# Framework to Assess Impacts of Advanced Work Packaging on Work Package and Project Performance:

## Construction Owners Association of Alberta

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# Executive summary

Advanced Work Packaging (AWP) was announced as a best practice by the Construction Industry Institute (CII) in 2015 and has since been adopted by the Construction Owners Association of Alberta (COAA). Case studies conducted on AWP report a number of benefits in the areas of productivity, cost, safety, and schedule (CII 2016). 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. The COAA Advanced Work Packaging Committee has designated a sub-committee to focus specifically on the completion of industry research projects that will facilitate the further development, growth, and improvement of Advanced Work Packaging best practices within the industrial construction sector. The COAA sub-committee on AWP has partnered with the University of Alberta's NSERC Industrial Research Chair in Strategic Construction Modeling and Delivery to undertake a research project to identify benefits of effective AWP implementation. Results from this study will thus help to encourage more widespread implementation of AWP on Alberta construction projects. The objectives of this proposed research study are as follows:

- Develop an approach for assessing the maturity of an AWP/WorkFace Planning (WFP) program on Alberta industrial construction projects;
- Develop an approach for assessing the indirect costs associated with implementing an AWP/WFP program and distinguishing such costs from other project indirect costs;
- Develop an approach to characterize the qualifications of WorkFace planners.
- Develop metrics to assess the impacts of an AWP/WFP program on the performance of installation work packages, construction work packages (CWP), and/or on the project as a whole;
- Develop a framework and systematic methodology to collect data for the purposes of assessing the costs and impacts of an AWP/WFP program;
- Develop a data analysis method in support of the efforts of the COAA Advanced Work Packaging Committee to quantify the costs and benefits of implementing an AWP/WFP program.

This report presents the steps and results of the study undertaken to fulfil these objectives. The study presents a structured framework to assess multiple aspects of AWP implementation, in an effort to quantify both its costs and benefits. The framework provides a systematic approach for measuring AWP maturity, AWP additional costs, WorkFace planner qualifications, foreman and crew characteristics, problem sources, and key performance indicators. A methodology is also presented to support the analysis of data collected using the framework, which will help construction organizations to assess costs associated with implementing AWP and relate different levels of AWP implementation to improved project performance.

First, a literature review of existing AWP practices was conducted, and a report detailing the results was developed (Halala et al. 2016). Second, data collection forms were

developed based on the information gathered during the literature review process. The data collection forms developed were presented to members of the COAA sub-committee, and the forms were improved based on the discussion that followed. The study was also presented at the COAA best practices conference, and the feedback obtained was used to further evaluate the utility of the forms in addressing different facets of AWP implementation. Furthermore, the sub-committee provided updated information on the current methods of AWP implementation.

Six data collection forms were developed, each of which is discussed in Section 2: (1) AWP maturity assessment; (2) AWP additional costs; (3) WorkFace planner qualification characterization; (4) crew and foreman characterization; (5) problem sources; and (6) KPIs (key performance indicators). The data collection forms address components that impact AWP implementation, such as the cost of implementing AWP, and the qualification characterization of those who implement AWP, including WorkFace planners, crew members, and foremen. Once the data collection forms were complete, the forms were pilot tested on an industrial construction project. The pilot project was also used to test the data collection methodology.

After data collection, the data gathered from the pilot project were analyzed using methods developed for each data collection form. Using the AWP maturity form, an overall maturity score for the project was determined using a weighted aggregation method. The cost of AWP was calculated using the AWP additional cost form as a summation of costs incurred from AWP implementation. The scores for individual WorkFace planners were combined to determine a final aggregation score representing all WorkFace planners involved in the project. The data collected from the crew and foreman forms will be used to compare the qualifications of the crew and foremen against those on future projects in the developed framework; as such, these forms were not analyzed at this stage. The data from the problems sources form was aggregated to determine a final score for the project. The KPIs collected will be used in the framework to compare a given project against other projects. Following the presentation of results from data analysis, the methodology for calculating the costs and benefits of AWP implementation using the developed framework is discussed. The AWP framework assesses two components of AWP implementation, the first of which is determining the return on investment (ROI) of implementing AWP on a construction project. The second component of the AWP framework is determing the relationship between AWP maturity and project performance, based on KPIs.

Future research will include further data collection to apply the AWP framework in practice, and to draw conclusions about the costs and benefits of AWP implementation based on results from multiple projects. In addition to AWP, different project planning and execution methodologies exist to address the challenges of industrial construction. Future research will also compare the ROI of AWP with such project planning and execution methodologies.

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# 1. Introduction

Completing a project on time and within the allocated budget are two primary objectives for any 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 due to an increase in the level of project detail, lack of predictability, and types and levels of stakeholder interactions associated with industrial construction, improvement in existing methods for project planning and control is 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.

