A Framework to Assess the Costs and Benefits of Advanced Work Packaging

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Abstract

The term advanced work packaging (AWP), coined by the Construction Industry Institute (CII), 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. 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 paper presents a structured framework to assess multiple aspects of AWP implementation, which will enable the quantification of both its costs and benefits. The framework will enable the future comparison of AWP and non-AWP projects. This paper contributes to the industrial construction sector by providing a first-of-its kind framework and methodology to assess AWP implementation in practice.

Keywords: advanced work packaging, workface planning, best practice, industrial construction, project planning.

1. Introduction

Completing the project on time and within the allocated budget are two primary objectives for a construction project. To achieve these two objectives, a planning and a control system to manage project execution is necessary. A plan establishes the goals for a project's schedule, cost, and resource usage, and it specifies the activities and methods utilized to carry out the scope of work. A control system collects feedback on the progress of the construction project and compares the progress to the existing plan for informed and timely decision-making. 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). With increasing project complexity, development of new methods and improvement of existing methods for planning and control are necessary. Some of the new methods developed are based on pre-project collaboration between planning, engineering, and construction stakeholders to proactively assess potential risks and opportunities. These conditions are especially true in the area of industrial construction, where the emergence of mega projects requires the use of more sophisticated levels of planning and control.

Several planning and control methods have been developed for construction by researchers. For instance, Liu et al. (2015) developed a building information modeling (BIM) based method to facilitate the automatic generation of optimized activity-level construction schedules for building projects under resource constraints. Hu and Mohammed (2013) utilized a time-stepped simulation technology to develop a congestion-constrained, dynamic resource allocation scheduling framework (CRDASS). The method enabled variable resource allocation and variable durations in the execution of work packages. Another author, Ibrahim et al. (2009) proposed a framework for the automatic generation of work packages, as well as a system that employs computer vision techniques to report on the progress of these work packages. Some authors developed methods based on data-driven planning and control. One such author, Tang et al. (2014) developed a data-driven planning and control method that utilizes a historical database of productivity data to identify the most likely production rate of crews. Similarly, Cho et al. (2013) proposed a construction information database framework (CIDF) that aims to integrate cost, schedule, and performance data.

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 construction before commencement. 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 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.

Another CII research team, RT 319, analyzed the causality relationship between AWP and project predictability, based on survey data using the partial least square (PLS) statistical technique (CII 2015). The results showed that AWP influences 25% of project predictability. However, RT 319 did not analyze the relationship between AWP and other dimensions of project performance, such as cost and schedule performance. AWP implementation maturity versus performance was assessed, and the research indicated that 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 maturity, followed by fast growth in the middle phase, and moderate advances in the final phase. Ponticelli et al. (2015) also 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. Ponticelli et al. (2015) also suggested that the development of performance metrics to measure the maturity of AWP, as well as a comparison between different levels of maturity and project performance would be an important contribution for future research. However, the authors did not consider the effect of crew performance on AWP implementation, and the crews 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.

This paper presents a structured framework to assess multiple aspects of AWP implementation, which will enable quantification of both its costs and benefits. Moreover, this framework will allow for projects in which AWP has been implementing to 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 paper 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 paper is organized as follows. Section 2 presents the data collection forms developed for the framework. The basis for these data collection forms and the data collection and analysis method is also discussed in this section. Section 3 demonstrates the framework developed using a case study and illustrates the data analysis to calculate the cost, benefit, maturity, and performance of AWP. Section 4 presents the methodology to calculate the costs and benefits of AWP implementation using the framework. Finally, Section 5 summarizes the work presented and discusses future research areas.

2. Data collection form design

The proposed 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.

