Alberta Report II

COAA Major Projects Performance Assessment System
Project Performance Engineering Productivity Construction Productivity
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Executive Summary

The Construction Owners Association of Alberta (COAA) established a benchmarking database of capital industrial projects that has been in operation since 2006, allowing COAA members to assess the performance of their projects against projects in their industry. The benchmarking database is identified as the COAA Performance Assessment System (COAA PAS). COAA members participating in the benchmarking program input project cost, schedule and safety data, and engineering and construction information into the COAA PAS at two specific times in the project life cycle, namely sanction (budget) and completion (actual). Participating COAA members are those who have provided funding for the COAA PAS and have submitted detailed project data to the database. The system utilizes the project data to calculate metrics that can be further analyzed to assess project performance and engineering, and construction productivity.

As we analyzed the data for Alberta projects, we also compared project performance and productivity numbers for different types of Alberta projects (Oil Sands SAGD versus Pipeline), for projects in different time periods, 2006-2009 (Phase 1) versus 2010-2014 (Phase 2), and for projects located in the U.S. These comparisons generated much information and identified some interesting trends.

In general, Alberta projects showed improved performance from Phase 1 to Phase 2. However, when compared to U.S. projects, Alberta projects generally experienced poorer cost and schedule performance than U.S. projects. The average cost growth for Alberta projects was 15.9% while U.S. projects had 0.5% cost growth. The average schedule growth for Alberta projects was 16.2% versus 5.4% for U.S. projects. Construction cost growth performance was 24.8% for Alberta projects and 1.7% for U.S. projects. Construction schedule growth was 17.5% for Alberta projects and 7% for U.S. projects.

Engineering and construction productivity numbers for Alberta and U.S. projects showed wide variances for some disciplines and similarities for other disciplines. For example, the average structural steel engineering productivity for Alberta projects was 17.8 work hours per ton and 13.5 work hours per ton for U.S. projects. Average piping engineering productivity was 7.4 work hours per ton for Alberta projects and 7.9 work hours per ton for U.S. projects. Average construction productivity for structural steel was 53.8 work hours per ton for Alberta projects and 36.3 work hours per ton for U.S. projects. Average piping construction productivity was 3.9 work hours per ton for Alberta projects and 3.4 work hours per ton for U.S. projects.

One area that may be a factor in performance and productivity numbers is the per cent of engineering design that was completed prior to the start of construction. The average per cent engineering design completed prior to the start of construction was 55% for Alberta projects and 75% for U.S. projects. Another area that requires further study is scaffolding. There has been much discussion about scaffolding for Alberta projects. For Alberta projects, scaffolding hours are 13% of construction hours versus U.S. projects that have scaffolding hours as 7% of
construction hours. To fully understand the foregoing high-level comparisons, it is necessary to delve into more detailed analyses.

Phase 2 projects were smaller in size (total project cost) than the Phase 1 projects and U.S. projects were smaller in size than Alberta projects. Alberta projects of different types also exhibited differences in overall project performance. Pipeline projects performed better than Oil Sands SAGD projects in terms of cost and schedule growth. Although we must be cautious when comparing different project types, we can obtain learnings from one project type that we can use in other projects. All projects are managed and executed by following engineering, construction and management practices that are similar from project to project. Size, complexity and other challenges can affect performance so it is imperative to continually analyze project performance with an objective to improve the outcomes on the next project.

To provide local support capability for the COAA PAS, COAA invited a team of professionals from the Schulich School of Engineering Department of Civil Engineering at the University of Calgary (U of C) to participate in Phase 2. The U of C team supports the COAA members participating in the COAA PAS. This support includes training and assisting the participating COAA members to gather project data, and to analyze the benchmarking information. As of March 2014 the U of C has trained over 200 benchmarking associates (professionals from participating COAA members). The U of C team conducts research into what other benchmarking techniques might be incorporated into the benchmarking system to enhance its performance assessment capabilities.

In this report we present and discuss a representative sample of the many project performance metrics, and engineering and construction productivity metrics to demonstrate the ability of the COAA PAS to assess project performance. Not all metrics that are available in the database are presented. Broad findings and interpretations of the data are provided to industry at large through this report, and through presentations and workshops at the annual COAA Best Practices conference. Participating COAA members can access the COAA PAS to obtain detailed project comparisons.

This report presents a brief history of the COAA Performance Assessment System (COAA PAS), and describes the new features and enhancements incorporated into the benchmarking system during Phase 2. Descriptions of the metrics and a glossary of key terms used in the benchmarking system are presented in appendices.

A brief summary of the research conducted by the U of C team is presented and discussed. Recommendations arising from the research study will be presented to the COAA Benchmarking Committee. The COAA Benchmarking Committee will determine how these recommendations may be implemented in the benchmarking system.

The assessments of project performance and engineering, and construction productivity presented in this report demonstrate the capabilities of the COAA PAS to identify areas for improvement that participating COAA members can address as they develop and execute future
projects. As noted in the report, there is a need for more detailed analysis of benchmarking data. COAA is proposing a new research study to develop new analysis techniques for benchmarking data and to develop a new benchmarking technique that can identify areas for improvement during project execution. Based on the findings of this research study, recommendations for additions, revisions and changes to the COAA PAS would be presented to the COAA Benchmarking Committee for review. The COAA Benchmarking Committee would determine how these recommendations were implemented in the COAA PAS.

