdependencies. | | | 1 | 2 | 3 | 4 | 5 | 0 | 1 | 2 | 3 | 4 | 5 |
| *3.12* | IWP progress in the field is monitored on a regular basis by the planner. | | | 1 | 2 | 3 | 4 | 5 | 0 | 1 | 2 | 3 | 4 | 5 |

| Importance | | | | | Maturity | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| *Level 1* | *Level 2* | *Level 3* | *Level 4* | *Level 5* | *Level 0* | *Level 1* | *Level 2* | *Level 3* | *Level 4* | *Level 5* |
| *Extremely Unimportant* | *Unimportant* | *Neither Unimportant or Important* | *Important* | *Extremely Important* | *Not Applicable* | *(Not Consistently Applied)* | *(Disciplined Practice for Project )* | *(Disciplined Practice Across All Project)* | *(Quantitative Practice Control)* | *(Continuous Process Improvement)* |

| No. | Evaluation Criteria | Primary Responsibility for Task | Not able to Evaluate | Importance | | | | | Maturity | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *3.13* | Periodic audits are conducted to ensure that the IWP close out process is working and is accurately collecting and validating planned versus actual data. | | | 1 | 2 | 3 | 4 | 5 | 0 | 1 | 2 | 3 | 4 | 5 |
| *3.14* | Lessons learned are being captured in the IWP close out process. | | | 1 | 2 | 3 | 4 | 5 | 0 | 1 | 2 | 3 | 4 | 5 |
| *3.15* | A backlog of IWPs is created and issued to minimize the impact of unforeseen circumstances. | | | 1 | 2 | 3 | 4 | 5 | 0 | 1 | 2 | 3 | 4 | 5 |
| *3.16* | General foremen, planners, and construction superintendents review and agree to the schedule, scope, sequence, and timing of the IWP. | | | 1 | 2 | 3 | 4 | 5 | 0 | 1 | 2 | 3 | 4 | 5 |
| *3.17* | IWP Status (progress and cost) is tracked in a visible way, including completion of IWP against targets. | | | 1 | 2 | 3 | 4 | 5 | 0 | 1 | 2 | 3 | 4 | 5 |
| *3.18* | A schedule and release plan is developed for all IWPs based on CWPs. | | | 1 | 2 | 3 | 4 | 5 | 0 | 1 | 2 | 3 | 4 | 5 |

| | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *3.19* | IWPs are retained in electronic format and are not issued until one to two weeks prior to execution, or until all known constraints have been met. | | | 1 | 2 | 3 | 4 | 5 | 0 | 1 | 2 | 3 | 4 | 5 |
| *3.20* | System turnover designations are added to the coding systems for all IWPs. | | | 1 | 2 | 3 | 4 | 5 | 0 | 1 | 2 | 3 | 4 | 5 |
| *3.21* | The Bill of Materials is segregated by IWP. | | | 1 | 2 | 3 | 4 | 5 | 0 | 1 | 2 | 3 | 4 | 5 |
| *3.22* | The project is able to roll-up data from the IWP level to the appropriate level for management review. | | | 1 | 2 | 3 | 4 | 5 | 0 | 1 | 2 | 3 | 4 | 5 |
| *3.23* | Planners use IWP checklist to develop the packages for different construction disciplines. | | | 1 | 2 | 3 | 4 | 5 | 0 | 1 | 2 | 3 | 4 | 5 |
| *3.24* | EWP are formally accepted by construction after checked for completion. | | | 1 | 2 | 3 | 4 | 5 | 0 | 1 | 2 | 3 | 4 | 5 |

| Importance | | | | | Maturity | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| *Level 1* | *Level 2* | *Level 3* | *Level 4* | *Level 5* | *Level 0* | *Level 1* | *Level 2* | *Level 3* | *Level 4* | *Level 5* |
| *Extremely Unimportant* | *Unimportant* | *Neither Unimportant or Important* | *Important* | *Extremely Important* | *Not Applicable* | *(Not Consistently Applied)* | *(Disciplined Practice for Project)* | *(Disciplined Practice Across All Project)* | *(Quantitative Practice Control)* | *(Continuous Process Improvement)* |

| No. | Evaluation Criteria | Primary Responsibility for Task | Not able to Evaluate | Importance | | | | | Maturity | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *2.25* | Close out verification include punch list generation and evaluation guidelines. | | | 1 | 2 | 3 | 4 | 5 | 0 | 1 | 2 | 3 | 4 | 5 |
| *2.26* | Safety instruments tied into CWP are correspondingly reported at the IWP level (e.g. field-level and job hazard analysis). | | | 1 | 2 | 3 | 4 | 5 | 0 | 1 | 2 | 3 | 4 | 5 |
| *3.24* | EWP are formally accepted by construction after checked for completion. | | | 1 | 2 | 3 | 4 | 5 | 0 | 1 | 2 | 3 | 4 | 5 |
| *3.25* | Close out verification include punch list generation and evaluation guidelines. | | | 1 | 2 | 3 | 4 | 5 | 0 | 1 | 2 | 3 | 4 | 5 |
| *3.26* | Safety instruments tied into CWP are correspondingly reported at the IWP level (e.g. field-level and job hazard analysis). | | | 1 | 2 | 3 | 4 | 5 | 0 | 1 | 2 | 3 | 4 | 5 |
| *3.27* | Safety assessments are checked before IWP release. | | | 1 | 2 | 3 | 4 | 5 | 0 | 1 | 2 | 3 | 4 | 5 |
| *3.28* | The role of Planners is appointed to experienced construction personnel. | | | 1 | 2 | 3 | 4 | 5 | 0 | 1 | 2 | 3 | 4 | 5 |

| | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *3.29* | Appropriate stakeholders have signed off on issued IWPs to indicate that constraints have been met. | | | 1 | 2 | 3 | 4 | 5 | 0 | 1 | 2 | 3 | 4 | 5 |
| *3.30* | The owner does not directly manage field activities but continues playing an important leadership, control and auditing role | | | 1 | 2 | 3 | 4 | 5 | 0 | 1 | 2 | 3 | 4 | 5 |
| *3.31* | The Owner finalizes the sequence and completes the process for start-up. | | | 1 | 2 | 3 | 4 | 5 | 0 | 1 | 2 | 3 | 4 | 5 |
| *3.32* | Specific responsibilities are assigned to key individuals for the correct close out of an issued IWP. | | | 1 | 2 | 3 | 4 | 5 | 0 | 1 | 2 | 3 | 4 | 5 |
| *3.33* | Planners build system packages for commissioning. | | | 1 | 2 | 3 | 4 | 5 | 0 | 1 | 2 | 3 | 4 | 5 |
| *3.34* | Onsite materials are traceable and identifiable by IWP | | | 1 | 2 | 3 | 4 | 5 | 0 | 1 | 2 | 3 | 4 | 5 |

**Other (Please list and evaluate):**

| No. | **Evaluation Criteria** | **Primary Responsibility for Task** | **Not able to Evaluate** | **Importance** | | | | | **Maturity** | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *3.35* | | | | 1 | 2 | 3 | 4 | 5 | 0 | 1 | 2 | 3 | 4 | 5 |
| *3.36* | | | | 1 | 2 | 3 | 4 | 5 | 0 | 1 | 2 | 3 | 4 | 5 |
| *3.37* | | | | 1 | 2 | 3 | 4 | 5 | 0 | 1 | 2 | 3 | 4 | 5 |
| *3.38* | | | | 1 | 2 | 3 | 4 | 5 | 0 | 1 | 2 | 3 | 4 | 5 |

*Thank you for completing the survey*

## A.2. AWP Additional Costs Form Evaluation Criteria

The different AWP tasks used to evaluate AWP Exclusive Costs are listed in Table A.2.

Table A.1. AWP Exclusive Task Descriptions

| Responsible for Task | No | Task Description |
|---|---|---|
| 1.1 Owner | 1.1.1 | Assign sponsors and champions |
| | 1.1.2 | Review and integrate processes and support functions |
| | 1.1.3 | Develop Advanced Work Packaging (AWP) strategy |
| | 1.1.4 | Define AWP as required for all participants |
| | 1.1.5 | Ensure AWP requirements are in contracts |
| | 1.1.6 | Establish internal AWP audit protocols |
| | 1.1.7 | Develop Project Level 1 Schedule (consider the additional effort for AWP only) |
| | 1.1.8 | Revision of standard contract schedules to ensure AWP requirements are in place. |
| | 1.1.9 | Appoint Construction data Coordinator |
| | 1.1.10 | Control Owner/project data requirements |
| | 1.1.11 | Initiate and coordinate management audit of AWP |
| | 1.1.12 | Engage auditor |
| 1.2 Project Management | 1.2.1 | Demonstrate Capacity(ability) to support or conduct AWP |
| | 1.2.2 | Write the requirement for AWP into Contracts |
| | 1.2.3 | Assign AWP Auditors |
| | 1.2.4 | Integration of AWP into the WBS |
| | 1.2.5 | Setup server to host the databases used by all participants (consider the additional effort for AWP only) |
| | 1.2.6 | Develop Project Level 2 Schedule (consider the additional effort for AWP only) |
| | 1.2.7 | Appoint AWP Manager |
| | 1.2.8 | Ensure AWP systems and support functions are aligned |
| | 1.2.9 | Develop Project Level 3 Schedule (consider the additional effort for AWP only) |
| | 1.2.10 | Implement processes to ensure that Workface planners have access to the latest project data |