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) notes that before AWP development, a common standard for work packaging had not been 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 these 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 in order to identify critical target areas or factors for improving productivity. Addressing the challenges of front-end planning was considered an important component in improving productivity on Alberta oil and gas construction projects.

The benefits attributed to AWP are based on case studies conducted on companies that had 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. The COAA sub-committee on AWP has partnered with the University of Alberta's NSERC Industrial Research Chair in Strategic Construction Modeling and Delivery to undertake a research project to identify the benefits that may be achieved when AWP is implemented effectively, thus encouraging its implementation on Alberta construction projects. The objectives of the proposed research study are as follows:

- Develop an approach for assessing the maturity of an AWP/WFP program on Alberta industrial construction projects;
- Develop an approach for assessing the indirect costs associated with implementing an AWP/WFP program, and distinguishing such costs from other project indirect costs;
- Develop an approach to characterize the qualifications of WorkFace planners;

- Develop metrics to assess the impacts of an AWP/WFP program on the performance of individual work packages, construction work packages (CWP), and/or on the project as a whole;
- Develop a framework and systematic methodology to collect data for the purpose of assessing the costs and benefits of an AWP/WFP program;
- Develop a data analysis method in support of the efforts of the COAA Advanced Work Packaging Committee in quantifying the costs and benefits of implementing an AWP/WFP program.

This report discusses the process of conducting the study and its key findings. A report addressing a literature review of AWP precedes this current report (Halala et al. 2016). This report is organized as follows. Section 2 presents the data collection forms developed for the framework. The basis for these data collection forms and for the data collection and analysis methods are also discussed in this section. Section 3 demonstrates the framework developed using a case study, and illustrates the data analysis procedure for calculating the costs, benefits, maturity, and performance of AWP. Section 4 presents the methodology for calculating the costs and benefits of AWP implementation using the developed framework. Finally, Section 5 summarizes the work presented and discusses future research areas.

## 2. Data collection form design

The proposed framework uses six data collection forms that assess different components of the AWP process across the three project phases of planning, engineering and construction: (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 each data collection form with sample categories of criteria; each component is assessed using a dedicated data collected form.

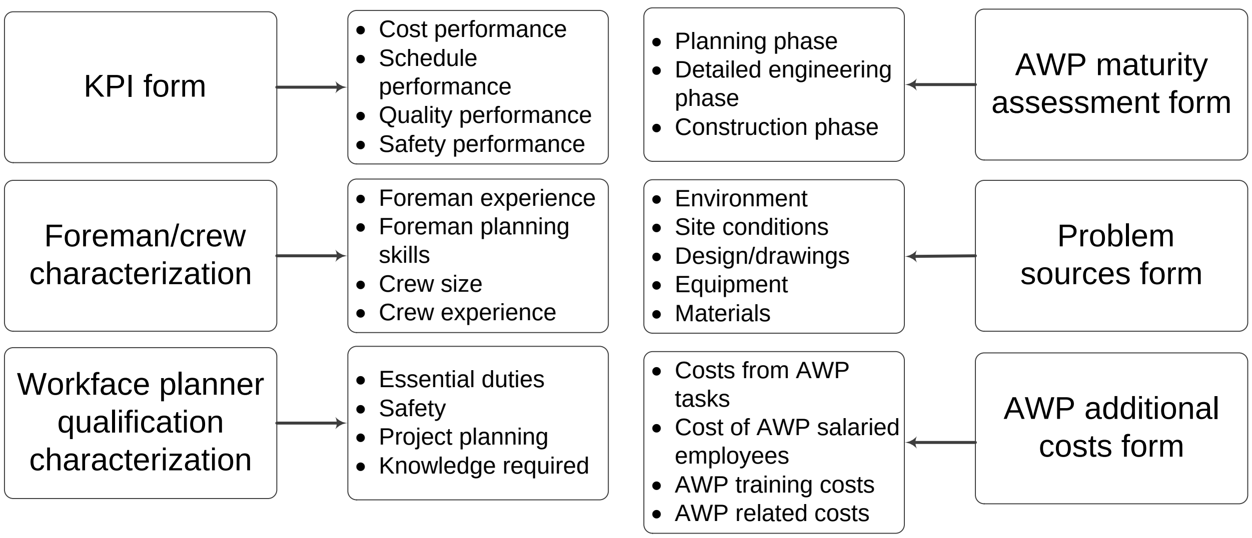


Figure 1. Data collection forms with sample categories of criteria

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 created 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; these scales are based on previous work by Omar and Fayek (2016b). 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; it can also vary across five levels, as shown in Table 2. 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 3 and the full form is given in Appendix A1.

Table 1. 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 2. 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 3. 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 AWP maturity assessment form was administered as a self-completed survey, and potential participants included 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).