Project performance assessment over the last ten years has created an awareness of the abilities of Alberta based companies and personnel to manage the unique projects found in Alberta. The value of benchmarking can only be realized through continued measurement. Participating COAA members are encouraged to submit completed projects to the COAA PAS. There is ample reason to suspect that tomorrow's projects will be much better than those executed today.
1.0 Introduction

Benchmarking is the process of gathering information about other companies in your industry to compare your performance, to find best practices that can lead to superior performance when implemented and to set goals for continuous improvement. The Construction Owners Association of Alberta (COAA) established a benchmarking database of capital projects that has been in operation since 2006, allowing COAA members participating in the benchmarking program to assess the performance of their projects against projects in their industry. Participating COAA members are those who have provided funding for the benchmarking system and have submitted detailed project data to the database. Participating COAA members input project cost, schedule, safety data, as well as engineering and construction information into the benchmarking system at two specific times in the project life cycle, namely sanction (budget) and completion (actual). The system utilizes this data to calculate metrics that can be further analyzed to assess project performance, i.e. engineering and construction productivity.

The Construction Industry Institute (CII) at the University of Texas in Austin developed the COAA Performance Assessment System (COAA PAS). Since 1996, CII has been developing and managing a global benchmarking database of CII member capital projects. The ongoing and diversified relationship between COAA and CII, especially in Phase 2 of the COAA PAS, provides a unique opportunity for participating COAA members to compare their projects with similar projects in their region (Alberta) and also with similar projects in other regions including Asia, Africa, Australia, North America, South America, Mexico, the Caribbean and Central America. The CII and COAA benchmarking databases offer participating COAA and CII members many opportunities to promote cross learning.

The COAA PAS has been developed in two phases. Phase 1 (2003-2009) included the initial development of the system and the addition of twenty-six (26) Alberta capital projects to the database. Following the completion of Phase 1, COAA and CII analyzed the results of the benchmarking activities to that point and determined that there was a need for new metrics and modifications to current metrics to expand performance measurements. Ongoing development in Phase 2 (2010-2014) has included a new system developed by CII, new user interfaces, customized reporting, enhanced data analysis and a new feature, data mining, which offers participating COAA members the opportunity to explore metrics, criteria and variables in a variety of combinations to identify areas for improvement in project performance.

To provide local support capability for the COAA PAS, COAA invited a team of professionals from the Schulich School of Engineering Department of Civil Engineering at the University of Calgary (U of C) to participate in Phase 2. The U of C team supports the COAA members participating in the COAA PAS. This support includes training and assisting the participating COAA members to gather project data, and to analyze the benchmarking information. As of March 2014 the U of C has trained over 200 Benchmarking Associates (professionals from participating COAA members). The U of C team conducts research into what other benchmarking techniques might be incorporated into the COAA PAS to enhance its performance assessment capabilities.
Phase 2 (2010-2014) development has been completed and thirty-three (33) new Alberta capital projects have been added to the database for a total of fifty-nine (59) completed projects. In addition, there are fourteen (14) Alberta capital projects that are in-progress, awaiting information at project completion.

In this report we present and discuss a representative sample of the many project performance metrics, and engineering and construction productivity metrics to demonstrate the ability of the COAA PAS to assess project performance. Not all metrics that are available in the database will be presented.

Broad findings and interpretations of the data are provided to industry at large through this report, and through presentations and workshops at the annual COAA Best Practices conferences. Participating COAA members can access the COAA PAS to obtain detailed project comparisons.

The features of the COAA PAS and a brief history of the COAA Performance Assessment System (COAA PAS) from concept, to development, to operation and the partnership that developed the system are presented in Appendix C. This partnership continues to manage and operate the COAA PAS, and supports participating COAA members that input and retrieve benchmarking information.

**Hierarchical Structure of Alberta Project Types**

The hierarchical structure of Alberta project types is shown in Table 1. Alberta projects are divided into five types. (Level 1), includes upstream and downstream oil and gas, and natural gas and pipeline projects. This was done for data comparison and analysis purposes. A Level 1 project can be further broken down into a second level (Level 2). For example, Upstream (Oil Exploration/Production) is divided into Oil Sands Steam Assisted Gravity Drainage (SAGD) and Oil Sands Mining/Extraction. A Level 2 project can be further broken down to a third level (Level 3). For example, Oil Sands SAGD is divided into Cogeneration, Central Plant Processing Facilities, and Pad and Gathering. Metric values are calculated for each project and then compared with similar projects.
Table 1: Hierarchical Structure of Alberta Project Types

<table>
<thead>
<tr>
<th>Level 1</th>
<th>Level 2</th>
<th>Level 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Upstream (Oil Exploration/ Production)</td>
<td>Oil Sands SAGD</td>
<td>Cogeneration</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Central Plant Processing Facilities</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Pad and Gathering</td>
</tr>
<tr>
<td></td>
<td>Oil Sands Mining</td>
<td>Oil Sands Mining</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Central Plant Processing Facilities</td>
</tr>
<tr>
<td>Downstream</td>
<td>Oil Sands Upgrading</td>
<td>Naptha Hydrotreater Unit</td>
</tr>
<tr>
<td></td>
<td>Oil Refining</td>
<td>Hydrogen Plant</td>
</tr>
<tr>
<td>Natural Gas</td>
<td>Natural Gas Processing</td>
<td>Utilities and Offsite</td>
</tr>
<tr>
<td>Pipelines</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Well Sites / Well Pads</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Benchmarking Database – Phase 1 and Phase 2

A history of the development and operation of the COAA Performance Assessment System (COAA PAS) and the benchmarking partnership between COAA, CII, the University of Calgary (U of C) and industry partners (participating COAA members) is presented later in this report. 73 Alberta-based projects have been established in the COAA PAS during Phase 1 and Phase 2 (2006-2014). By the end of Phase 1 (2006-2009), a total of 26 projects were submitted, completed and validated. In Phase 2 (2010-2014), 47 projects were established with 33 projects being completed and validated by April 2014 with 14 projects still in-progress (awaiting information at completion). As can be seen in Table 2, the majority of submitted projects are Oil Sands SAGD and upgrading facilities. One trend we see in Phase 2 projects is the increase in the number of pipeline projects being completed accompanied by a decrease in the number of Oil Sands SAGD and Oil Sands Upgrading projects being completed.
Table 2: Projects Completed and In-Progress