| Responsible for Task | No | Task Description |
|---|---|---|
| | 1.2.11 | Implement AWP automation/input systems |
| | 1.2.12 | Revise functional procedures to establish or integrate AWP processes |
| 1.3 Construction Management | 1.3.1 | Demonstrate Capacity(ability) to support or conduct AWP |
| | 1.3.2 | AWP execution plan |
| | 1.3.3 | Turnover Plan (consider the additional effort for AWP only) |
| | 1.3.4 | Construction input into path of construction |
| | 1.3.5 | Appoint AWP Manager (CM) |
| | 1.3.6 | Develop Staffing Plan (CM) (consider additional cost for AWP only) |
| | 1.3.7 | Review and revise Path of Construction and development of CWPs from CWAs (consider the additional effort for AWP only) |
| | 1.3.8 | Issue CWP release plan (consider the additional effort for AWP only) |
| | 1.3.9 | Appoint Construction Model Admin. |
| 1.4 Supply Chain Management | 1.4.1 | Request for proposal (consider the additional effort for AWP only) |
| | 1.4.2 | Contract Formation for engineering (consider the additional effort for AWP only) |
| | 1.4.3 | Management of Procurement Strategy (consider the additional effort for AWP only) |
| | 1.4.4 | Management of Contracting Strategy (consider the additional effort for AWP only) |
| | 1.4.5 | Align procurement process with Advanced Work Packaging |
| | 1.4.6 | Request For Proposal (consider the additional effort for AWP only) |
| | 1.4.7 | Contract development for const. contractor, Fabricator (consider the additional effort for AWP only) |
| | 1.4.8 | Management of Procurement plan (consider the additional effort for AWP only) |
| | 1.4.9 | Management of Contracting Plan (consider the additional effort for AWP only) |
| 1.5 Engineering Contractor | 1.5.1 | Demonstrate Capacity(ability) to support or conduct AWP |
| | 1.5.2 | Assign AWP champion |
| | 1.5.3 | Develop primary plot plan (consider the additional effort for AWP only) |
| | 1.5.4 | Design Area Definition (consider the additional effort for AWP only) |

| Responsible for Task | No | Task Description |
|---|---|---|
| | 1.5.5 | Develop EWP release plan (consider the additional effort for AWP only) |
| | 1.5.6 | Issue EWP release plan (consider the additional effort for AWP only) |
| 1.6 Construction Contractor | 1.6.1 | Demonstrate Capacity(ability) to support or conduct AWP |
| | 1.6.2 | Appoint AWP Lead |
| | 1.6.3 | Develop Staffing Plan for AWP |
| | 1.6.4 | Appoint support administrator for AWP information management |
| | 1.6.5 | Construction Input to plan |
| 1.7 Coordinated Efforts | 1.7.1 | Integrated planning sessions (consider the additional effort for AWP only) |
| | 1.7.2 | Level 2 Schedule Review with construction input (consider the additional effort for AWP only) |
| | 1.7.3 | Contract format constructability reviews (consider the additional effort for AWP only) |
| | 1.7.4 | Integrated Planning sessions / Level 3 schedule review (consider the additional effort for AWP only) |
| 2.1 Owner | 2.1.1 | Initiate and coordinate management audit of AWP |
| | 2.1.2 | Engage AWP auditor |
| 2.2 Project Management | 2.2.1 | Align Document control process to support WFP |
| | 2.2.2 | Review alignment of work processes (consider the additional effort for AWP only) |
| 2.3 Construction Management | 2.3.1 | Develop regular report intervals for AWP integrated systems |
| | 2.3.2 | Add definition and IFC to planned CWPs |
| | 2.3.3 | Assign dedicated coordinators for scaffold, and equipment and other support trades (consider the additional effort for AWP only) |
| 2.4 Supply Chain Management | 2.4.1 | Purchase equipment and materials (consider the additional effort for AWP only) |
| | 2.4.2 | Appoint dedicated material coordinator for WFP |
| 2.5 Engineering | 2.5.1 | Establish regular delivery for 3D model |
| | 2.5.2 | Track Engineering progress by EWP (consider the additional effort for AWP only) |
| | 2.5.3 | Complete detailed design (consider the additional effort for AWP only) |

| Responsible for Task | No | Task Description |
|---|---|---|
| | 2.5.4 | Engineering release EWPs (consider the additional effort for AWP only) |
| 2.6 Construction Contractor | 2.6.1 | WFP lead; Report regularly to CMT on integrated systems |
| | 2.6.2 | Appoint Workface Planners (Phased) |
| | 2.6.3 | Develop IWP release plan |
| | 2.6.4 | Develop level 4 schedule (consider the additional effort for AWP only) |
| | 2.6.5 | Issue IWP release plan |
| | 2.6.6 | Appoint WFP equipment & scaffold coordinators |
| 2.7 Coordinated Efforts | 2.7.1 | Detailed Constructability Reviews (consider the additional effort for AWP only) |
| 3.1 Owner | 3.1.1 | Initiate and coordinate management audit of WFP |
| | 3.1.2 | Engage WFP auditor |
| | 3.1.3 | Finalize start up sequence (consider the additional effort for AWP only) |
| | 3.1.4 | Complete pre start up safety review (consider the additional effort for AWP only) |
| | 3.1.5 | Owner completes start up process (consider the additional effort for AWP only) |
| | 3.1.6 | Initiate and coordinate management audit of Workface Planning |
| | 3.1.7 | Engage 3rd party WFP auditor |
| 3.2 Project Management | 3.2.1 | Coordinate and address findings from the audits |
| | 3.2.2 | Coordinate overall project needs and reporting (consider the additional effort for AWP only) |
| | 3.2.3 | Review report on constraint satisfaction (consider the additional effort for AWP only) |
| | 3.2.4 | Close out and Handover (consider the additional effort for AWP only) |
| | 3.2.5 | Coordinate overall project needs and reporting (consider the additional effort for AWP only) |
| | 3.2.6 | Collect and Document Lessons Learned |
| | 3.3.1 | Release CWP |

| Responsible for Task | No | Task Description |
|---|---|---|
| 3.3 Construction Management | 3.3.2 | Track progress of IWP creation |
| | 3.3.3 | Initiate and coordinate regular management audit of WFP |
| | 3.3.4 | Maintain Constraint matrix in Database |
| | 3.3.5 | Constraints analyzed, logged and managed on CWPs and resolve any required RFIs (consider the additional effort for AWP only) |
| | 3.3.6 | Report Progress from field at CWP level (consider the additional effort for AWP only) |
| | 3.3.7 | Complete QC Documentation |
| | 3.3.8 | Facilitate Punch lists and start up process (consider the additional effort for AWP only) |
| | 3.3.9 | Collect and Document Lessons Learned |
| 3.4 Supply Chain Management | 3.4.1 | Assign IWP limits into MMS (consider the additional effort for AWP only) |
| | 3.4.2 | Bag and Tag Materials by IWP (consider the additional effort for AWP only) |
| | 3.4.3 | Collect and Document Lessons Learned |
| 3.5 Engineering | 3.5.1 | Finalize As-Builts |
| | 3.5.2 | Collect and Document Lessons Learned |
| 3.6 Construction | 3.6.1 | Workface Planners break down CWPs into 500 – 1000hr IWPs |
| | 3.6.2 | Workface Planners develop IWP backlog |
| | 3.6.3 | Initiate and coordinate regular management audit of WFP |
| | 3.6.4 | Constraints analyzed and removed prior to issue of IWPs and file any required RFIs |
| | 3.6.5 | Issue IWPs sequentially to the field |
| | 3.6.6 | Field Executes the IWP |
| | 3.6.7 | Report IWP progress to project controls (consider the additional effort for AWP only) |
| | 3.6.8 | Prepare System Completion Packages From IWPs (consider the additional effort for AWP only) |
| | 3.6.9 | Workface Planners facilitate Hydro testing and turnover packages (consider the additional effort for AWP only) |

| Responsible for Task | No | Task Description |
|---|---|---|
| Construction Contractor | 3.6.10 | Workface Planners Build system packages for commissioning |
| | 3.6.11 | Collect and Document Lessons Learned |
| 3.7 Coordinated Efforts | 3.7.1 | Construction readiness meetings |

A.3. Workface Planner Qualification Characterization Criteria

STUDY TO ASSESS THE ADVANTAGES OF UTILIZING ADVANCED WORK PACKAGING (AWP) ON CONSTRUCTION PROJECTS

*WorkFace Planner Qualification Characterization*

*Self-evaluation Survey*

Dear Participant,

The University of Alberta under the Natural Sciences and Engineering Research Council of Canada (NSERC), and the Industrial Research Chair in Strategic Construction Modeling and Delivery would like to thank you for agreeing to participate in this survey. This study is intended to assess the advantages of utilizing Advanced Work Packaging (AWP) for the improvement of project performance. This interview survey is intended to assess the maturity of AWP within your organization and on this project.

Background:

Advanced Work Packaging (AWP) was announced as a best practice by the Construction Industry Institute (CII) in 2015 and has been adopted by the Construction Owners Association of Alberta (COAA). This study aims to quantify the costs and benefits of implementing an Advanced Work Packaging/WorkFace Planning (AWP/WFP) program on construction projects by measuring the impacts of such a program on schedule performance, cost performance, predictability, field productivity, rework, safety, and indirect costs. Characterizing the qualifications of WorkFace planners on a project is one factor that needs to be considered before assessing the impacts of AWP on the performance of a project.

Your participation in this survey is purely voluntary. You do not have to participate, and there are no consequences if you do not. All answers will remain confidential, and only the aggregated results will be made public in the form of reports and publications.

Your participation will be limited to completing this survey, which will take approximately *twenty minutes* to complete.

This survey consists of two main sections. The first section is designed to collect general information about the project and yourself. The second section includes a list of qualifications of WorkFace planners, and you are asked to assess yourself in terms of the relative importance of each qualification to your job as a WorkFace Planner and your level of agreement that you possess this qualification.

Note: The COAA definitions of the different types of WorkFace Planners, who are dedicated solely to AWP, are presented below to assist in filling out the second section of this form.

*WorkFace Planner*

The WorkFace Planner is responsible for the conversion of Construction Work Packages (CWP) into Installation Work Packages (IWP). He or she is also responsible for ensuring that all necessary resources are available prior to releasing the IWP and for monitoring and control of the IWP. The primary responsibilities of the WorkFace Planner include (1) ensuring safety, quality and efficiency at the WorkFace are considered in the planning process; (2) developing IWPs; (3) coordinating with and imparting WorkFace construction knowledge to project schedulers, engineers, superintendents, and managers; and (4) acting as a liaison between the project controls department and workforce supervision.