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

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).

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

Where $n^{(h)}$ is the number of AWP maturity assessment form respondents 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.

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

The AWP maturity assessment form 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, 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 personnel, training for AWP, costs stemming from AWP-specific tasks, and miscellaneous AWP-related costs (e.g., IT costs). The AWP additional costs form contains four components, which 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 costs 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 costs.

The first component gathers information on employees whose responsibilities are dedicated solely to AWP tasks. The second component of the AWP additional costs 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. The third component of the form collects data related to AWP training. In cases where training is specific to the project, additional costs are directly attributed to training. For training provided on an organizational 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.

$$C_{AWP} = \text{Costs from AWP Tasks} + \text{Cost of AWP Salaried Employees} + \text{AWP Training Costs} + \text{AWP Related Costs} \tag{4}$$

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, so that actual, rather than estimated, costs can be allocated to AWP tasks. 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 WorkFace planners was developed using the

COAA characterizations. The criteria category is shown in Table 4. 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; these scales are based on previous work by Omar and Fayek (2016b). 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 satisfies 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 5 and Table 6. A sample of the WorkFace planner qualification characterization form criteria is given in Table 7, and the full form is provided in Appendix A3.

Table 4. 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 5. 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 6. Agreement scale

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

Table 7. 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 5 is used to determine the importance score, $Y_{l,i}$, for each qualification criterion $l, l = 1, \ldots, k$, and individual *i*, where $k$ stands for the total number of qualification criteria; in this case $k$ is equal to 44. Second, the agreement scale shown in Table 6 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 $i = 1, \ldots, n_I$, 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) $$V_i = \sum_{l=1}^{k} \left( \frac{Y_{l,i}}{\sum_{j=1}^{k} Y_{j,i}} \times P_{l,i} \right)$$

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, $n_I$, 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 $FC$ score 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. A sample of the crew and foreman characterization form criteria is given in Table 8, and the full form is available in Appendix A4.

Table 8. 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 scale (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, in hors) |
| Craftsperson technical training | Real number (no. training sessions attended x duration of Training, in hors) |
| 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, in hours) |
| 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 whether some criterion exists on a project, while the level of impact scale is used to identify the level of impact that particular criterion has on the project. The description for the agreement scale is shown in Table 6. The level of impact scale is shown in Table 9. A sample of the problem sources form criteria is given in Table 10, and the full form is available in Appendix A5.

Table 9. Level of impact scale

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

Table 10. 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 was 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) $$T_r = \frac{(A_r * 1 + B_r * 2 + C_r * 3 + D_r * 4 + E_r * 5)}{(A_r + B_r + C_r + D_r + E_r)} \ , \ r = 1, \ldots, f$$

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 was 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 $L_r$ was calculated based on the value assigned by each respondent to each criterion *r* (Equation 9).

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

Where $n$ is the number of respondents of the AWP source form; and $L_{r,i}$ is the level of impact scores given by the $i$th respondent for a given criterion $r$.

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

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

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 Development and use of key performance indicators (KPIs) in AWP framework

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 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 11 and 12. A sample of the work package and project KPI forms is given in Table 11 and 12 respectively. The full forms for the work package KPIs and the project KPIs are available in Appendix A6.

Table 11. Work package performance indicators sample

| KPI No. | KPI name | KPI definition | KPI formula |
|---|---|---|---|
| 1. Work package cost performance indicators | | | |
| 1.1 | Cost per unit at completion | Actual cost for the product at work package completion per unit of measurement (e.g., cost per $m^2$ of floor space) | $\dfrac{\textit{actual work package cost}}{\textit{quantity of completed work}}$ |
| 1.2 | Work package budget factor | The ratio of the actual work package cost to the sum of the estimated work package cost at tender stage and approved changes to work package cost | $\dfrac{\textit{actual work package cost}}{\textit{(estimated work package cost at tender stage + approved changes to work package cost)}}$ |
| 2. Work package schedule performance indicators | | | |
| 2.1 | Work package schedule factor | The ratio of the actual work package duration to the sum of the estimated work package duration at tender stage and approved changes to work package duration | $\dfrac{\textit{actual work package duration}}{\textit{(estimated work package duration at tender stage + approved changes to work package duration)}}$ |
| 2.2 | Time per unit at completion | Actual duration for the product at work package completion per unit of measurement (e.g., months per $m^2$ of floor space) | $\dfrac{\textit{actual work package duration}}{\textit{quantity of completed work}}$ |
| 3. Work package quality performance indicators | | | |
| 3.1 | Work package rework cost factor | The ratio of the total direct cost of work package rework to the actual work package direct cost | $\dfrac{\textit{total direct cost of work package rework}}{\textit{actual work package direct cost}}$ |
| 3.2 | Work package rework time factor | The ratio of the total duration of work package rework to the actual work package duration | $\dfrac{\textit{total duration of work package rework}}{\textit{actual work package duration}}$ |
| 4. Work package safety performance indicators | | | |
| 4.1 | Lost time rate | The ratio of the amount of time lost to incidents on the work package to the total hours worked on the work package | $\dfrac{\textit{amount of lost time to incidents on work package (hours)}}{\textit{total hours worked on work package}}$ |