<table>
<thead>
<tr>
<th>Project Type</th>
<th>Completed</th>
<th>In-Progress</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Phase 1</td>
<td>Phase 2</td>
<td>Total</td>
</tr>
<tr>
<td>Oil Sands SAGD</td>
<td>11</td>
<td>6</td>
<td>17</td>
</tr>
<tr>
<td>Pipeline</td>
<td>2</td>
<td>12</td>
<td>14</td>
</tr>
<tr>
<td>Oil Sands Upgrading</td>
<td>6</td>
<td>2</td>
<td>8</td>
</tr>
<tr>
<td>Cogeneration</td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>Oil &amp; Gas Exploration (well sites)</td>
<td></td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Oil Sands Mining/Extraction</td>
<td>2</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>Tailing</td>
<td></td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Natural Gas Processing</td>
<td>2</td>
<td></td>
<td>2</td>
</tr>
<tr>
<td>Other Infrastructure</td>
<td></td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Electrical Distribution</td>
<td></td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Gas Distribution</td>
<td>1</td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>Oil Refining</td>
<td>1</td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>Other Heavy Industrial</td>
<td></td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>26</strong></td>
<td><strong>33</strong></td>
<td><strong>59</strong></td>
</tr>
</tbody>
</table>

**Code of Conduct and Confidentiality Policy**

- Project data from participating COAA members are considered confidential
- Access to project data is limited to the CII and U of C teams. All persons with access to project data sign confidentiality agreements and abide by COAA confidentiality policies
- Data provided for research purposes has all confidential identifiers removed
- Reports and data files containing only individual participating COAA member project or company data are confidential, and will not be published
- All data published and presented must reflect the aggregate of at least 10 projects from 3 separate participating COAA members
Project Performance and Productivity Metrics

The COAA PAS measures five aspects of project performance, namely: cost, schedule, safety, change and field rework. Project cost and schedule performance metrics evaluate the amount of variation from planned cost and schedule estimates at sanction. These performance metrics are further decomposed to address five primary phases of capital project execution. Known as phase cost and schedule factors, these metrics portray the proportion of total project time and money expended during each phase of the project, namely: front end planning, engineering, procurement, construction, and commissioning and start up. Safety, change and rework are measured in terms of overall project performance at project completion. The safety performance metrics differ between the COAA and CII systems. The COAA safety metrics are those commonly used in Canada. The definitions of the metrics are described in detail in Appendix B.

Eighteen COAA-specific metrics are included, such as: direct and indirect costs, use of modularization, overtime, and peak workforce and overtime.

Projects in the system are also categorized by project size (total project cost). Project size ranges from small (<$50MM), to medium (<$500MM) and large or mega (> $1B) although these are arbitrary categories. Project size can be a factor in the performance of a project. Size brings complexity and uncertainty in multi-year life cycle projects.

Size (Total Project Cost) – Alberta and U.S. Projects

The size of Alberta projects by total project cost submitted in Phase 1 (2006-2009) and Phase 2 (2010-2014) can be seen in Figure 1. There were 26 completed projects submitted in Phase 1 and 33 completed projects submitted in Phase 2. The projects submitted during Phase 2 are generally smaller in size than projects submitted during Phase 1. This may indicate that the larger projects we saw in Phase 1 are still being executed but are being broken into smaller projects that are staged over a period of time. For comparison, the size of U.S. projects by total project cost can be seen in Figure 2. U.S. projects tend to be smaller in terms of total project cost.
Figure 1: Alberta Phase 1 and Phase 2 Projects by Total Project Cost

Figure 2: Alberta and U.S. Projects by Total Project Cost

Characteristics of Alberta Projects – Phase 1 and Phase 2

We can also describe Alberta projects according to several categories including the nature of the project, the project delivery system and contract type, as seen in the figures that follow.
Figure 3: Alberta Phase 1 and Phase 2 Projects by Project Nature

In Figure 3, we see that grassroots projects (42%) and addition projects (42%) formed the bulk of the projects completed in Phase 1. In Phase 2, brownfield projects (21%) were added to the projects completed list with more grassroots projects (46%) and less addition projects (30%).

Figure 4: Alberta Phase 1 and Phase 2 Projects by Project Delivery System

In Figure 4, we see that 54% of the projects were delivered by parallel prime and 23% by design-build. In Phase 2, 52% of the projects were delivered by design-bid-build and 27% by parallel prime.
In Figure 5, we see that 100% of the projects in Phase 1 were completed with a cost reimbursable contract. However, in Phase 2, we see that only 63% of the projects were completed with a cost reimbursable contract while 37% of the projects were completed with a lump sum contract. We do not have a sufficient number of projects completed with lump sum contracts to determine if this contract type has an effect on project performance and productivity. As more projects are completed with lump sum contracts and submitted to the COAA PAS, participating COAA members will be able to study if the use of lump sum contracts has an effect on project performance and productivity. We encourage participating COAA members to submit additional completed projects to the COAA PAS so that there are sufficient numbers of different types of projects for comparison purposes.
Display of Metrics

The metrics in the COAA PAS are visually displayed in quartiles in reports and graphs. The visual display is enhanced through the use of a colour code for the four quartiles as demonstrated in Figure 6.