*Equipment WorkFace Planner*

The Equipment WorkFace Planner (WFP) is responsible for supporting the execution of IWPs by coordinating the allocation of construction equipment to meet the needs of the plans. Construction equipment includes cranes, manlifts, heaters, pumps, generators, and welders. The Equipment WFP will do this by collecting requests for construction equipment from the WorkFace Planners two weeks in advance. The total projected needs of the IWPs will then form a forecast. The Equipment WFP will then balance the equipment pool to satisfy the forecast and share the forecast with the Equipment Coordinator. Essential duties of the Equipment WorkFace Planner include, (1) ensure needs of the IWP’s can be met and equipment is well utilized; (2) ensure equipment requests are received sufficiently ahead of execution; (3) work with the WorkFace Planners to match the equipment (size and reach of cranes & manlifts) to the tasks; and (4) work with WorkFace Planners to suggest alignment strategies for the shared use of cranes.

*Material Management WorkFace Planner*

The Material Management WorkFace Planner (WFP) is responsible for supporting the execution of work by coordinating the allocation and delivery of materials to satisfy the needs of the IWP’s. Working with the material management database, the Material Management WFP will align the received materials with the proposed IWP’s in order of priority (set by execution date). This will show the WorkFace Planners which IWP's are buildable and will produce a list of material shorts for each IWP four weeks prior to execution. The Material Management WFP will then produce a material take off for each IWP and give this information to the material management staff so that they may prepackage materials into IWP's. Essential duties of the Material Management WorkFace Planner include (1) provide an accurate assessment of which IWP's can be built based on the material received; (2) enable the material delivery system by identifying IWP's prior to their request for delivery; (3) work with the WFPs to develop a process for coordinated material delivery; and (4) coordinate alignment between the Material Management group and the WorkFace Planners.

*Scaffold WorkFace Planner*

The Scaffold WorkFace Planner (WFP) is responsible for supporting the execution of IWPs by coordinating the erection of scaffold prior to the plans being released. The Scaffold WFP will do this by collecting requests for scaffold from the WorkFace Planners on a daily basis and reviewing the requests for integration with other discipline needs so that multi-discipline scaffolds can be erected. The scaffolds will then be arranged into IWPs for the scaffold crews to complete. If a scaffold management database is to be used, then the Scaffold WorkFace Planner would administrate this process.

SECTION 1: GENERAL INFORMATION

*1.1.* Please select the industry that the current project belongs to:

□ New Home Building and Renovation - building, remodelling or renovating houses and apartment buildings

□ Civil Engineering Construction Engineering Projects - highways, dams, water and sewer lines, power and communication lines, and bridges

□ Institutional and Commercial Construction - building commercial and institutional buildings and structures such as stadiums, schools, hospitals, grain elevators and indoor swimming pools

□ Heavy Industrial Construction - building industrial facilities such as cement, automotive, chemical or power plants, refineries and oil-sands installations

□ Other (please specify): ______________________

*1.2.* Please indicate the current project name:

_____________________

*1.3.* Please indicate the current project location:

______________________________

*1.4.* Please rate the current project complexity:

□ Low □ Somewhat Low □ Average

□ Somewhat High □ High

*1. 5.* How long have you been employed in the current project?

________ Year(s) _________ Month(s)

*1.6.* Please select your organization type in this project: (please specify ALL that apply)

□ Owner

□ Consultant and/or project management services

□ Engineering Firm

□ Engineering and Procurement

□ EPC firm

□ Main Contractor

□ Construction Contractor

□ Fabrication Contractor

□ Other (please specify): ______________________

*1.7.* Please select the type of WorkFace planner that would best describe your position:

□ General WorkFace planner

□ Material WorkFace planner

□ Equipment WorkFace planner

□ Scaffold WorkFace planner

□ Other (please specify): ______________________

*1.8.* Please select the type of WorkFace planning you are involved in by discipline:

□ Piping WorkFace planner

□ Structural WorkFace planner

□ Electrical WorkFace planner

□ Scaffold WorkFace planner

□ Mechanical (without piping) WorkFace planner

□ Other (please specify): ______________________

*1.9.* How long have you been employed by your current employer?

________ Year(s) _________ Month(s)

*1.10.* How long have you worked as a WorkFace planner in total?

________ Year(s) ________Month(s)

*1.11.* Please specify your age:

□ Under 20 □ 20 - 30 □ 31 - 40 □ 41 - 50 □ 51 - 60 □ Over 60

*1. 12.* Approximately, how many years of experience do you have on projects that implemented WFP (WorkFace Planning)/AWP (Advanced Work Packaging)?

________ Year(s) ________Month(s)

SECTION 2: WORKFACE PLANNER QUALIFICATION CHARACTERIZATION

This section of the survey presents the competencies (i.e., qualifications) of WorkFace planners in different categories, which you are asked to evaluate for yourself on the basis of the two measurement scales that are provided as follows:

Importance Measurement: is to measure how important a qualification is to the category being evaluated (e.g., safety), which can vary within five levels as shown below:

| Scale value | Scale description |
|---|---|
| 1 | Criterion is extremely unimportant to the associated competency |
| 2 | Criterion is unimportant to the associated competency |
| 3 | Criterion is neither unimportant or important to the associated competency |
| 4 | Criterion is important to the associated competency |
| 5 | Criterion is extremely important to the associated competency |

Agreement Measurement: is to measure the extent to which you believe you possesses the qualification on this project, which can vary within five levels as shown below:

| Scale value | Scale description |
|---|---|
| 1 | Strongly disagree |
| 2 | Disagree |
| 3 | Neither Disagree Nor Agree |
| 4 | Agree |
| 5 | Strongly Agree |

Please provide your self-evaluation for the different qualifications of your role as a WorkFace planner by providing a value for each of the measurement scales (Importance and Agreement measurements) as identified above. Blank rows are provided for you to add additional criteria that you feel are critical to your qualifications as a WorkFace planner.

Note: If a qualification is not applicable to your role as a WorkFace planner on this project, please choose the “Not Applicable” column and proceed to the next qualification.

| No | Evaluation Criteria | Not Applicable | Importance | | | | | Agreement | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | *Extremely Unimportant* | *Unimportant* | *Neither Unimportant or Important* | *Important* | *Extremely Important* | *Strongly Disagree* | *Disagree* | *Neither Disagree Nor Agree* | *Agree* | *Strongly Agree* |
| ***1*** | **Essential Duties** | | | | | | | | | | | |
| *1.1* | Ensures that safety, quality and efficiency at the WorkFace are considered in the planning process | | 1 | 2 | 3 | 4 | 5 | 1 | 2 | 3 | 4 | 5 |
| *1.2* | Uses his/her hands-on construction expertise to develop Installation Work Packages (IWP) | | 1 | 2 | 3 | 4 | 5 | 1 | 2 | 3 | 4 | 5 |
| *1.3* | Coordinates with and provides WorkFace construction knowledge to project schedulers, engineers, superintendents and managers | | 1 | 2 | 3 | 4 | 5 | 1 | 2 | 3 | 4 | 5 |
| *1.4* | Acts as liaison between the project controls department and workforce supervision | | 1 | 2 | 3 | 4 | 5 | 1 | 2 | 3 | 4 | 5 |
| *1.5* | Identifies risks and opportunities associated with implementing IWPs | | 1 | 2 | 3 | 4 | 5 | 1 | 2 | 3 | 4 | 5 |
| *1.6* | Ensures that the equipment requests are received sufficiently ahead of execution | | 1 | 2 | 3 | 4 | 5 | 1 | 2 | 3 | 4 | 5 |
| *1.7* | Facilitates construction material management through the process of creating accurate bills of material by IWP and arranging delivery to support the construction schedule | | 1 | 2 | 3 | 4 | 5 | 1 | 2 | 3 | 4 | 5 |
| *1.8* | Coordinates the erection of scaffold prior to the plans being released | | 1 | 2 | 3 | 4 | 5 | 1 | 2 | 3 | 4 | 5 |

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *1.9* | Identifies and mitigates constraints for IWPs prior to IWP release | | 1 | 2 | 3 | 4 | 5 | 1 | 2 | 3 | 4 | 5 |
| *1.10* | | | 1 | 2 | 3 | 4 | 5 | 1 | 2 | 3 | 4 | 5 |
| *1.11* | | | 1 | 2 | 3 | 4 | 5 | 1 | 2 | 3 | 4 | 5 |

| | **Evaluation Criteria** | Not Applicable | **Importance** | | | | | **Agreement** | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | ***Extremely Unimportant*** | ***Unimportant*** | ***Neither Unimportant or Important*** | ***Important*** | ***Extremely Important*** | ***Strongly Disagree*** | ***Disagree*** | ***Neither Disagree Nor Agree*** | ***Agree*** | ***Strongly Agree*** |
| ***2*** | ***Safety*** | | | | | | | | | | | |
| *2.1* | Knows, understands and communicates the safety regulations (Occupational Health and Safety Act) and project specific safety policies and procedures. | | 1 | 2 | 3 | 4 | 5 | 1 | 2 | 3 | 4 | 5 |
| *2.2* | Identifies specific risks associated with executing the planned activities | | 1 | 2 | 3 | 4 | 5 | 1 | 2 | 3 | 4 | 5 |