| KPI No. | KPI name | KPI definition | KPI formula |
|---|---|---|---|
| 4.2 | Lost time frequency | The ratio of the number of lost time incidents on the work package to the total hours worked on the work package | $\frac{\textit{number of lost time incidents on work package}}{\textit{total hours worked on work package}}$ |
| 5. Work package productivity indicators | | | |
| 5.1 | Construction labor productivity (physical work) | The ratio of the actual direct person-hours of the work package to the total installed quantity of the work package | $\frac{\textit{actual direct person-hours of work package}}{\textit{total installed quantity of work package}}$ |
| 5.2 | Construction productivity (cost) | The ratio of the total installed cost of the work package to the total installed quantity of the work package | $\frac{\textit{total installed cost of work package}}{\textit{total installed quantity of work package}}$ |
| 6. Work package predictability performance indicators | | | |
| 6.1 | Cost predictability | The ratio of the difference between the actual work package cost and the estimated work package cost at tender stage to the estimated work package cost at tender stage | $\frac{\textit{(actual work package cost – estimated work package cost at tender stage)}}{\textit{estimated work package cost at tender stage}}$ |
| 6.2 | Time predictability | The ratio of the difference between the actual work package duration and the estimated work package duration at tender stage to the estimated work package duration at tender stage | $\frac{\textit{(actual work package duration – estimated work package duration at tender stage)}}{\textit{estimated work package duration at tender stage}}$ |

Table 12. Project performance indicators sample

| KPI No. | KPI name | KPI definition | KPI formula |
|---|---|---|---|
| 1. Project detailed design performance indicators | | | |
| 1.1 | EWP (Engineering Work Package) issue rate | The ratio of the number of EWPs issued on schedule to 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 ratio of the number of EWPs delayed due to incomplete vendor data to 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 ratio of the number of EWPs delayed due to project scope freeze/change to 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 indicators | | | |
| 2.1 | Project schedule factor | The ratio of the number of IWPs (Installation Work Packages) completed on schedule to 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 ratio of the number of IWPs delayed due to the late delivery of material to 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 ratio of the number of IWPs delayed due to unavailability of equipment to 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 development and analysis of the six data collection forms was discussed in this section. The data collection forms are used to collect data and the results of their analysis are used in the AWP framework.

### 2.6.1 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.

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

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 completed work ($Q$) 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.

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

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.

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

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.

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

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

# 3. Application of AWP framework

This section 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.

## 3.1 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.

### 3.1.1 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 2.6.1. 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 2.6.

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

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

The following figure demonstrates the framework used to calculate ROI.

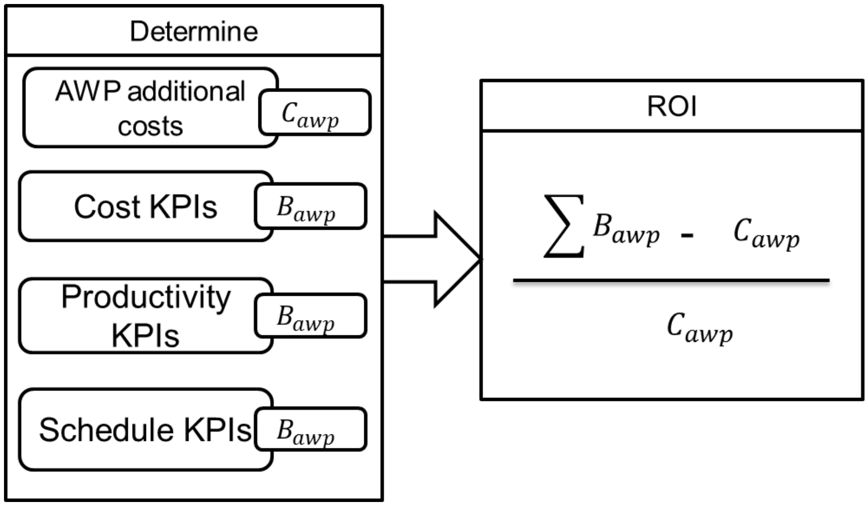


Figure 2. ROI calculation approach for a single project

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 13. 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 13 shows the data used to calculate the $B_{awp}$.

Table 13. Cost per unit at completion and quantity of completed work data for hypothetical projects

| Project | Work Package | Cost per unit at completion [$/unit] | | Quantity of completed work $(Q)$ [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.