**Figure 6: Visual Display of Quartiles**

**Mean**: the arithmetic average of a set of values - the sum of the variable values divided by the number of samples.

**Median**: the number separating the higher half of a sample from the lower half - equivalent to the second quartile (Q2) (50th percentile)

**Quartiles**: each quartile contains 25% of the projects selected for the sample

**First Quartile (Q1)**: the 25th percentile (green)

**Second Quartile (Q2)**: the 50th percentile (blue)

**Third Quartile (Q3)**: the 75th percentile (yellow)

**Fourth Quartile (Q4)**: the 100th percentile (red)

**Category**: the particular metric displayed in the graph

‘n’ **Value**: the 'n' value below the graph indicates the number of projects in the sample.
2.0 Project Performance Assessment

The categories of project performance metrics are those used in CII’s Performance Assessment System (PAS) for many years. The use of these metrics is necessary to ensure the compatibility of comparisons between project data collected by COAA in Alberta and by CII in the U.S. and in other countries around the world. The performance metrics formulas and definitions are described in Appendix A. A glossary of terms used in the COAA PAS is presented in Appendix B.

Project Cost Growth

Project cost growth compares the actual total project cost to the initial predicted project cost that was estimated at project sanction. The project cost growth metric is calculated as:

\[
\text{Project Cost Growth} = \frac{\text{Actual Total Project Cost} - \text{Initial Predicted Project Cost}}{\text{Initial Predicted Project Cost}}
\]

An immediate reaction to the graph in Figure 7 might be that project cost growth has improved substantially from Phase 1 to Phase 2 projects but we must exercise caution when analyzing these graphs. When we aggregate all project types (as we did in these graphs), the value of the metric may be distorted (or biased) by certain project types because project cost growth can vary greatly from one project type to the next. Also, is the average Phase 2 project cost performance (-0.9%) a true value? We could answer this query in Figure 8 that compares project cost growth for different types of projects. The graphs in Figure 8 also show that different samples of projects selected for comparison can have wider ranges (Q1 to Q4) of metric values.
In Figure 8, we can see that pipeline projects have a lower average project cost growth (-7%) than the Oil Sands SAGD projects (30.7%), in fact, the negative pipeline average project cost growth indicates that the pipeline actual total project cost was less than the initial predicted project cost at project sanction. This could partly explain why the aggregate sample of Phase 2 projects in Figure 7 shows a negative average project cost performance when we have seen that many COAA projects typically have had positive and often high project cost growth performance.

However, we must not jump to any definite conclusions until we examine each type of project independent from the aggregate sample of all project types. We see that there is a wider range of project cost growth (Q1 to Q4) for Oil Sands SAGD projects when compared to the range of project cost growth for the Pipeline projects. The caution here is that we must drill down into the details for each project type to analyze the data before we determine what the metric indicates about the performance for the project being studied.

We indicated earlier that the metrics included in the COAA PAS are the same metrics that are used in CII’s PAS. This allows us to make comparisons between project data collected by COAA in Alberta and by CII in the U.S. and in other countries around the world. The continuing COAA-CII relationship allows both participating COAA and CII members to compare their projects against projects in other global locations if there is sufficient data in the database i.e. data was submitted for specific metrics and the sample of projects meets the confidentiality rule of 10 projects from 3 separate participating COAA and CII members.
Figure 9: Project Cost Growth – Alberta and U.S. Projects

Taking advantage of the COAA-CII relationship, we present Figure 9 in which we compare the project cost growth of Alberta projects versus U.S. projects. The average project cost growth for Alberta projects is higher than for U.S. projects (15.9% versus 0.5%). We also see in these graphs that Alberta projects demonstrate a much wider range of cost performance than the U.S. projects. Again, we will need further analysis to determine why the cost performance is better in one location than in another location. The extensive list of data elements submitted for the projects in the COAA PAS and the CII PAS allows for this additional analysis to be completed.

Let us now look at project schedule performance.

Project Schedule Growth

Project schedule growth compares the actual total project duration to the initial predicted project duration that was estimated at project sanction. The project schedule growth metric is calculated as:

\[
\text{Project Schedule Growth} = \frac{\text{Actual Total Project Duration} - \text{Initial Predicted Project Duration}}{\text{Initial Predicted Project Duration}}
\]
In Figure 10, we see that the average project schedule performance has improved for Phase 2 projects (13.4%) versus Phase 1 projects (17.2%). In addition, we see that Phase 1 projects have a wider range of project schedule performance (Q1 to Q4) than the Phase 2 projects.

Participating COAA members who are participants can further analyze the benchmarking data for these Phase 2 projects to determine what changes or best practices may have led to this improvement in project schedule growth. They can then use these lessons learned as they develop and execute their next project. This is one of the many benefits of using the COAA PAS.

Participating COAA members can further study the Phase 1 and Phase 2 projects in more detail by project type, by contract type and other metrics to determine the effect a particular change or best practice can make in the performance of a project. As we did earlier for project cost growth, we can analyze project schedule performance based on project type.

**Figure 10: Project Schedule Growth – Phase 1 and Phase 2**

**Figure 11: Project Schedule Growth – Oil Sands SAGD and Pipeline Projects**
In Figure 11, we can see that pipeline projects have a much lower average project schedule growth (4.4%) than the Oil Sands SAGD projects (15.7%). The pipeline projects have a smaller range of project schedule growth than the Oil Sands SAGD projects. At this point, a participating COAA member could ask if this improved schedule performance was a result of project size, project type or some other metric. As discussed earlier, further detailed analysis of the data in the COAA PAS may provide the answer to this query.

Here we can again take advantage of the COAA-CII relationship to compare the project schedule performance of Alberta projects versus U.S. Projects.

As we analyze Figure 12, we see that U.S. projects have a better average project schedule growth (5.4%) versus the Alberta projects (16.2%). In these graphs we see that the range of project schedule growth values is similar for both the U.S. and Alberta projects so this may not be the reason for improved schedule performance for the U.S. projects. As before, participating COAA members will need to further analyze the benchmarking data for these projects to determine if particular changes or best practices were a reason that the U.S. projects performed better.