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *2.3* | Provides or arranges for inclusion of safety compliance in IWP to mitigate specific risks | | 1 | 2 | 3 | 4 | 5 | 1 | 2 | 3 | 4 | 5 |
| *2.4* | Ensures intended safety requirements are properly conveyed to workforce supervision | | 1 | 2 | 3 | 4 | 5 | 1 | 2 | 3 | 4 | 5 |
| *2.5* | | | 1 | 2 | 3 | 4 | 5 | 1 | 2 | 3 | 4 | 5 |
| *2.6* | | | 1 | 2 | 3 | 4 | 5 | 1 | 2 | 3 | 4 | 5 |
| *2.7* | | | 1 | 2 | 3 | 4 | 5 | 1 | 2 | 3 | 4 | 5 |
| ***3*** | ***Project Planning*** | | | | | | | | | | | |
| *3.1* | Develops IWP templates | | 1 | 2 | 3 | 4 | 5 | 1 | 2 | 3 | 4 | 5 |
| *3.2* | Prepares required project IWP, which includes determining required activities, resources, special conditions, quality control, risk planning, interdependencies | | 1 | 2 | 3 | 4 | 5 | 1 | 2 | 3 | 4 | 5 |
| *3.3* | Determines and coordinates resource requirements and works well with resource coordinators | | 1 | 2 | 3 | 4 | 5 | 1 | 2 | 3 | 4 | 5 |
| *3.4* | Reviews IWP for completeness and accuracy | | 1 | 2 | 3 | 4 | 5 | 1 | 2 | 3 | 4 | 5 |

| No | Evaluation Criteria | Not Applicable | Importance | | | | | Agreement | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | *Extremely Unimportant* | *Unimportant* | *Neither Unimportant or Important* | *Important* | *Extremely Important* | *Strongly Disagree* | *Disagree* | *Neither Disagree Nor Agree* | *Agree* | *Strongly Agree* |
| *3.5* | Coordinates IWP execution with field supervision | | 1 | 2 | 3 | 4 | 5 | 1 | 2 | 3 | 4 | 5 |
| *3.6* | Monitors and controls IWP and advises appropriate parties | | 1 | 2 | 3 | 4 | 5 | 1 | 2 | 3 | 4 | 5 |
| *3.7* | Coordinates activities with field supervision, resource coordinators, project controls, quality assurance other planners, and operations personnel | | 1 | 2 | 3 | 4 | 5 | 1 | 2 | 3 | 4 | 5 |
| *3.8* | Modifies, reviews or adjusts IWP as necessary | | 1 | 2 | 3 | 4 | 5 | 1 | 2 | 3 | 4 | 5 |
| *3.9* | Conducts post-mortem on IWP | | 1 | 2 | 3 | 4 | 5 | 1 | 2 | 3 | 4 | 5 |
| *3.10* | | | 1 | 2 | 3 | 4 | 5 | 1 | 2 | 3 | 4 | 5 |
| *3.11* | | | 1 | 2 | 3 | 4 | 5 | 1 | 2 | 3 | 4 | 5 |
| *3.12* | | | 1 | 2 | 3 | 4 | 5 | 1 | 2 | 3 | 4 | 5 |
| ***4*** | ***Knowledge Required*** | | | | | | | | | | | |
| *4.1* | Has knowledge of health, safety and environmental programs | | 1 | 2 | 3 | 4 | 5 | 1 | 2 | 3 | 4 | 5 |
| *4.2* | Knows the company and project environment | | 1 | 2 | 3 | 4 | 5 | 1 | 2 | 3 | 4 | 5 |

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *4.3* | Is a member of at least one specific construction trade discipline (at a minimum journeyman level), construction specialty, or engineering discipline | | 1 | 2 | 3 | 4 | 5 | 1 | 2 | 3 | 4 | 5 |
| *4.4* | Knows general construction and materials systems and procedures | | 1 | 2 | 3 | 4 | 5 | 1 | 2 | 3 | 4 | 5 |
| *4.5* | Has a basic understanding of project scheduling and estimating techniques | | 1 | 2 | 3 | 4 | 5 | 1 | 2 | 3 | 4 | 5 |
| *4.6* | Understands how the IWP fits into the overall project schedule | | 1 | 2 | 3 | 4 | 5 | 1 | 2 | 3 | 4 | 5 |

| No | **Evaluation Criteria** | Not Applicable | **Importance** | | | | | **Agreement** | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | ***Extremely Unimportant*** | ***Unimportant*** | ***Neither Unimportant or Important*** | ***Important*** | ***Extremely Important*** | ***Strongly Disagree*** | ***Disagree*** | ***Neither Disagree Nor Agree*** | ***Agree*** | ***Strongly Agree*** |
| *4.7* | Has completed training (internal or external) on Advanced Work Packaging and WorkFace Planning best practices | | 1 | 2 | 3 | 4 | 5 | 1 | 2 | 3 | 4 | 5 |
| *4.8* | | | 1 | 2 | 3 | 4 | 5 | 1 | 2 | 3 | 4 | 5 |
| *4.9* | | | 1 | 2 | 3 | 4 | 5 | 1 | 2 | 3 | 4 | 5 |
| ***5*** | ***Skills Required*** | | | | | | | | | | | |

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *5.1* | Has good problem solving skills | | 1 | 2 | 3 | 4 | 5 | 1 | 2 | 3 | 4 | 5 |
| *5.2* | Is able to resolve conflicts | | 1 | 2 | 3 | 4 | 5 | 1 | 2 | 3 | 4 | 5 |
| *5.3* | Has strong leadership skills | | 1 | 2 | 3 | 4 | 5 | 1 | 2 | 3 | 4 | 5 |
| *5.5* | Has effective oral and written communication skills | | 1 | 2 | 3 | 4 | 5 | 1 | 2 | 3 | 4 | 5 |
| *5.6* | Has strong organizational and documentation skills | | 1 | 2 | 3 | 4 | 5 | 1 | 2 | 3 | 4 | 5 |
| *5.7* | Has basic computer skills | | 1 | 2 | 3 | 4 | 5 | 1 | 2 | 3 | 4 | 5 |
| *5.8* | Is self-motivated and able to work with minimal supervision | | 1 | 2 | 3 | 4 | 5 | 1 | 2 | 3 | 4 | 5 |
| *5.9* | | | 1 | 2 | 3 | 4 | 5 | 1 | 2 | 3 | 4 | 5 |
| *5.10* | | | 1 | 2 | 3 | 4 | 5 | 1 | 2 | 3 | 4 | 5 |
| ***6*** | ***Other Desirable Characteristics*** | | | | | | | | | | | |
| *6.1* | Is willing to accept challenges | | 1 | 2 | 3 | 4 | 5 | 1 | 2 | 3 | 4 | 5 |
| *6.2* | Is willing to learn | | 1 | 2 | 3 | 4 | 5 | 1 | 2 | 3 | 4 | 5 |
| *6.3* | Is responsible and accountable | | 1 | 2 | 3 | 4 | 5 | 1 | 2 | 3 | 4 | 5 |
| *6.4* | Has good work ethic | | 1 | 2 | 3 | 4 | 5 | 1 | 2 | 3 | 4 | 5 |
| No | **Evaluation Criteria** | Not Applicable | **Importance** | | | | | **Agreement** | | | | |
| | | | ***Extremely Unimportant*** | ***Unimportant*** | ***Neither Unimportant or Important*** | ***Important*** | ***Extremely Important*** | ***Strongly Disagree*** | ***Disagree*** | ***Neither Disagree Nor Agree*** | ***Agree*** | ***Strongly Agree*** |

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *6.5* | Leads by example | | 1 | 2 | 3 | 4 | 5 | 1 | 2 | 3 | 4 | 5 |
| *6.6* | Is a team player | | 1 | 2 | 3 | 4 | 5 | 1 | 2 | 3 | 4 | 5 |
| *6.7* | Is honest and acts with integrity | | 1 | 2 | 3 | 4 | 5 | 1 | 2 | 3 | 4 | 5 |
| *6.8* | | | 1 | 2 | 3 | 4 | 5 | 1 | 2 | 3 | 4 | 5 |
| *6.9* | | | 1 | 2 | 3 | 4 | 5 | 1 | 2 | 3 | 4 | 5 |
| *6.10* | | | 1 | 2 | 3 | 4 | 5 | 1 | 2 | 3 | 4 | 5 |

*Thank you for completing the survey*

## A.4. Crew and Foreman Qualification Characterization Form

The different evaluation criteria used for crew and foreman qualification characterization are listed in Table A.4.1 and Table A.4.2 respectively.

Table A.4.1 Crew Qualification Characterization

| Factor ID | Sub - Factors | Scale of Measure | Predetermined Ratings (1 - 5)/ Note |
|---|---|---|---|
| 1.1.1 | Crew Size | Integer number (crew size) | |
| 1.1.2 | Adequacy of Crew Size | 1-5 Predetermined rating | 1- Crew size is VERY POOR fit for the activity's volume of work.<br>2- Crew size is POOR fit for the activity's volume of work.<br>3- Crew size is FAIR fit for the activity's volume of work.<br>4- Crew size is GOOD fit for the activity's volume of work.<br>5- Crew size is VERY GOOD fit for the activity's volume of work. |
| 1.1.3 | Craftsperson Education | Categorical | |
| 1.1.4 | Craftsperson on Job Training | Real number (No. trainings attended x Duration of Training, hrs) | |
| 1.1.5 | Craftsperson Technical Training | Real number (No. trainings attended x Duration of Training, hrs) | |
| 1.1.6 | Crew Composition | Integer numbers (no. journeymen, no. apprentices) | |
| 1.1.7 | Crew Experience | Integer number (years of experience) | |

| Factor ID | Sub - Factors | Scale of Measure | Predetermined Ratings (1 - 5)/ Note |
|---|---|---|---|
| 1.1.8 | Number of Languages Spoken in the Crew | Integer number | |
| 1.1.9 | Co-operation among Craftsperson | 1 - 5 Predetermined rating | 1- VERY DIVERSE Ability, VERY LOW Stake Value, VERY LARGE Crew Size2- DIVERSE Ability, LOW Stake Value, LARGE Crew size3- DIVERSE Ability, MEDIUM Stake Value, AVERAGE Crew Size4- SIMILAR Ability, HIGH Stake Value, SMALL Crew Size5- SIMILAR Ability, VERY HIGH Stake Value, VERY SMALL Crew Size |
| 1.1.10 | Craftsperson Age | Integer number (Age) | |
| 1.1.11 | Craftsperson Learning Effect | | Y = a xb, Y=time for xth unit, a=time for first unit, x=number of the unit is being produced, and b=learning curve coefficient |
| 1.1.11.1 | Time to Install the First Unit (a) | Real number (time to install first unit, min) | |
| 1.1.11.2 | Learning Coefficient (b) | Percentage (average time saving between first and consecutive units) | |
| 1.1.12 | Crew Motivation | | |
| 1.1.12.1 | Intensity of Effort | 1-5 Predetermined rating | 1- VERY LOW effort intensity to perform the task<br>2- LOW intensity of effort to perform the task<br>3- AVERAGE intensity of effort to perform the task<br>4- HIGH intensity of effort to perform the task<br>5- VERY HIGH intensity of effort to perform the task |
| 1.1.12.2 | Persistence of Effort | 1-5 Predetermined rating | 1- VERY LOW persistence of effort to perform the task<br>2- LOW persistence of effort to perform the task<br>3- AVERAGE persistence of effort to perform the task |