### 3.1.2 Comparison of performance between projects implementing AWP

The AWP framework is used to evaluate multiple projects and compare the performance of projects with varying levels of AWP maturity. 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 3 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 3 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 3, are the dependent variable. By using this approach the relationship between different levels of AWP maturity and project performance can be evaluated.

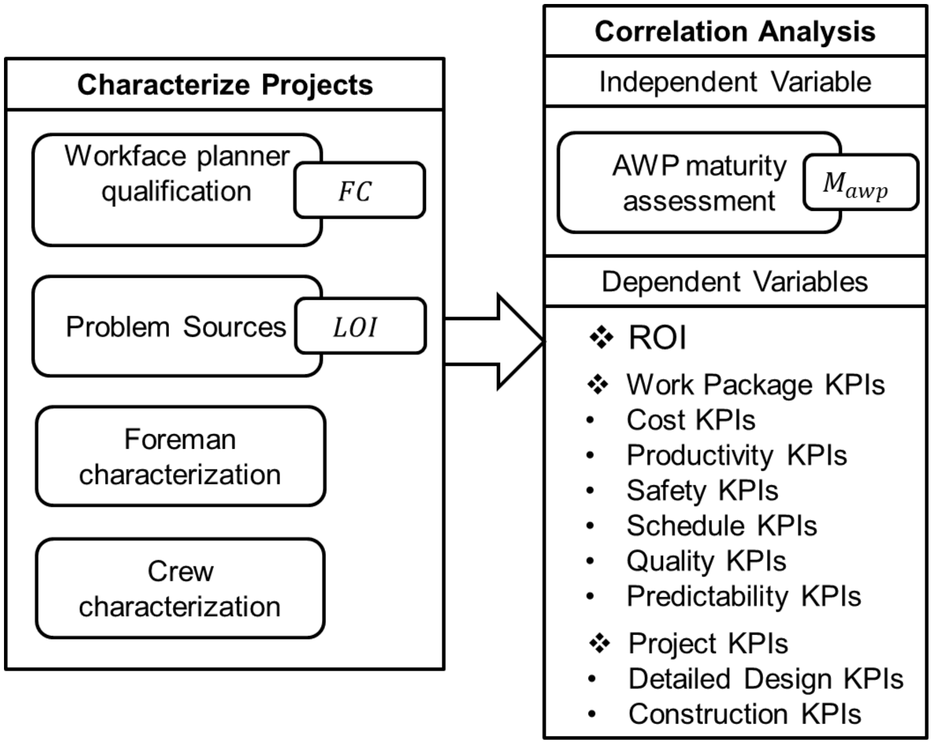


Figure 3. Context characterization and correlation analysis approach for multiple projects

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. 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 case study is used to demonstrate the calculation and application of the AWP framework components using data from the construction phase of an industrial construction project. One of the limitations of this research is that data were not collected from all stakeholders involved in the AWP process. The project was the module yard component of an oil sands project, 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. From the construction contractor, participants include 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. The participants completed different data collection forms depending on the data collection form requirements, which are based on specific types of personnel or levels of expertise on a specific topic. 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 3. The importance values, given by the construction manager based on the importance scale shown in Table 2, 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.

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

$$M_{awp} = 3.75$$

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 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 14 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 14. 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 $e$ are shown in Table 14. 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.

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

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

$$V_1 = 3.8$$

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

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

$$V_1^s = 4.59$$

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 6, for the first five problem sources are 1, 2, 3, 4, and 1 respectively; the level of impact values, given based on Table 9, 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.

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

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

$$LOI = 1.54$$

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

The use of the KPI forms was demonstrated using hypothetical data for ROI determination for a single project. To compare the performance of projects with varying levels of AWP maturity, the KPI forms require multiple sets of data for meaningful correlation analysis. Once sufficient data are collected for correlation analysis, the AWP framework developed can be used to assess the relationship between AWP maturity and ROI and between AWP maturity and project performance in terms of each KPI.

# 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 to determine ROI and to examine the performance of AWP on projects with varying levels of maturity is presented in this report. The first stage of data collection and analysis in developing a structured framework to assess these benefits quantitatively is presented in this report. 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 key performance indicators. In addition, this report 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. Furthermore, future research will develop software-based tools to implement the data collection forms presented in this report to automate data collection and analysis. These tools will enable organizations to assess different components of AWP implementation.