Another metric we can use to analyze cost and schedule growth is to look at the construction phase of the projects.

**Construction Cost Growth**

Construction cost growth compares the actual construction cost to the initial predicted construction cost that was estimated at project sanction. The construction cost growth metric is calculated as:

\[
\text{Construction Cost Growth} = \frac{\text{Actual Construction Cost} - \text{Initial Predicted Construction Cost}}{\text{Initial Predicted Construction Cost}}
\]
Here we are analyzing cost growth for the construction phase of a project. The COAA PAS contains data that allows participating COAA members to analyze cost (and schedule) performance for the other phases of a project namely, front end planning, engineering, procurement, and commissioning and start-up.

Figure 13: Construction Cost Growth – Phase 1 and Phase 2

In Figure 13, we again see an improvement in average construction cost growth in Phase 2 projects (19.1%) versus Phase 1 projects (31.2%). The Phase 1 projects have a wider range of construction cost growth values (Q1 to Q4) than the Phase 2 projects. As before, when we were analyzing project cost performance, participating COAA members may ask what has caused this improvement in construction cost performance. Since we are using an aggregate sample that includes all types of projects in these graphs, the value of the metric may be distorted (or biased) by certain project types because the construction cost growth can vary greatly from one project type to the next. The next step is therefore to compare the construction cost growth for different types of projects.

Figure 14: Construction Cost Growth – Pipeline Projects
Here we experience one limitation of the COAA Benchmarking System in that there are not enough projects of a specific type (Oil Sands SAGD) submitted to the database to allow the system to provide output that compares metrics. It is important that participating COAA members continue to submit project data to the COAA PAS so that the value of the benchmarking system can be realized. We are unable to analyze projects and present metrics if there are not enough projects in the database to meet the 10/3 rule which protects the confidentiality of the raw data.

In Figure 14, we see that the average construction cost growth performance for Pipeline projects is 14.5%. At present, the COAA PAS does not contain enough projects of different types to present metrics that meet the 10/3 rule. We continue to work with participating COAA members to have projects of all types submitted into the COAA PAS.

As we have presented earlier, we can compare the construction cost growth of Alberta projects versus U.S. projects.

![Construction Cost Growth Chart]

**Figure 15: Construction Cost Growth – Alberta and U.S. Projects**

In Figure 15, we see that the U.S. projects have a better average construction cost growth (1.7%) versus the Alberta projects (24.8%). As before, participating COAA members will need to further analyze the benchmarking data for these projects to determine if particular changes or best practices were a reason that the U.S. projects performed better.

**Construction Cost Factor**

We can also analyze the cost of the construction phase of a project in relation to the total project cost. Construction cost factor is a measure of the costs expended in the construction phase of a project. The construction cost factor metric is calculated as:

\[
\text{Construction Cost Factor} = \frac{\text{Actual Construction Phase Cost}}{\text{Actual Total Project Cost}}
\]
We see in Figure 16 that the average actual cost expended in the construction phase of a project in relation to the actual total project cost is similar for both Phase 1 and Phase 2 projects. Phase 1 projects expended an average of 66.7% of the actual total project cost in the construction phase while the Phase 2 projects expended an average of 65.9% of the actual total project cost in the construction phase. Knowing that we expend over 2/3 of the actual total project cost in the construction phase is one reason why we should be following best practices in managing the construction phase of a project. Controlling cost during the construction phase is critical to controlling the cost of the total project. We can also compare the construction cost factors for different types of projects.

In Figure 17, we see that, on average, 74.8% of the actual total project cost is expended in the construction phase of a pipeline project, whereas, for Oil Sands SAGD projects, an average of 57.5% of the actual total project cost is expended in the construction phase. It is interesting to note that the projects (both Oil Sands SAGD and Pipeline) in the first quartile (Q1) exhibit a wide
range of cost factor values while the range of cost factor values across the other three quartiles (Q2, Q3 and Q4) is small compared to the first quartile.

This is one situation where we may want to examine the construction phase costs in greater detail for these first quartile projects to determine what may have caused them to exhibit a wider range of values.

Figure 18: Construction Cost Factor – Alberta and U.S. Projects

In Figure 18, we see that the average actual cost expended in the construction phase of U.S. projects was 63.8% of the actual total project cost. The average actual cost expended in the construction phase of Alberta projects was 67.7% of the actual total project cost. Although the average actual construction costs were similar, the U.S. projects had a wider range of values across all projects than the projects in Alberta. We will need to examine this in greater detail to determine if changes or particular best practices were the cause of this wide range of values.

Engineering Design

Researchers continue to examine the effect of engineering design completeness before the start of construction on construction cost and other metrics. The COAA PAS does not yet have a sufficient number of projects to fully examine this effect for different project types. At this point, we can only compare the % design complete for Alberta and U.S projects.
Figure 19: % Design Complete before Construction – Alberta and U.S. Projects

In Figure 19, we find that the U.S. projects in the selected sample had engineering design 75.7% complete before the start of construction whereas the Alberta projects in the selected sample had engineering design 55.7% complete before the start of construction.

Figure 20: % Design Complete before Construction – Alberta Phase 1 Projects

In Figure 20, Phase 1 projects had an average of 53.7% of engineering design complete before the start of construction. There are not enough completed Phase 2 projects in the COAA PAS with per cent of engineering design information for us to present this metric for Phase 2 projects. We do, however, have a sufficient number of completed Oil Sands SAGD projects from Phase 1 and Phase 2 to present this engineering metric as seen in Figure 21 that indicates an average of 47.7% engineering design completed before the start of construction.
**Figure 21:** % Design Complete before Construction – Oil Sands SAGD Projects

The relationship between per cent engineering design completed before construction started and construction phase cost growth can be seen in Figure 22. Figure 22 uses a cubic polynomial pattern to demonstrate that as more design is completed before construction begins the project tends to have less construction phase cost growth. An optimum value can be found at approximately 85% engineering design complete. The results are statistically significant, meaning that a strong relationship exists between the percentage of engineering design completed prior to construction start and construction phase cost growth.