| Factor ID | Sub - Factors | Scale of Measure | Predetermined Ratings (1 - 5)/ Note |
|---|---|---|---|
| | | | 4- HIGH persistence of effort to perform the task<br>5- VERY HIGH persistence of effort to perform the task |
| 1.1.12.3 | Direction of Effort | 1-5 Predetermined rating | 1- VERY LOW consistency between direction of effort and the assigned goals2- LOW consistency between direction of effort and the assigned goals3- AVERAGE consistency between direction of effort and the assigned goals4- HIGH consistency between direction of effort and the assigned goals5- VERY HIGH consistency between direction of effort and the assigned goals |
| 1.1.13 | Total Overtime Work | Integer (total daily overtime work, hrs) | |
| 1.1.14 | Craftsperson Trust in Foreman | 1 - 5 Predetermined rating | 1- VERY LOW Trust<br>2- LOW Trust<br>3- AVERAGE Trust<br>4- HIGH Trust<br>5- VERY HIGH Trust |
| 1.1.15 | Team Spirit of Crew | 1 - 5 Predetermined rating | 1- VERY LOW Team Spirit<br>2- LOW Team Spirit<br>3- AVERAGE Team Spirit<br>4- HIGH Team Spirit<br>5- VERY HIGH Team Spirit |
| 1.1.16 | Level of Absenteeism | Percentage (average number of absent crew members to total crew size) | |
| 1.1.17 | Crew Turnover Rate | Percentage (no. of separated crew members | |

| Factor ID | Sub - Factors | Scale of Measure | Predetermined Ratings (1 - 5)/ Note |
|---|---|---|---|
| | | divided by weekly average crew size) | |
| 1.1.18 | Crew Makeup Changes | Percentage (occurrence of crew member changes divided by weekly average crew size) | |
| 1.1.19 | Level of Interruptions and Disruptions | Real number (total time lost due to interruptions, min) | |
| 1.1.20 | Number of Consecutive Days Worked per Week | Integer (average days for crew) | |
| 1.1.21 | Fairness of Work Assignment | 1 - 5 Predetermined rating | 1- Inconsistent work assignment on a daily basis, Unreasonable work assignment among crew members, VERY POOR Information provision2- Inconsistent work assignment on a daily basis, Unreasonable work assignment among crew members, POOR Information provision3- Consistent work assignment on a daily basis, Reasonable work assignment among crew members, AVERAGE Information provision4- Consistent work assignment on a daily basis, Reasonable work assignment among crew members, GOOD Information provision5- Consistent work assignment on a daily basis, Reasonable work assignment among crew members, VERY GOOD Information provision |
| 1.1.22 | Crew Flexibility | 1 - 5 rating | |

| Factor ID | Sub - Factors | Scale of Measure | Predetermined Ratings (1 - 5)/ Note |
|---|---|---|---|
| 1.1.22.1 | Ability of Crew or Perform Other's Task | Percentage (no. of tasks which can be done by all crew members divided by total no. of the tasks) | |
| 1.1.22.2 | Willingness to Perform Other's Tasks | 1-5 Predetermined rating | 1- Completely Unwilling<br>2- Somewhat NOT Willing<br>3- Somewhat Willing<br>4- Willing<br>5- Completely Willing |
| 1.1.23 | Job Site Orientation Program | Categorical | |
| 1.1.24 | Crew Skill Level | 1-5 Predetermined rating | 1- Skill level of the crew is VERY LOW for execution of the activity.<br>2- Skill level of the crew is LOW for execution of the activity.<br>3- Skill level of the crew is FAIR for execution of the activity.<br>4- Skill level of the crew is HIGH for execution of the activity.<br>5- Skill level of the crew is VERY HIGH for execution of the activity. |
| 1.1.25 | Multiskilling of Crew | Categorical | |
| 1.1.26 | Crew Makeup Continuity | Integer number (no. of days crew members have worked together continuously) | |

Table A.4.2 Foreman Qualification Characterization

| Factor ID | Sub - Factors | Scale of Measure | Predetermined Ratings (1 - 5)/ Note |
|---|---|---|---|
| 1.2.1 | Foreman Experience | Integer number (years of experience ) | |
| 1.2.2 | Foreman Training | Real number (No. trainings attended x Duration of Training, hrs) | Leadership for Safety Excellence, CSTS, Standard First Aid Certificate, Supervisory Training Program |
| 1.2.3 | Foreman Leadership Style | Categorical | |
| 1.2.4 | Foreman Leadership Skills | 1-5 Predetermined rating | 1- INADEQUATE Orientation of crew members; VERY POOR in Assigning individual and crew tasks<br>2- INADEQUATE Orientation of crew members; POOR in Assigning individual and crew tasks<br>3- ADEQUATE Orientation of crew members; FAIR in Assigning individual and crew tasks<br>4- ADEQUATE Orientation of crew members; GOOD in Assigning individual and crew tasks<br>5- ADEQUATE Orientation of crew members; VERY GOOD in Assigning individual and crew tasks |
| 1.2.5 | Foreman Supervisory Skill | 1-5 Predetermined rating | 1- VERY POOR in Communicating the job to and with the crew; VERY POOR in Controlling and maintaining work standards<br>2- POOR in Communicating the job to and with the crew; POOR in Setting and maintaining work standards<br>3- FAIR in Communicating the job to and with the crew; FAIR in Setting and maintaining work standards<br>4- GOOD in Communicating the job to and with the crew; GOOD in Setting and maintaining work standards<br>5- VERY GOOD in Communicating the job to and with the crew; VERY GOOD in Setting and maintaining work standards |

| Factor ID | Sub - Factors | Scale of Measure | Predetermined Ratings (1 - 5)/ Note |
|---|---|---|---|
| 1.2.6 | Provision of Clear Goals to Crafts | 1 - 5 Predetermined rating | 1-VERY POOR Clarity in assignment of Tasks<br>2- POOR Clarity in assignment of Tasks<br>3- AVERAGE Clarity in assignment of Tasks<br>4- GOOD Clarity in assignment of Tasks<br>5- VERY GOOD Clarity in assignment of Tasks |
| 1.2.7 | Foreman Skill in Proper Resource Allocation | 1 - 5 Predetermined rating | 1- VERY POOR Understanding of schedule & plans, VERY POOR in Identifying resource availability<br>2- POOR Understanding of schedule & plans, POOR in Identifying resource availability<br>3- FAIR Understanding of schedule & plans, FAIR in Identifying resource availability<br>4- GOOD Understanding of schedule & plans, GOOD in Identifying resource availability<br>5- VERY GOOD Understanding of schedule & plans, VERY GOOD in Identifying resource availability |
| 1.2.8 | Fairness in Performance Review of Crew by Foreman | 1 - 5 Predetermined rating | 1-VERY Unfair performance review<br>2- Unfair performance review<br>3- SOMEWHAT Fair performance review<br>4- Fair performance review<br>5- VERY Fair performance review |
| 1.2.9 | Change of Foreman (Supervisor) | Integer number (no. changes of foreman [supervisor] per month) | |
| 1.2.10 | Span of Control | Integer (average total number of crews per foreman) | |
| 1.2.11 | Treatment of Craftsperson by Foreman | 1 - 5 Predetermined rating | 1- ALWAYS Disrespectful, Insincere, NO Counselling<br>2- OFTEN Disrespectful, Insincere, NO Counselling<br>3- SOMETIMES Respectful, Sincere, Counselling<br>4- OFTEN Respectful, Sincere, Counselling<br>5- ALWAYS Respectful, Sincere, Counselling |

| Factor ID | Sub - Factors | Scale of Measure | Predetermined Ratings (1 - 5)/ Note |
|---|---|---|---|
| 1.2.12 | Coordination between Labour and Equipment Operators | Real number (total time lost due to lack of coordination, min) | |

## A.5. Problem Sources Form Criteria

STUDY TO ASSESS THE ADVANTAGES OF UTILIZING ADVANCED WORK PACKAGING (AWP) ON CONSTRUCTION PROJECTS

*Project Problem Sources Assessment*

Dear Participant,

The University of Alberta under the Natural Sciences and Engineering Research Council of Canada (NSERC), Industrial Research Chair in Strategic Construction Modeling and Delivery would like to thank you for agreeing to participate in this survey. This study is intended to assess the advantages of utilizing Advanced Work Packaging (AWP) for the improvement of project performance. This interview survey is intended to identify the major problems encountered by the project that in turn affect the level of impact from AWP.

Background:
Advanced Work Packaging (AWP) was announced as a best practice by the Construction Industry Institute (CII) in 2015 and has been adopted by the Construction Owners Association of Alberta (COAA). This study aims to quantify the costs and benefits of implementing an Advanced Work Packaging/Workface Planning (AWP/WFP) program on construction projects by measuring the impacts of such a program on schedule performance, cost performance, predictability, field productivity, rework, safety, and indirect costs. The impact of unexpected problems or challenges in a construction project can directly affect the success of a project, in some cases independent of the practice of AWP. Thus, identifying these problems or challenges is an important step in assessing the benefits of AWP on construction projects.

Your participation in this survey is purely voluntary. You do not have to participate, and there are no consequences if you do not. All answers will remain confidential, and only the aggregated results will be made public in the form of reports and publications.

Your participation will be limited to completing the survey, which will take approximately twenty to thirty minutes to complete.

This survey consists of two main sections. The first section is designed to collect general information about your role in the construction project. The second section includes a list of problem sources under ten different categories, which you are asked to rate in terms of level of impact on the construction project.

SECTION 1: GENERAL INFORMATION

5. *3.* Please indicate the name of your current employer (Company you work for):

______________________________

5. *4.* Approximately, how long have you been employed by your current employer?

________ Year(s) ________Month(s)

*1.5.* Please select your current occupation:

□ Advanced Work Packaging Manager □ Engineering Manager □ Project Manager

□ Construction Manager □ Procurement Manager □ WFP Lead

□ Superintendent □ General Foreman □ Foreman

□ Other (please specify):

_____________

*1. 6.* Approximately, how long have you worked in the stated occupation?