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. 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. 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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# APPENDIX

## 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 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:
AWP was announced as a best practice by the Construction Industry Institute (CII) in 2015 and has since 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 (the 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:

☐ AWP 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

☐ Bachelor's degree

☐ College diploma

☐ Technical, vocational, or trade school

☐ Master's degree or above

☐ Some university credit (no degree)

☐ Some college credit (no degree)

☐ 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 labor group is involved in this project? (Please specify ALL that apply)

☐ Merit ☐ CLAC ☐ Building Trades

☐ United Association ☐ United Brotherhood of Carpenters and Joiners of ☐ United Steelworkers

☐ International Brotherhood of Electrical Workers ☐ International Association of Bridge, Structural, Ornamental, and Reinforcing Iron Workers

☐ 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 below:

*Importance measurement:* measures how important a practice is to the phase it is associated with; values 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 |

*Maturity measurement:* measures the extent to which an AWP practice pertaining to a given phase of AWP exists; values 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 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 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. 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 |

*1)* 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 |

2) 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 IWPs. | | | 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 | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *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 indirect costs form evaluation criteria

The different AWP tasks used to evaluate AWP Indirect costs are listed in Table A.2 1.

**Table A.2 1 AWP indirect costs 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 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 |
| | 1.2.11 | Implement AWP automation/input systems |
| | 1.2.12 | Revise functional procedures to establish or integrate AWP processes |

| Responsible for task | No | Task description |
|---|---|---|
| 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) |
| | 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) |
| | 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 Construction management | 3.3.1 | Release CWP |
| | 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 contractor | 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) |
| | 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 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:

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 (WFPs) 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 WFPs, and you are asked to assess yourself in terms of the relative importance of each qualification to your job as a WFP and your level of agreement that you possess this qualification.

Note: The COAA definition a WorkFace Planner is presented below to assist in filling out the second section of this form.

*WorkFace planner (WFP)*

The WFP 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 WFP include ensuring safety, quality and efficiency at the WorkFace are considered in the planning process; developing IWPs; coordinating with and imparting WorkFace construction knowledge to project schedulers, engineers, superintendents, and managers; and acting as a liaison between the project controls department and workforce supervision.

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/AWP?

________ 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:* measures 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*: measures 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 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 |

| 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* |
| *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 nor 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 AWP 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; 2. Crew size is POOR fit for the activity's volume of work; 3. Crew size is FAIR fit for the activity's volume of work; 4. Crew size is GOOD fit for the activity's volume of work; 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, in hours) | |
| 1.1.5 | Craftsperson technical training | Real number (No. trainings attended x Duration of training, in hours) | |
| 1.1.6 | Crew composition | Integer numbers (no. journeymen, no. apprentices) | |
| 1.1.7 | Crew experience | Integer number (years of experience) | |
| 1.1.8 | Number of languages spoken in the crew | Integer number | |
| 1.1.9 | Co-operation among craftsperson | 1-5 predetermined rating scale | 1. VERY DIVERSE ability, VERY LOW stake value, VERY LARGE crew size; 2. DIVERSE ability, LOW stake value, LARGE crew size; 3. DIVERSE ability, MEDIUM stake value, AVERAGE crew size; 4. SIMILAR ability, HIGH stake value, SMALL crew size; 5. SIMILAR ability, VERY HIGH stake value, VERY SMALL crew size |

| Factor ID | Sub-factors | Scale of measure | Predetermined ratings (1-5)/Note |
|---|---|---|---|
| 1.1.10 | Craftsperson age | Integer number (age) | |
| 1.1.11 Craftsperson learning effect: $Y = a\,xb$, $Y$ is time for $xth$ unit, $a$ is time for first unit, $x$ is number of the unit is being produced, and $b$ is learning curve coefficient | | | |
| 1.1.11.1 | Time to install the first unit (a) | Real number (time to install first unit, in minutes) | |
| 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 scale | 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 scale | 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<br>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 scale | 1. VERY LOW consistency between direction of effort and the assigned goals; 2. LOW consistency between direction of effort and the assigned goals; 3. AVERAGE consistency between direction of effort and the assigned goals; 4. HIGH consistency between direction of effort and the assigned goals; 5. VERY HIGH consistency between direction of effort and the assigned goals |
| 1.1.13 | Total overtime work | Integer (total daily overtime work, in hours) | |
| 1.1.14 | Craftsperson trust in foreman | 1-5 predetermined rating scale | 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 scale | 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 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 scale | 1. Inconsistent work assignment on a daily basis, Unreasonable work assignment among crew members, VERY POOR Information provision; 2. Inconsistent work assignment on a daily basis, Unreasonable work assignment among crew members, POOR Information provision; 3. Consistent work assignment on a daily basis, Reasonable work assignment among crew members, AVERAGE Information provision; 4. Consistent work assignment on a daily basis, Reasonable work assignment among crew members, GOOD Information provision; 5. 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 scale | | | |
| 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 scale | 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 scale | 1. Skill level of the crew is VERY LOW for execution of the activity; 2. Skill level of the crew is LOW for execution of the activity; 3. Skill level of the crew is FAIR for execution of the activity; 4. Skill level of the crew is HIGH for execution of the activity; 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 scale | 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 scale | 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 |
| 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 |

| Factor ID | Sub-factors | Scale of measure | Predetermined ratings (1-5)/Note |
|---|---|---|---|
| 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 scale | 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 |
| 1.2.12 | Coordination between labor and equipment operators | Real number (total time lost due to lack of coordination, in minutes) | |