**Figure 22:** % Design Complete before start Construction versus Construction Cost Growth
Professionals at CII and the U of C prepared the analysis shown in Figure 22. This type of analysis requires access to all project data in the COAA PAS. Having signed confidentiality agreements, the CII and U of C teams have been given full access to the data for all projects submitted to the COAA PAS. This access to all project data allows CII and U of C to prepare such analyses for the benefit of participating COAA members. Participating COAA members are given access that allows them to retrieve aggregate data through the metrics available in the COAA PAS.

In addition to cost performance, we can analyze the schedule performance for the construction phase of projects.

**Construction Schedule Growth**

Construction schedule growth compares the actual construction duration to the initial predicted construction duration that was estimated at project sanction. The construction schedule growth metric is calculated as:

\[
\text{Construction Schedule Growth} = \frac{\text{Actual Construction Duration} - \text{Initial Predicted Construction Duration}}{\text{Initial Predicted Construction Duration}}
\]

![Construction Schedule Growth Graph](image)

**Figure 23: Construction Schedule Growth – Phase 1 and Phase 2**

As we saw in Figure 7 earlier, an immediate reaction to this graph might be that construction schedule growth has improved substantially from Phase 1 (27.4%) to Phase 2 (-8.3%) projects. As before, we must exercise caution when analyzing these graphs because we have aggregated data from projects of all types. We must examine construction schedule growth for different types of projects. There is danger in aggregating data when projects vary significantly.
In Figure 24, we see that Oil Sands SAGD projects have an average construction schedule growth of 18.8% while Pipeline projects have an average construction schedule growth of -9.6% that indicates that the actual construction duration was less than the predicted construction duration estimated at project sanction. At this point, we will need to examine this data with the participating COAA members who develop and manage pipeline projects to determine if the construction schedule growth has been affected by particular practices that may have been followed for these pipeline projects. Other questions for these participating COAA members could be how they estimate construction schedules and whether other activities in these projects affected construction schedules. This example demonstrates how participating COAA members can include benchmark data in their evaluation of the performance of their projects. Benchmarking data will not provide all the answers but it certainly can be one piece of information that can assist participating COAA members to improve project performance.

When we aggregate this data as shown in Figure 23, we see the effect of the pipeline project data on the aggregate data. This again demonstrates that we need to exercise caution when we are analyzing the benchmarking data, and making conclusions and decisions based on the data.

Again we can take advantage of the COAA-CII relationship to compare the construction schedule growth of Alberta projects versus U.S. Projects.
Figure 25: Construction Schedule Growth – Alberta and U.S. Projects

In Figure 25, we see that U.S. projects have a better average construction schedule growth (7.0%) versus the Alberta projects (17.5%). In these graphs we see that the Alberta projects have a wider range of construction schedule growth values than the U.S. projects. As before, participating COAA members will need to further analyze the benchmarking data for these projects to determine if particular changes or best practices were the cause of this wide range of values and may be a reason that the U.S. projects performed better.

Contingency/Budget (%)

The COAA PAS contains various cost related data such as: contingency, cost estimate at sanction (budget), construction management cost, and owner’s cost. COAA members can use the Data Miner feature to generate customized metrics that compares one cost item against another cost item. One example of a customized metric is to compare contingency with budget.

Figure 26: Contingency/Budget (%) – Phase 1 and Phase 2
We see in Figure 26 that Phase 2 projects have higher contingency funds as a percentage of the cost estimate at sanction (budget). This metric can then be correlated with other performance metrics to determine what effect the amount of contingency funds may have on project performance.

We can also compare contingency versus budget for different types of projects and also compare Alberta with U.S. projects as shown in the next graphs.

**Figure 27: Contingency/Budget (%) – Oil Sands SAGD & Pipeline Projects**

**Figure 28: Contingency/Budget (%) – Alberta and U.S. Projects**
We see a wide range of values for particular projects in these graphs. Participating COAA members will need to conduct further analyses to determine what may have happened in these projects to cause this wide range of values.

**Modularization**

One of the innovations made in capital projects is module fabrication. Data regarding the degree of modularization in completed projects has been submitted to the COAA PAS and is presented here.

![Graph showing per cent modularization for Phase 1 and Phase 2 projects](image)

**Figure 29: Per Cent Modularization – Phase 1 and Phase 2**

In Figure 29, we see that Phase 1 projects had an average of 20% modularization while Phase 2 projects had 14% modularization. One factor for this difference is that many of the projects in Phase 2 were pipeline projects that may have less modularization than other project types.
3.0 Project Productivity Assessment

As mentioned earlier, the COAA PAS has many metrics to measure performance and productivity. We have presented a sample of the performance metrics available in the system. Participating COAA members are able to access the system to analyze the many other performance metrics available to them.

We will now present, and discuss engineering and construction productivity metrics, and make comparisons between Phase 1 and Phase 2 projects between Alberta and U.S. projects, and between different types of projects in a similar manner to what was presented for project performance metrics. We will see that the data for engineering and construction productivity is not as complete as for project performance. Again we continue to work with participating COAA members to submit engineering and construction information to the COAA PAS so that we have sufficient numbers of projects to allow us to report metrics that meet the 10/3 rule that protects the confidentiality of the data submitted by participating COAA members.

Productivity Metrics

The productivity metrics used in the COAA PAS are based on the engineering and construction productivity measurements used in the CII PAS. Engineering and construction productivity metrics are defined as ratios of work hours (WH) to quantities. For most, these metrics are easy to understand, and are consistent with most estimating and cost accounting systems. For these metrics, a lower productivity rate is generally preferred.