________ Year(s) ________Month(s)

*1.7.* Please specify your highest educational degree: (please specify ALL that applies)

□ Professional designation/degree □ Master's degree or above

□ Bachelor's degree □ Some university credit (no degree)

□ College Diploma □ Some college credit (no degree)

□ Technical, vocational, or trade school □ Other (please specify): ___________

SECTION 2: PROBLEM SOURCES

This section of the survey presents problem sources associated with different aspects of construction. The level of impact of each problem source is assessed using the measurement scale provided as follows:

Level of Impact Measurement: is to measure the level of impact of a problem source on the particular project and can vary within four levels as shown below:

| Scale value | Scale description |
|---|---|
| 1 | No impact |
| 2 | Slightly Negative |
| 3 | Negative |
| 4 | Strongly Negative |

Agreement Measurement: is to measure the extent to which you believe the problem identified in the list was encountered on this project, which can vary within five levels as shown below:

| Scale value | Scale description |
|---|---|
| 1 | Strongly disagree |
| 2 | Disagree |
| 3 | Neither Disagree Nor Agree |
| 4 | Agree |
| 5 | Strongly Agree |

Please provide your evaluation for the various problem sources, pertaining to each category, by providing a value for each of the measurement scales (level of impact measurement) as identified above. Blank rows are provided for you to add additional problem sources that you feel were a determining factor in the project.

Note: If you are unfamiliar with the impact from the problem source evaluated, please check the “Not able to Evaluate” column and proceed to the next problem source. If the problem source is not applicable to the project, please choose “Not applicable” under the impact measurement.

Project Problem Sources

| No | Evaluation Criteria | Not Applicable | Agreement | | | | | Impact | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | *Strongly Disagree* | *Disagree* | *Neither Disagree Nor Agree* | *Agree* | *Strongly Agree* | *No Impact* | *Slightly Negative* | *Negative* | *Strongly Negative* |
| ***1*** | ***Environment*** | | | | | | | | | | |
| *1.1* | Temperature too high | | 1 | 2 | 3 | 4 | 5 | 1 | 2 | 3 | 4 |
| *1.2* | Temperature too low | | 1 | 2 | 3 | 4 | 5 | 1 | 2 | 3 | 4 |
| *1.3* | Wind too high | | 1 | 2 | 3 | 4 | 5 | 1 | 2 | 3 | 4 |
| *1.4* | Too much precipitation | | 1 | 2 | 3 | 4 | 5 | 1 | 2 | 3 | 4 |
| *1.5* | Too little precipitation | | 1 | 2 | 3 | 4 | 5 | 1 | 2 | 3 | 4 |
| *1.6* | Humidity too high | | 1 | 2 | 3 | 4 | 5 | 1 | 2 | 3 | 4 |
| *1.7* | Humidity too low | | 1 | 2 | 3 | 4 | 5 | 1 | 2 | 3 | 4 |
| *1.8* | Freeze-thaw cycles | | 1 | 2 | 3 | 4 | 5 | 1 | 2 | 3 | 4 |
| *1.9* | | | 1 | 2 | 3 | 4 | 5 | 1 | 2 | 3 | 4 |
| *1.10* | | | 1 | 2 | 3 | 4 | 5 | 1 | 2 | 3 | 4 |
| *1.11* | | | 1 | 2 | 3 | 4 | 5 | 1 | 2 | 3 | 4 |
| ***2*** | ***Site Conditions*** | | | | | | | | | | |
| *2.1* | Insufficient storage space | | 1 | 2 | 3 | 4 | 5 | 1 | 2 | 3 | 4 |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| *2.2* | Inadequate external access | | 1 | 2 | 3 | 4 | 5 | 1 | 2 | 3 | 4 |
| *2.3* | Inadequate internal access | | 1 | 2 | 3 | 4 | 5 | 1 | 2 | 3 | 4 |
| *2.4* | Congestion | | 1 | 2 | 3 | 4 | 5 | 1 | 2 | 3 | 4 |

| No | **Evaluation Criteria** | Not Applicable | **Agreement** | | | | | **Impact** | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | ***Strongly Disagree*** | ***Disagree*** | ***Neither Disagree Nor Agree*** | ***Agree*** | ***Strongl y Agree*** | ***No Impact*** | ***Slightly Negativ e*** | ***Negative*** | ***Strong ly Negati ve*** |
| *2.5* | Site not prepared/available | | 1 | 2 | 3 | 4 | 5 | 1 | 2 | 3 | 4 |
| *2.6* | Poor ground conditions | | 1 | 2 | 3 | 4 | 5 | 1 | 2 | 3 | 4 |
| *2.7* | Change in/unexpected ground conditions | | 1 | 2 | 3 | 4 | 5 | 1 | 2 | 3 | 4 |
| *2.8* | Work space not cleaned | | 1 | 2 | 3 | 4 | 5 | 1 | 2 | 3 | 4 |
| *2.9* | Work conditions (noise, dust, and fumes) | | 1 | 2 | 3 | 4 | 5 | 1 | 2 | 3 | 4 |
| *2.10* | Insufficient protection of work area from weather | | 1 | 2 | 3 | 4 | 5 | 1 | 2 | 3 | 4 |
| *2.11* | | | 1 | 2 | 3 | 4 | 5 | 1 | 2 | 3 | 4 |
| *2.12* | | | 1 | 2 | 3 | 4 | 5 | 1 | 2 | 3 | 4 |

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *2.13* | | | 1 | 2 | 3 | 4 | 5 | 1 | 2 | 3 | 4 |
| ***3*** | ***Owner and consultants*** | | | | | | | | | | |
| *3.1* | Delay in decisions required | | 1 | 2 | 3 | 4 | 5 | 1 | 2 | 3 | 4 |
| *3.2* | Large amount of change requested | | 1 | 2 | 3 | 4 | 5 | 1 | 2 | 3 | 4 |
| *3.3* | Interference or stop work orders | | 1 | 2 | 3 | 4 | 5 | 1 | 2 | 3 | 4 |
| *3.4* | Extra work requested | | 1 | 2 | 3 | 4 | 5 | 1 | 2 | 3 | 4 |
| *3.5* | Awaiting inspections/tests | | 1 | 2 | 3 | 4 | 5 | 1 | 2 | 3 | 4 |
| *3.6* | Excessive quality demanded | | 1 | 2 | 3 | 4 | 5 | 1 | 2 | 3 | 4 |
| *3.7* | | | 1 | 2 | 3 | 4 | 5 | 1 | 2 | 3 | 4 |
| *3.8* | | | 1 | 2 | 3 | 4 | 5 | 1 | 2 | 3 | 4 |

| No | Evaluation Criteria | Not Applicable | Agreement | | | | | Impact | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | *Strongly Disagree* | *Disagree* | *Neither Disagree Nor Agree* | *Agree* | *Strongl y Agree* | *No Impact* | *Slightly Negativ e* | *Negative* | *Strong ly Negati ve* |
| ***4*** | ***Design/ Drawings*** | | | | | | | | | | |
| *4.1* | Drawing errors | | 1 | 2 | 3 | 4 | 5 | 1 | 2 | 3 | 4 |
| *4.2* | Design changes/ additions | | 1 | 2 | 3 | 4 | 5 | 1 | 2 | 3 | 4 |
| *4.3* | Drawings insufficient/incomplete | | 1 | 2 | 3 | 4 | 5 | 1 | 2 | 3 | 4 |
| *4.4* | Conflicting Information | | 1 | 2 | 3 | 4 | 5 | 1 | 2 | 3 | 4 |
| *4.5* | Poor design coordination | | 1 | 2 | 3 | 4 | 5 | 1 | 2 | 3 | 4 |
| *4.6* | Poor response time for design/drawing questions | | 1 | 2 | 3 | 4 | 5 | 1 | 2 | 3 | 4 |
| *4.7* | Poor readability of drawings and specifications | | 1 | 2 | 3 | 4 | 5 | 1 | 2 | 3 | 4 |
| *4.8* | | | 1 | 2 | 3 | 4 | 5 | 1 | 2 | 3 | 4 |
| *4.9* | | | 1 | 2 | 3 | 4 | 5 | 1 | 2 | 3 | 4 |
| ***5*** | ***Schedule*** | | | | | | | | | | |
| *5.1* | Delay of activity predecessors | | 1 | 2 | 3 | 4 | 5 | 1 | 2 | 3 | 4 |
| *5.2* | Work done out of sequence | | 1 | 2 | 3 | 4 | 5 | 1 | 2 | 3 | 4 |
| *5.3* | Improper sequencing of activities | | 1 | 2 | 3 | 4 | 5 | 1 | 2 | 3 | 4 |
| *5.4* | Delay of off-site procurement | | 1 | 2 | 3 | 4 | 5 | 1 | 2 | 3 | 4 |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| *5.5* | | | 1 | 2 | 3 | 4 | 5 | 1 | 2 | 3 | 4 |
| *5.6* | | | 1 | 2 | 3 | 4 | 5 | 1 | 2 | 3 | 4 |
| *5.7* | | | 1 | 2 | 3 | 4 | 5 | 1 | 2 | 3 | 4 |

| No | **Evaluation Criteria** | Not Applicable | **Agreement** | | | | | **Impact** | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | ***Strongly Disagree*** | ***Disagree*** | ***Neither Disagree Nor Agree*** | ***Agree*** | ***Strongly Agree*** | ***No Impact*** | ***Slightly Negative*** | ***Negative*** | ***Strongly Negative*** |
| *6* | ***Workforce*** | | | | | | | | | | |
| *6.1* | Undermanning | | 1 | 2 | 3 | 4 | 5 | 1 | 2 | 3 | 4 |
| *6.2* | Overmanning | | 1 | 2 | 3 | 4 | 5 | 1 | 2 | 3 | 4 |
| *6.3* | Low skill level | | 1 | 2 | 3 | 4 | 5 | 1 | 2 | 3 | 4 |
| *6.4* | Excessive turnover | | 1 | 2 | 3 | 4 | 5 | 1 | 2 | 3 | 4 |
| *6.5* | Low motivation/morale | | 1 | 2 | 3 | 4 | 5 | 1 | 2 | 3 | 4 |
| *6.6* | Inadequate instructions | | 1 | 2 | 3 | 4 | 5 | 1 | 2 | 3 | 4 |
| *6.7* | Unsafe practices/accidents | | 1 | 2 | 3 | 4 | 5 | 1 | 2 | 3 | 4 |
| *6.8* | Fatigue (long shifts/overtime) | | 1 | 2 | 3 | 4 | 5 | 1 | 2 | 3 | 4 |
| *6.9* | Interference of other trades (trade stacking) | | 1 | 2 | 3 | 4 | 5 | 1 | 2 | 3 | 4 |