## 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 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:

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

*1.3.* Please indicate the name of your current employer (the 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:

☐ AWP 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

☐ Bachelor's degree

☐ College diploma

☐ Technical, vocational, or trade school

☐ Master's degree or above

☐ Some university credit (no degree)

☐ Some college credit (no degree)

☐ 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* | *Strongly agree* | *No impact* | *Slightly negative* | *Negative* | *Strongly negative* |
| *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*** | ***Strongly agree*** | ***No impact*** | ***Slightly negative*** | ***Negative*** | ***Strongly negative*** |
| *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* | Under-manning | | 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*** | ***Strongly agree*** | ***No impact*** | ***Slightly negative*** | ***Negative*** | ***Strongly negative*** |
| *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 man lift 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 |
| *9.5* | Damage 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*** | ***Strongly agree*** | ***No impact*** | ***Slightly negative*** | ***Negative*** | ***Strongly negative*** |
| *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 |

*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 ratio of the difference between the actual total work package cost and total work package estimated cost at tender stage to the total work package estimated cost at tender stage | $\dfrac{\textit{(actual total work package cost − total work package estimated cost at tender stage)}}{\textit{total work package estimated cost at tender stage}}$ |
| *1.2* | Work package budget factor | The ratio of the actual work package cost to the sum of the estimated work package cost at tender stage and approved changes to work package cost | $\dfrac{\textit{actual work package cost}}{\textit{(estimated work package cost at tender stage + approved changes to work package cost)}}$ |
| *1.3* | Work package indirect cost factor | The ratio of the actual work package indirect cost to the actual total work package cost | $\dfrac{\textit{actual work package indirect cost}}{\textit{actual total work package cost}}$ |
| *1.4* | Work package direct cost factor | The ratio of the actual work package direct cost to the actual total work package cost | $\dfrac{\textit{actual work package direct cost}}{\textit{actual total work package cost}}$ |
| *1.5* | Work package net variation cost factor | The ratio of the net value of the work package cost variations within the same work scope to the total work package cost estimated at tender stage | $\dfrac{\textit{net value of variations in work package cost}}{\textit{total work package cost estimated at tender stage}}$ |
| *1.6* | Cost per unit at completion | Actual cost for the product at work package completion per unit of measurement (e.g., cost per m² of floor space) | $\dfrac{\textit{actual work package cost}}{\textit{quantity of completed work}}$ |
| *1.7* | Cost defects warranty | The ratio of the contractor’s cost taken to rectify all defects of work package to the actual work package cost | $\dfrac{\textit{cost to rectify work package defects}}{\textit{actual work package cost}}$ |

**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 of the actual work package duration to the sum of the estimated work package duration at tender stage and approved changes to work package duration | $\dfrac{\textit{actual work package duration}}{\textit{(estimated work package duration at tender stage + approved changes to work package duration)}}$ |
| *2.2* | Work package schedule growth | The ratio of the difference between the actual work package duration and the estimated work package duration at tender stage to the estimated work package duration at tender stage | $\dfrac{\textit{(actual work package duration – estimated work package duration at tender stage)}}{\textit{Estimated work package duration at tender stage}}$ |
| *2.3* | Time variance | The ratio of the difference between the increase or decrease in actual work package duration and the extension of time (EOT) from the original time granted by the client to the estimated work package duration at tender stage | $\dfrac{\textit{increase/decrease in actual work package duration - EOT}}{\textit{estimated work package duration at tender stage}}$ |
| *2.4* | Time per unit at completion | Actual duration for the product at work package completion per unit of measurement (e.g., months per $m^2$ of floor space) | $\dfrac{\textit{actual work package duration}}{\textit{quantity of completed work}}$ |

**Table A.6 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 of the total direct cost of work package rework to 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 of the total duration of work package rework to 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 of the sum of direct and indirect cost of work package rework to 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 of the total time lost to incidents in work package to the total hours worked on the work package. | $\dfrac{\textit{amount of lost time to incidents in work package(hr.)}}{\textit{total hours worked}}$ |
| *4.2* | Lost time frequency | The ratio of the number of lost time incidents on the work package to the total hours worked on the work package | $\dfrac{\textit{number of lost time incidents on work package}}{\textit{total hours worked on work package}}$ |
| *4.3.* | Reported incidents frequency | The ratio of number of reported incidents in work package to the total hours worked on the work package | $\dfrac{\textit{number of reported incidents in work package}}{\textit{total hours worked}}$ |
| *4.4* | First aid frequency | The ratio of the number of reported first aid cases in work package to the total hours worked on the work package | $\dfrac{\textit{number of reported first aid cases in work package}}{\textit{total hours worked}}$ |
| *4.5* | Near miss incident frequency | The ratio of the number of reported near miss incidents in work package to the total hours worked on the work package | $\dfrac{\textit{number of reported near miss incidents in work package}}{\textit{total hours worked}}$ |