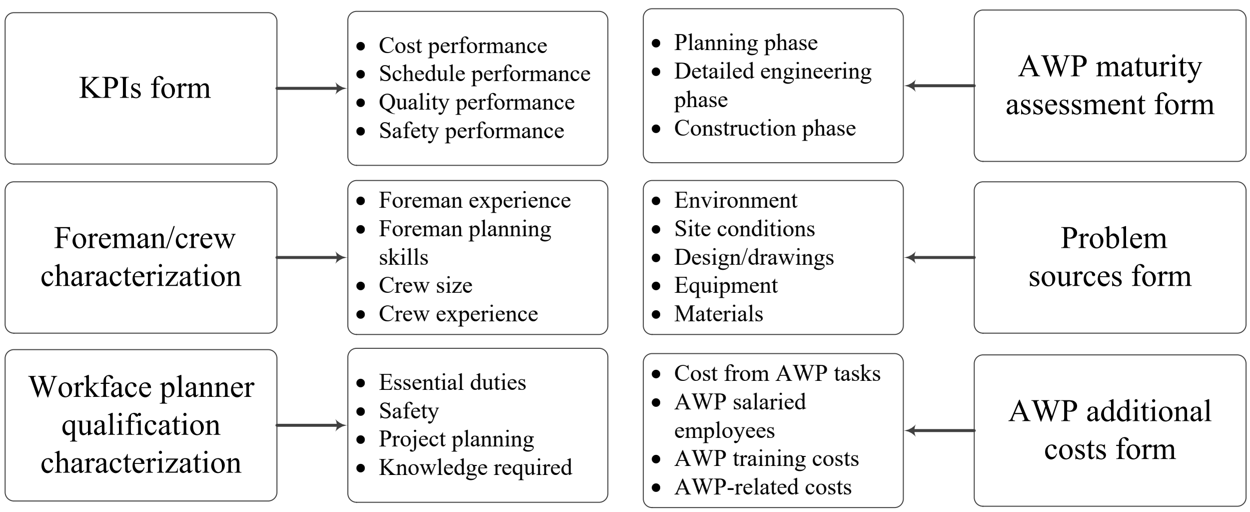

Figure 1. Components of framework to assess AWP costs and benefits.

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

2.1 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 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 1. 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 1. 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 2.

Table 1. Maturity and importance scales to assess AWP practices.

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

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

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.

2.2 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.

2.3 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 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 3. A sample of the workface planner qualification characterization form is also given in Table 4.

Table 3. Importance and agreement scales for workface planner qualification criteria evaluation.

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
Agreement scale	
Scale	Scale description
1	Strongly disagree
2	Disagree
3	Neither disagree nor agree
4	Agree
5	Strongly agree

Table 4. 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 3 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 3 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, $AV_i, i = 1, \ldots, n_I$, 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.

2.4 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. Samples of the crew and foreman characterization forms are given in Table 5.

Table 5. 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.

2.5 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 3. The level of impact scale has four levels: (1) no impact, (2) slightly negative, (3) negative and (4) strongly negative. A sample of the problem sources form is also shown in Table 6.

Table 6. 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* $1, \ldots, f$, where f is the total number of criteria; in this case f is equal to 83.

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

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”); and 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 ith 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.

2.6 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 7. Samples of the work package KPIs and the project KPIs are shown in Table 7.

Table 7. Work package and project performance indicators sample metrics.

KPI No.	KPI name	KPI definition	KPI formula
		Work package level KPIs	
1. Work package cost performance indicators			
1.1	Work package cost growth	The difference between the actual total work package cost and total work package estimated cost at tender stage, over the 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 the total work package estimated cost at tender stage plus the cost of approved changes to work package.	$\frac{\textit{actual total work package cost}}{\textit{(total work package estimate at tender stage + approved changes to work package)}}$
2. Work package schedule performance metrics			
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 difference between the actual work package duration and the estimated work package duration at tender stage, over the estimated work package duration at tender stage.	$\frac{\textit{(actual work package duration – estimated work package duration at tender stage)}}{\textit{Estimated work package duration at tender stage}}$

KPI No.	KPI name	KPI definition	KPI formula
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. Work package safety performance indicators			
4.1	Lost time rate	The ratio between the amount of 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 amount 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			
5.1	Construction productivity factor (physical work	The ratio between the actual direct man-hours required to install a unit quantity of the work package output, and the total installed quantity.	*Actual direct man-hours of work package* / *total installed quantity*
5.2	Construction productivity factor (cost)	The ratio between the total installed cost of work package, and the actual direct man-hours	*total installed cost of work package* / *actual direct man-hours of work package*
6. Work package predictability performance indicators			
6.1	Cost predictability	The difference between the actual work package cost and the estimated work package cost at tender stage, over the estimated work package cost at tender stage.	*(actual work package cost – estimated work package cost at tender stage)* / *Estimated work package cost at tender stage*

KPI No.	KPI name	KPI definition	KPI formula
6.2	Time predictability	The difference between the actual work package duration and the estimated work package duration at tender stage, over the estimated work package duration at tender stage.	$\frac{\textit{(actual work package duration – estimated work package duration at tender stage)}}{\textit{Estimated work package duration at tender stage}}$
Project level KPIs			
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.	$\frac{\textit{number of EWPs issued on schedule}}{\textit{total number of project EWPs}}$
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.	$\frac{\textit{number of EWPs delayed due to project scope freeze/change}}{\textit{total number of project EWPs}}$
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.	$\frac{\textit{Number of IWPs completed on schedule}}{\textit{total number of project IWPs}}$
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.	$\frac{\textit{number of IWPs delayed due to equipment unavailability}}{\textit{total number of project IWPs}}$

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

3. Case study: Application of AWP framework

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 2. The importance values, given by the construction manager based on the importance scale shown in Table 1, 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 1, 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 2.3. Table 8 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 8. 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 8. 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 2.5 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 3, for the first five problem sources are 1, 2, 3, 4, and 1 respectively; the level of impact values, given based on the level of impact scale described in Section 2.5, 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 10 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 11.