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *6.10* | Poor crew coordination | | 1 | 2 | 3 | 4 | 5 | 1 | 2 | 3 | 4 |
| *6.11* | Lack of crew experience | | 1 | 2 | 3 | 4 | 5 | 1 | 2 | 3 | 4 |
| *6.12* | Absenteeism | | 1 | 2 | 3 | 4 | 5 | 1 | 2 | 3 | 4 |
| *6.13* | Language barrier affects communication | | 1 | 2 | 3 | 4 | 5 | 1 | 2 | 3 | 4 |
| *6.14* | | | 1 | 2 | 3 | 4 | 5 | 1 | 2 | 3 | 4 |
| *6.15* | | | 1 | 2 | 3 | 4 | 5 | 1 | 2 | 3 | 4 |
| *6.16* | | | 1 | 2 | 3 | 4 | 5 | 1 | 2 | 3 | 4 |
| *6.17* | | | 1 | 2 | 3 | 4 | 5 | 1 | 2 | 3 | 4 |

| No | **Evaluation Criteria** | Not Applicable | **Agreement** | | | | | **Impact** | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | ***Strongly Disagree*** | ***Disagree*** | ***Neither Disagree Nor Agree*** | ***Agree*** | ***Strongl y Agree*** | ***No Impact*** | ***Slightly Negativ e*** | ***Negative*** | ***Strong ly Negati ve*** |
| ***7*** | ***Work*** | | | | | | | | | | |
| *7.1* | Estimating error | | 1 | 2 | 3 | 4 | 5 | 1 | 2 | 3 | 4 |
| *7.2* | Error in construction | | 1 | 2 | 3 | 4 | 5 | 1 | 2 | 3 | 4 |
| *7.3* | Layout error | | 1 | 2 | 3 | 4 | 5 | 1 | 2 | 3 | 4 |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| *7.4* | Poor Workmanship | | 1 | 2 | 3 | 4 | 5 | 1 | 2 | 3 | 4 |
| *7.5* | Rework (design changes) | | 1 | 2 | 3 | 4 | 5 | 1 | 2 | 3 | 4 |
| *7.6* | Rework (workmanship) | | 1 | 2 | 3 | 4 | 5 | 1 | 2 | 3 | 4 |
| *7.7* | Rework(work damaged by others) | | 1 | 2 | 3 | 4 | 5 | 1 | 2 | 3 | 4 |
| *7.8* | Lack of effective integration among project participants | | 1 | 2 | 3 | 4 | 5 | 1 | 2 | 3 | 4 |
| *7.9* | Electrical power disconnection during operation | | 1 | 2 | 3 | 4 | 5 | 1 | 2 | 3 | 4 |
| *7.10* | | | 1 | 2 | 3 | 4 | 5 | 1 | 2 | 3 | 4 |
| *7.11* | | | 1 | 2 | 3 | 4 | 5 | 1 | 2 | 3 | 4 |
| *7.12* | | | 1 | 2 | 3 | 4 | 5 | 1 | 2 | 3 | 4 |
| ***8*** | ***Supplies and Equipment*** | | | | | | | | | | |
| *8.1* | Insufficient materials | | 1 | 2 | 3 | 4 | 5 | 1 | 2 | 3 | 4 |
| *8.2* | Insufficient transportation equipment (cranes, forklifts) | | 1 | 2 | 3 | 4 | 5 | 1 | 2 | 3 | 4 |
| *8.3* | Insufficient hand tools | | 1 | 2 | 3 | 4 | 5 | 1 | 2 | 3 | 4 |
| *8.4* | Insufficient power tools | | 1 | 2 | 3 | 4 | 5 | 1 | 2 | 3 | 4 |

| No | Evaluation Criteria | Not Applicable | Agreement | | | | | Impact | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Strongly Disagree | Disagree | Neither Disagree Nor Agree | Agree | Strongly Agree | No Impact | Slightly Negative | Negative | Strongly Negative |
| *8.5* | Poor quality of work tools | | 1 | 2 | 3 | 4 | 5 | 1 | 2 | 3 | 4 |
| *8.6* | Late delivery of materials | | 1 | 2 | 3 | 4 | 5 | 1 | 2 | 3 | 4 |
| *8.7* | Late delivery of equipment | | 1 | 2 | 3 | 4 | 5 | 1 | 2 | 3 | 4 |
| *8.8* | Tools/equipment breakdown | | 1 | 2 | 3 | 4 | 5 | 1 | 2 | 3 | 4 |
| *8.9* | Damage deliveries | | 1 | 2 | 3 | 4 | 5 | 1 | 2 | 3 | 4 |
| *8.10* | Fabrication errors | | 1 | 2 | 3 | 4 | 5 | 1 | 2 | 3 | 4 |
| *8.11* | Inefficient material handling | | 1 | 2 | 3 | 4 | 5 | 1 | 2 | 3 | 4 |
| *8.12* | Shortage of consumables | | 1 | 2 | 3 | 4 | 5 | 1 | 2 | 3 | 4 |
| *8.13* | Inadequate material tracking system | | 1 | 2 | 3 | 4 | 5 | 1 | 2 | 3 | 4 |
| *8.14* | Excessive manlift waiting time | | 1 | 2 | 3 | 4 | 5 | 1 | 2 | 3 | 4 |
| *8.15* | | | 1 | 2 | 3 | 4 | 5 | 1 | 2 | 3 | 4 |
| *8.16* | | | 1 | 2 | 3 | 4 | 5 | 1 | 2 | 3 | 4 |
| *8.17* | | | 1 | 2 | 3 | 4 | 5 | 1 | 2 | 3 | 4 |
| ***9*** | ***Utilities/City*** | | | | | | | | | | |
| *9.1* | Awaiting permits | | 1 | 2 | 3 | 4 | 5 | 1 | 2 | 3 | 4 |

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *9.2* | Awaiting connection | | 1 | 2 | 3 | 4 | 5 | 1 | 2 | 3 | 4 |
| *9.3* | Awaiting inspections/tests | | 1 | 2 | 3 | 4 | 5 | 1 | 2 | 3 | 4 |
| *9.4* | Interference of existing utilities | | 1 | 2 | 3 | 4 | 5 | 1 | 2 | 3 | 4 |

| No | **Evaluation Criteria** | Not Applicable | **Agreement** | | | | | **Impact** | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | ***Strongly Disagree*** | ***Disagree*** | ***Neither Disagree Nor Agree*** | ***Agree*** | ***Strongl y Agree*** | ***No Impact*** | ***Slightly Negativ e*** | ***Negative*** | ***Strong ly Negati ve*** |
| *9.5* | Damage of existing utilities | | 1 | 2 | 3 | 4 | 5 | 1 | 2 | 3 | 4 |
| *9.6* | Unanticipated utilities | | 1 | 2 | 3 | 4 | 5 | 1 | 2 | 3 | 4 |
| *9.7* | | | 1 | 2 | 3 | 4 | 5 | 1 | 2 | 3 | 4 |
| *9.8* | | | 1 | 2 | 3 | 4 | 5 | 1 | 2 | 3 | 4 |
| *9.9* | | | 1 | 2 | 3 | 4 | 5 | 1 | 2 | 3 | 4 |
| ***10*** | ***Miscellaneous*** | | | | | | | | | | |
| *10.1* | Theft | | 1 | 2 | 3 | 4 | 5 | 1 | 2 | 3 | 4 |
| *10.2* | Strikes | | 1 | 2 | 3 | 4 | 5 | 1 | 2 | 3 | 4 |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| *10.3* | Vandalism | | 1 | 2 | 3 | 4 | 5 | 1 | 2 | 3 | 4 |
| *10.4* | Workers/ Compensation Board shutdown | | 1 | 2 | 3 | 4 | 5 | 1 | 2 | 3 | 4 |
| *10.5* | Delay/change in award of contract | | 1 | 2 | 3 | 4 | 5 | 1 | 2 | 3 | 4 |
| *10.6* | Natural disaster | | 1 | 2 | 3 | 4 | 5 | 1 | 2 | 3 | 4 |
| *10.7* | | | 1 | 2 | 3 | 4 | 5 | 1 | 2 | 3 | 4 |
| *10.8* | | | 1 | 2 | 3 | 4 | 5 | 1 | 2 | 3 | 4 |
| *10.9* | | | 1 | 2 | 3 | 4 | 5 | 1 | 2 | 3 | 4 |
| *10.10* | | | 1 | 2 | 3 | 4 | 5 | 1 | 2 | 3 | 4 |
| *10.11* | | | 1 | 2 | 3 | 4 | 5 | 1 | 2 | 3 | 4 |

*Thank you for completing the survey*

## A.6. Work Package Performance Indicators (KPIs), Definitions, and Formulae

The following tables define the different categories of KPIs utilized in the research (Omar and Fayek 2016b).