Engineering Productivity Metrics

Engineering productivity metrics are defined as actual engineering work hours per Issued for Construction (IFC) quantities i.e. the number of actual direct work hours to design a particular unit. Engineering productivity metrics are captured for significant work activities for several design disciplines including: concrete, structural steel, piping, electrical, instrumentation and equipment. Engineering productivity metrics are calculated as:

\[
\text{Engineering Productivity} = \frac{\text{Actual Direct Design Work Hours}}{\text{IFC Quantity}}
\]

The COAA PAS allows the participating COAA members to assess productivity performance by accessing the project data through metrics that can be standard or customized. Standard engineering productivity metrics are those included in the COAA PAS for the different disciplines. Participating COAA members can create customized engineering productivity metrics by using the Data Miner to specify design items in more detail and even to combine design items to compare engineering productivity for particular areas of work. For example, participating COAA members can assess structural steel productivity metrics and also combine
all steel elements into one productivity metric using the Data Miner feature. We will present samples of the types of engineering productivity metrics available in the system.

**Engineering Productivity – Structural Steel**

![Figure 30: Structural Steel Engineering Productivity – Alberta and U.S. Projects](image)

We can see in Figure 30 that Alberta projects have a higher number of work hours per ton of structure steel – Alberta projects 17.8 work hours/ton and U.S. projects 13.4 work hours/ton. Participating COAA members could examine this metric in more detail to determine if it was affected by changes or specific best practices in U.S. projects as compared to Alberta projects. This may give them information they could use to improve their productivity numbers. The COAA PAS system has the capability of comparing many different data elements to assist participating COAA members in determining how they might improve the productivity performance in their projects.

One limitation mentioned earlier is that the COAA PAS system does not have sufficient data to allow comparisons and evaluations to be made for some engineering disciplines. Again we continue to work with participating COAA members to submit projects to the database to increase the project numbers available for analysis.

Having evaluated the structural steel engineering productivity metric, the participating COAA members could then assess steel engineering productivity in more detail by selecting specific steel elements or combining steel elements to create a customized steel metric. For example, the participating COAA members could assess engineering productivity for a combination of steel elements as shown in Figure 31.
Here we see, in Figure 31, the engineering productivity number for Alberta projects is much higher than for structural steel seen in Figure 30. This provides participating COAA members with additional information to allow them to further examine the engineering activity for their projects. This comparison and evaluation of engineering productivity metrics can continue using the Data Miner feature to examine productivity metrics for specific steel or other elements.

**Engineering Productivity – Piping**

In Figure 32 we see that the piping engineering productivity is similar for the Alberta and U.S. projects – Alberta is 0.74 work hours/linear foot – U.S. is 0.79 work hours/linear foot. From this metric, participating COAA members could think that their productivity for this discipline
compares well with projects in other locations. However, if we look at the piping engineering productivity in greater detail, as shown in Figure 33, they might have a different opinion.

![Graph showing piping productivity for Alberta and U.S. projects](image)

**Figure 33: Piping (Large Bore) Engineering Productivity – Alberta & U.S. Projects**

Here we see that Alberta projects (0.24 work hours/LF) are taking less time for large bore (3 inch and more) piping than U.S. projects (1.1 work hours/LF). More analysis may answer why this occurred.

**Engineering Productivity – Wire and Cable**

![Graph showing wire and cable productivity for Alberta and U.S. projects](image)

**Figure 34: Wire and Cable Engineering Productivity – Alberta & U.S. Projects**

In Figure 34, we see that engineering productivity for wire and cable for Alberta projects is 0.06 work hours/linear foot and for U.S. projects it is 0.028 work hours/linear foot. Engineering productivity can also be examined for other instrumentation items including: loops, tagged devices and input/output devices.
Engineering Productivity – Equipment

Figure 35: Equipment Engineering Productivity – Alberta & U.S. Projects

Figure 35 demonstrates how participating COAA members can evaluate equipment engineering productivity.

Construction Productivity Metrics

As discussed previously, the productivity metrics used in the COAA PAS are based on the engineering and construction productivity measurements used in the CII PAS. Engineering and construction productivity metrics are defined as ratios of work hours (WH) to quantities. For most, these metrics are easy to understand, and are consistent with most estimating and cost accounting systems. For these metrics, a lower productivity rate is generally preferred.

Construction productivity metrics are defined as actual work hours per unit quantity i.e. the number of actual direct work hours to construct a unit quantity. Construction productivity metrics are captured for significant work activities for several disciplines including: concrete, structural steel, equipment, piping, electrical, instrumentation, insulation and scaffolding. Construction productivity metrics are calculated as:

\[
\text{Construction Productivity} = \frac{\text{Actual Installed Direct Work Hours}}{\text{Installed Quantity}}
\]

The COAA PAS allows participating COAA members to assess productivity performance by accessing the project data through metrics that can be standard or customized. All construction productivity metrics are defined as actual construction work hours per unit of quantity installed. Standard construction productivity metrics are those included in the COAA PAS for the different disciplines. Participating COAA members can create customized construction productivity metrics by using the Data Miner to specify discipline items in more detail and even to combine discipline items to compare construction productivity for particular areas of work. For example,
participating COAA members can assess structural steel productivity metrics and also combine all steel elements into one productivity metric using the Data Miner feature.

We will present samples of the types of construction productivity metrics available in the COAA PAS.

**Construction Productivity – Structural Steel**

![Chart of structural steel productivity](chart.png)

**Figure 36: Structural Steel Construction Productivity – Alberta & U.S. Projects**

We can see in Figure 36 that Alberta projects have a higher number of work hours per ton of structure steel – Alberta projects have 53.8 works hours/ton and U.S. projects have 36.3 work hours/ton. Participating COAA members could then examine this metric in more detail to determine if it was affected by changes or specific best practices in U.S. projects as compared to Alberta projects. This may give them information that they could use to improve their productivity numbers. The COAA PAS system has the capability of comparing many different data elements to assist COAA members in determining how they might improve the productivity performance in their projects.