## 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 ratio of the difference between the actual work package cost and the estimated work package cost at tender stage to the estimated work package cost at tender stage | $\frac{\textit{(actual work package cost – estimated work package cost at tender stage)}}{\textit{estimated work package cost at tender stage}}$ |
| *5.2* | Time predictability | The ratio of the difference between the actual work package duration and the estimated work package duration at tender stage to the estimated work package duration at tender stage | $\frac{\textit{(actual work package duration – estimated work package duration at tender stage)}}{\textit{estimated work package duration at tender stage}}$ |

## Table A.6 6 Productivity performance indicators

| KPI No. | KPI name | KPI definition | KPI formula |
|---|---|---|---|
| *6.* Work package productivity performance indicators | | | |
| *6.1* | Construction labor productivity (physical work) | The ratio of the actual direct person-hours of the work package to the total installed quantity of the work package | $\frac{\textit{actual direct person-hours of work package}}{\textit{total installed quantity of work package}}$ |
| *6.2* | Construction productivity (cost) | The ratio of the total installed cost of the work package to the total installed quantity of the work package | $\frac{\textit{total installed cost of work package}}{\textit{total installed quantity of work package}}$ |
| *6.3* | Productivity estimate accuracy (productivity index) | The ratio of the estimated productivity rate of the work package to the actual productivity rate of the work package | $\frac{\textit{estimated productivity rate of work package}}{\textit{actual productivity rate of work package}}$ |
| *6.4* | Project absenteeism rate | The ratio of the total person-hours lost due to unplanned absenteeism on the work package to the total person-hours worked on the work package | $\frac{\textit{person-hours lost due to unplanned absenteeism on work package}}{\textit{total person-hours worked on work package}}$ |

## Table A.6 7 Project performance indicators

| KPI No. | KPI name | KPI definition | KPI formula |
|---|---|---|---|
| *1.* Project detailed design performance indicators | | | |
| 1.1 | EWP (Engineering Work Package) issue rate | The ratio of the number of EWPs issued on schedule to 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 rate | The ratio of the number of EWPs delayed due to incomplete vendor data to 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 rate | The ratio of the number of EWPs delayed due to project scope freeze/change to 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 rate | The ratio of the number of EWPs issued incomplete in the first issue to 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 ratio of the duration of overlap between the engineering and construction phase of the project to the estimated construction phase duration at tender stage | $\frac{\textit{Duration of overlap between engineering and construction}}{\textit{estimated construction phase duration at tender stage}}$ |
| 1.6 | Procurement and engineering alignment | The ratio of the number of the procurement items that have all the associated items specified by the engineering documents to the total number of procurement items | $\frac{\textit{number of complete procurement items referring to design documents}}{\textit{total number of procurement items}}$ |
| *2.* Project construction performance indicators | | | |
| 2.1 | Project schedule factor | The ratio of the number of IWPs (Installation Work Packages) completed on schedule to 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 ratio of the number of IWPs delayed due to the late delivery of material to the total number of IWPs of the project | $\frac{\textit{number of IWPs delayed due to late material delivery}}{\textit{total number of project IWPs}}$ |

| KPI No. | KPI name | KPI definition | KPI formula |
|---|---|---|---|
| 2.3 | Equipment-related delay factor | The ratio of the number of IWPs delayed due to unavailability of equipment to the total number of IWPs of the project | $\dfrac{\textit{number of IWPs delayed due to equipment unavailability}}{\textit{total number of project IWPs}}$ |
| 2.4 | Labor-related delay factor | The ratio of the number of IWPs delayed due to unavailability/inadequacy of labor to the total number of IWPs of the project | $\dfrac{\textit{number of IWPs delayed due to labor unavailability/inadequacy}}{\textit{total number of project IWPs}}$ |
| 2.5 | Design-related delay factor | The ratio of the number of IWPs delayed due to the late delivery of engineering deliverables to the total number of IWPs of the project | $\dfrac{\textit{number of IWPs delayed due to late engineering deliverables}}{\textit{total number of project IWPs}}$ |
| 2.6 | Design-related change factor | The ratio of the number of IWPs that have change orders issued as the result of RFIs to the total number of IWPs of the project | $\dfrac{\textit{number of IWPs changed due to RFIs}}{\textit{total number of project IWPs}}$ |