Table A.6.1 Work Package Cost Performance Indicators

| KPI No. | KPI Name | KPI Definition | KPI Formula |
|---|---|---|---|
| **1.** | **Work Package Cost Performance Indicators** | | |
| *1.1* | Work Package Cost Growth | The variance between the actual total work package cost and total work package estimated cost at tender stage, expressed as a ratio of total work package estimated cost at tender stage. | $\frac{\textit{(actual total work package cost − total work package estimate cost at tender stage)}}{\textit{total work package estimate cost at tender stage}}$ |
| *1.2* | Work Package Budget Factor | The ratio between the actual total work package cost, and total work package estimated cost at tender stage and cost of approved changes to work package. | $\frac{\textit{actual total work package cost}}{\textit{(total work package estimate at tender stage + approved changes to work package)}}$ |
| *1.3* | Project Indirect Cost Factor | The ratio between the actual construction phase indirect cost and the actual total project cost | $\frac{\textit{actual work package indirect cost}}{\textit{actual total work package cost}}$ |
| *1.4* | Work Package Direct Cost Factor | The ratio between the actual work package direct cost and actual total work package cost. | $\frac{\textit{actual work package direct cost}}{\textit{actual total work package cost}}$ |
| *1.5* | Work Package Net Variation Over Final Cost | The ratio between the net value of the work package cost variations within the same work scope and the total work package cost estimate at tender stage. | $\frac{\textit{net value of variations in work package cost}}{\textit{total work package estimated at tender stage}}$ |
| *1.6* | Cost Per Unit at Completion | Average cost for the product at work package completion (e.g., cost per m² of floor space). | $\frac{\textit{actual total work package cost}}{\textit{quantity of completed work}}$ |

| KPI No. | KPI Name | KPI Definition | KPI Formula |
|---|---|---|---|
| *1.7* | Cost Defects Warranty | The contractor's cost taken to rectify all defects of work package, expressed as a ratio of the actual work package cost. | $\frac{\textit{actual work package duration}}{\textit{quantity of completed work}}$ |

Table A.6.2 Work Package Schedule Performance Indicators

| KPI No. | KPI Name | KPI Definition | KPI Formula |
|---|---|---|---|
| **2. Schedule Performance Indicators** | | | |
| *2.1* | Work Package Schedule Factor | The ratio between the actual work package duration and the sum of the estimated work package duration at tender stage and approved changes to work package duration. | $\frac{\textit{actual work package duration}}{\textit{(estimated work package duration at tender stage + approved changes to work package)}}$ |
| *2.2* | Work Package Schedule Growth | The variance between the actual work package duration and the estimated work package duration at tender stage, expressed as a ratio of the estimated work package duration at tender stage. | $\frac{\textit{(actual work package duration – estimated work package duration at tender stage)}}{\textit{Estimated work package duration at tender stage}}$ |
| *2.3* | Time Variance | The ratio between the increase or decrease in the actual work package duration discounting the effect of Extension Of Time (EOT) granted by the client and the original period, and the estimated work package duration at tender stage | $\frac{\textit{increase/decrease in actual work package duration - EOT}}{\textit{estimated work package duration at tender stage}}$ |
| *2.4* | Time per Unit at Completion | The average product duration at work package completion per unit of measurement (e.g., months per m2 of floor space) | $\frac{\textit{actual work package duration}}{\textit{quantity of completed work}}$ |

Table A.2.3 Work Package Quality performance indicators

| KPI No. | KPI Name | KPI Definition | KPI Formula |
|---|---|---|---|
| **3. Work Package Quality Performance Indicators** | | | |
| *3.1* | Work Package Rework Cost Factor | The ratio between the total direct cost of work package rework, and the actual work package direct cost | $\frac{\textit{total direct cost of work package rework}}{\textit{actual work package direct cost}}$ |
| *3.2* | Work Package Rework Time Factor | The ratio between total duration of work package rework, and the actual work package duration | $\frac{\textit{Total duration of work package rework}}{\textit{actual work package duration}}$ |
| *3.3* | Work Package Rework Index | The ratio between the sum of direct and indirect cost of work package rework and the actual total work package cost | $\frac{\textit{total direct and indirect cost for work package rework}}{\textit{actual total work package cost}}$ |
| *3.4* | Quality Issues - Available for Use | The level of client satisfaction with the quality of completed work package based on the number of open (outstanding) non-conformances when work package is completed | Rating of performance from 1 to 7 with 1 being extremely dissatisfied and 7 being extremely satisfied |

Table A.6.4 Safety performance indicators

| KPI No. | KPI Name | KPI Definition | KPI Formula |
|---|---|---|---|
| **4. Safety Performance Indicators** | | | |
| *4.1* | Lost Time Rate | The ratio between the total time lost to incidents in work package and the total hours worked on the work package. | $\frac{\textit{amount of lost time to incidents in work package(hr.)}}{\textit{total hours worked}}$ |
| *4.2* | Lost Time Frequency | The ratio between the total number of lost time cases reported in work package and the total hours worked on the work package | $\frac{\textit{amount of lost time to incidents in work package(hr.)}}{\textit{total hours worked}}$ |

| | | | |
|---|---|---|---|
| *4.3.* | Reported Incidents Rate | The number of reported incidents in work package measured over the total hours worked on the work package the work package | $\frac{\text{Number of reported incidents in work package}}{\text{total hours worked}}$ |
| *4.4* | First Aid Frequency Rate | The ratio between the number of reported first aid cases in work package measured over the total hours worked on the work package | $\frac{\text{number of reported first aid cases in work package}}{\text{Total hours worked}}$ |
| *4.5* | Near Miss Incident Frequency Rate | The ratio between the number of reported near miss incidents in work package measured over the total hours worked on the work package | $\frac{\text{number of reported near miss incidents in work package}}{\text{total hours worked}}$ |

Table A.6.5 Work Package predictability performance indicators

| KPI No. | KPI Name | KPI Definition | KPI Formula |
|---|---|---|---|
| **5. Work Package Predictability Performance Indicators** | | | |
| *5.1* | Cost Predictability | The variance between the actual work package cost and estimated work package cost at tender stage, expressed as a ratio of the estimated construction cost. | $\frac{\text{(actual work package cost – estimated work package cost at tender stage)}}{\text{Estimated work package cost at tender stage}}$ |
| *5.2* | Time Predictability | The variance between the actual work package duration and the estimated work package duration at tender stage, expressed as a ratio of the estimated work package duration. | $\frac{\text{(actual work package duration – estimated work package duration at tender stage)}}{\text{Estimated work package duration at tender stage}}$ |

Table A.6.6 Productivity performance indicators

| KPI No. | KPI Name | KPI Definition | KPI Formula |
|---|---|---|---|
| **6. Work Package Productivity Performance Indicators** | | | |
| *6.1* | Construction Productivity Factor (Physical Work) | The actual direct work man-hours required to install a unit quantity of the work package output | $\frac{\textit{Actual direct man-hours of work package}}{\textit{total installed quantity}}$ |
| *6.2* | Construction Productivity Factor (Cost) | The ratio between the total installed work cost and the total actual man-hours | $\frac{\textit{total installed cost of work package}}{\textit{actual direct man-hours of work package}}$ |
| *6.3* | Productivity Estimate Accuracy (Productivity Index) | The ratio between estimated productivity rate and the actual productivity rate for the entire project | $\frac{\textit{estimated productivity rate}}{\textit{actual productivity rate}}$ |
| *6.4* | Project Absenteeism Rate | The ratio between the amount of man-hours lost due to unplanned absenteeism and the total actual man-hours worked on the work package | $\frac{\textit{man-hours lost due to unplanned absenteeism}}{\textit{total man hours worked}}$ |

Table A.6.7 Project Performance Indicators

| KPI No. | KPI Name | KPI Definition | KPI Formula |
|---|---|---|---|
| 1. Project Detailed Design Performance Metrics | | | |
| 1.1 | EWPs Issue Rate | The number of EWPs issued on schedule divided by the total number of EWPs of the project. | $\frac{\textit{number of EWPs issued on schedule}}{\textit{total number of project EWPs}}$ |

| KPI No. | KPI Name | KPI Definition | KPI Formula |
|---|---|---|---|
| 1.2 | Vendor Data Incompleteness | The number of EWPs delayed due to the vendor data incompleteness divided by the total number of EWPs of the project. | $\frac{\textit{number of EWPs delayed due to incomplete vendor data}}{\textit{total number of project EWPs}}$ |
| 1.3 | Project Scope Data Incompleteness | The number of EWPs delayed due to the project scope freeze/change divided by the total number of EWPs of the project. | $\frac{\textit{number of EWPs delayed due to project scope freeze/change}}{\textit{total number of project EWPs}}$ |
| 1.4 | EWPs Issue Completeness | The number of EWPs issued incomplete in the first issue divided by the total number of EWPs of the project. | $\frac{\textit{number of EWPs issued in complete}}{\textit{total number of project EWPs}}$ |
| 1.5 | Designing and Construction Overlap | The length of the overlap between the engineering and construction phase of the project divided by the total estimated construction phase duration at tender stage. | $\frac{\textit{Duration of overlap between engineering and construction}}{\textit{estimated construction duration at tender stage}}$ |
| 1.6 | Procurement and Engineering Alignment | The number of the procurement items which readily have all the associated items specified by engineering documents divided by the total number of procurement items. | $\frac{\textit{number of completed procurement items referring to design documents}}{\textit{Total number of procurement items}}$ |
| 2. | Project Construction Performance Metrics | | |

| KPI No. | KPI Name | KPI Definition | KPI Formula |
|---|---|---|---|
| 2.1 | Project Schedule Factor | The number of IWPs completed on schedule divided by the total number of IWPs of the project. | $\frac{\textit{Number of IWPs completed on schedule}}{\textit{total number of project IWPs}}$ |
| 2.2 | Material Related Delay Factor | The number of the IWPs delayed due to the late delivery of material divided by the total number of IWPs of the project. | $\frac{\textit{number of IWPs delayed due to late material delivery}}{\textit{total number of project IWPs}}$ |
| 2.3 | Equipment Related Delay Factor | The number of the IWPs delayed due to unavailability of equipment divided by the total number of IWPs of the project. | $\frac{\textit{number of IWPs delayed due to equipment unavailability}}{\textit{total number of project IWPs}}$ |
| 2.4 | Labor Related Delay Factor | The number of the IWPs delayed due to unavailability/inadequacy of labor divided by the total number of IWPs of the project. | $\frac{\textit{Number of IWPs delayed due to labor unavailability}}{\textit{total number of project IWPs}}$ |
| 2.5 | Design Related Delay Factor | The number of the IWPs delayed due to the late delivery of engineering deliverables divided by the total number of IWPs of the project. | $\frac{\textit{Number of IWPs delayed due to late engineering deliverables}}{\textit{total number of project IWPs}}$ |
| 2.6 | Design Related Change Factor | The number of the IWPs have change orders issued as the result of RFIs divided by the total number of IWPs of the project. | $\frac{\textit{Number of IWPs changed due to RFIs}}{\textit{total number of project IWPs}}$ |

| KPI No. | KPI Name | KPI Definition | KPI Formula |
| --- | --- | --- | --- |
| 2.7 | Crew Cohesion Factor | Total duration of time spent by the foreman on the field with the crew divided by the total time the foreman spent on the project. | $\frac{\textit{Total time spent by foreman on field with crews}}{\textit{Total time spent by foreman on the project}}$ |