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

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

$$LOI = 1.54$$

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 were determined using a similar process. The resulting KPIs were used in the framework described below. The KPI forms require multiple sets of data for meaningful analysis.

4. Proposed methodology to calculate cost-benefit of AWP implementation using framework

Once data were collected and analyzed, the individual components of the framework were integrated to calculate the costs and benefits of AWP implementation. The AWP framework assesses two components of AWP implementation, the first of which is the relationship of AWP maturity to project performance based on KPIs. Using the data from the forms developed, the performance of construction projects with different levels of AWP maturity and different workface planners, crew, and foremen can be analyzed and compared. The steps for this analysis are described next.

In step 1, the M_{awp} (aggregated AWP maturity score), FC (final workface planner characterization score), and LOI (level of impact score) values are calculated using the data analysis method presented in Sections 2.1, 2.3, and 2.5 respectively. Construction projects without AWP implementation would be classified as having an AWP maturity (M_{awp}) of 0 for comparison purposes. Next, in step 2, the KPIs for projects with different levels of AWP implementation are calculated. In step 3, the FC , LOI, and the crew and foreman characterization values are used to identify projects that have similar characteristics. Next, the KPIs of projects with different AWP maturity levels, but similar characteristics are compared in step 4 using methods such as correlation analysis. Finally, in step 5, the relationship between AWP maturity and KPI performance is determined based on the results from Step 4.

The second component of the AWP framework is designed to determine the return on investment (ROI) of implementing AWP on a construction project. In step 1 of the second component, the cost of AWP implementation is obtained using the Additional Cost Form. Next, in step 2, the benefit of AWP is determined. This benefit refers to the value gained from AWP implementation, as compared to a traditional method of project planning and execution. Previous research on AWP states that AWP reduces the cost of construction projects. On that basis, for projects in which AWP has been implemented, the cost estimate for a project should be less than the cost estimate for the same project using a traditional planning and execution approach. Thus, in step 2, an expert in cost estimation using the traditional planning and execution approach would estimate the cost of the project. Similarly, an expert in AWP cost estimation would estimate the cost of the project. The difference in cost between the two estimates represents the benefit of AWP implementation. Additionally, if AWP is implemented correctly, it should also improve project predictability, as captured by some of the KPIs. Therefore, another measure of benefit could be the predictability of an AWP project versus that of a non-AWP project. Using both of these approaches, the benefit of AWP implementation is then determined by calculating the sum of the cost savings at the estimate stage plus the measure of costs savings due to predictability, as compared to non-AWP projects.

Finally, in step 3, the ROI of AWP is calculated using Equation 11 (Pearce 2015).

(11) $$ROI = \frac{Benefit from\ AWP\ implemenation - Cost\ of\ AWP}{Cost\ of\ AWP}$$

By utilizing the AWP framework outlined above, the relationship between AWP maturity and performance and the ROI of AWP can be assessed.

5. Conclusions and future work

The reported benefits of AWP state that savings in schedule and cost can be achieved through AWP implementation. A structured framework to assess these benefits quantitatively and to examine the performance of AWP on projects with varying levels of maturity is presented in this paper. The framework assesses multiple aspects of AWP implementation, which will enable the quantification of both its costs and benefits, so that projects implementing AWP can 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, this paper 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. This paper 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 quantify the benefits associated with implementing AWP in practice. The results from the AWP framework will facilitate improved decision making for construction practitioners regarding AWP implementation.

Further data collection is required to determine the costs and benefits of implementing AWP in practice.. In addition to AWP, different project planning and execution methodologies exist to address the challenges of industrial construction. Future research can thus provide a comparison of the ROI of AWP against other project planning and execution methodologies. Another future research area is identifying the types of project delivery methods most suited to AWP implementation. Future research may also explore the different types of organizational structures (i.e., those with varying contractual relationships between the owner, design firm, and construction contractor) most suited to AWP implementation.

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