One limitation mentioned earlier is that the COAA PAS system does not have sufficient data to allow comparisons and evaluations to be made for some construction disciplines. Again we encourage participating COAA members to submit projects to the database to increase the project numbers available for analysis.

Having evaluated the structural steel engineering productivity metric, the participating COAA members could then assess total steel construction productivity in more detail by selecting specific steel elements or combining steel elements to create a customized steel metric. For example, the participating COAA members could assess construction productivity for all steel elements as shown in Figure 37.
We see that there is less variance in total steel construction productivity numbers for Alberta projects and U.S. projects than for structural steel seen in Figure 36. This provides participating COAA members with additional information to allow them to further examine the construction activity for their projects. This comparison and evaluation of construction productivity metrics can continue by using the Data Miner feature to examine productivity metrics for specific elements.

**Construction Productivity – Piping**

Here we see the piping construction productivity metric is similar for Alberta and U.S. projects. Further analysis by participating COAA members could determine if changes and specific best practices are the reason for these improved productivity numbers as compared to steel.
Construction Productivity – Concrete

![Concrete Productivity Chart]

**Figure 39: Concrete Construction Productivity – Alberta & U.S. Projects**

Here we see a difference of approximately 3 work hours per unit of concrete installed between Alberta and U.S. projects. Further analysis may determine if a specific best practice may be the reason.

Construction Productivity – Insulation (Piping)

![Insulation (Piping) Productivity Chart]

**Figure 40: Insulation (Piping) Construction Productivity – Alberta & U.S. Projects**

For this discipline, the Alberta and U.S. productivity numbers are very similar.
Construction Productivity – Electrical Equipment

Figure 41: Electrical Equipment Construction Productivity – Alberta & U.S. Projects

Here we see a low mean value for U.S. project productivity but the range of productivity numbers is wide for these projects. Again, this requires further analysis.

Construction Productivity – Instrumentation Devices

Figure 42: Instrumentation Devices Construction Productivity – Alberta & U.S. Projects

Here we see similar mean productivity numbers but with a wide range of productivity numbers for both Alberta and U.S. projects. Further analysis may provide a reason for this wide range.
Construction Productivity – Cable Tray

![Graph showing productivity comparison between Alberta, n = 14, and U.S., n = 68 projects.]

**Figure 43: Cable Tray Construction Productivity – Alberta & U.S. Projects**

For this discipline we see similar mean productivity numbers and ranges of values. This is not to say that the productivity numbers are acceptable, just that they compare well between projects.

Construction Productivity – Wire and Cable

![Graph showing productivity comparison between Alberta, n = 14, and U.S., n = 68 projects.]

**Figure 44: Wire and Cable Construction Productivity – Alberta & U.S. Projects**

Here we see a wide variance in the Alberta and U.S. mean productivity numbers and a very wide range of numbers for Alberta projects. This much variance requires more detailed analysis to determine what caused this variance.
Construction Productivity – Electrical Heat Tracing

Here again we see a wide variance in the Alberta mean productivity metric and a very small range of numbers for U.S. projects. As for wire and cable, this much variance requires more detailed analysis to determine the cause of the variance.

Construction Productivity – Scaffolding

There has been much discussion about scaffolding for Alberta projects. The metrics in Figure 46 only add to that discussion – for Alberta projects, scaffolding hours are 13% of construction hours versus U.S. projects that have scaffolding hours as 7% of construction hours. This definitely requires more detailed analysis seeking reasons for the large difference.
There has been much discussion between COAA members in Alberta about the ratio of indirect to direct work hours for construction. The ratio for Alberta projects (40.5 %) is higher than for U.S. projects (36.7 %) but further analysis is required to determine if this variance is significant.

COAA has defined engineering and construction activities that are to be considered as direct and indirect work for productivity metrics. In an effort to standardize the definition of direct and indirect work, the COAA PAS has defined engineering and construction work activities as direct and indirect to assist participating COAA members to input project work hours that are consistent from project to project allowing for valid comparisons to be made.
4.0 Conclusions and Recommendations

In recent years, numerous global forces have been at work dramatically altering the worldwide marketplace for energy. These forces have also led to a significant increase in the amount of investment and project activity in Alberta surrounding its oil sands resources. Owner companies holding leases in the oil sands accelerated their development of capital projects needed for increased production. This acceleration of the pace of development may be explanatory to the findings and results in this report. To be sure, the increased pace and amount of capital projects in Alberta resulted in many effects observed in this data. These effects were further compounded by extremes experienced in Alberta related to such things as labour availability, harsh weather conditions and remote project locations, amongst others. The benefit of the COAA Performance Assessment System (PAS) is that it is able to objectively quantify the performance of observed projects.

The projects submitted during Phase 2 (2010-2014) are generally smaller in size (total project cost) than projects submitted during Phase 1 (2006-2009). This may indicate that the larger projects we saw in Phase 1 are still being executed but are being broken into smaller projects that are staged over a period of time. For comparison, U.S. projects tend to be smaller in size than Alberta projects.

In general, Alberta projects showed improved performance from Phase 1 to Phase 2. However, when compared to U.S. projects, Alberta projects generally experienced poorer cost and schedule performance than U.S. projects. One factor that requires further investigation is project size (i.e. total project cost). Phase 2 projects were smaller in size than Phase 1 projects and U.S. projects were smaller in size than Alberta projects. Alberta projects of different types also exhibited differences in overall project performance. Pipeline projects performed better than Oil Sands SAGD project in terms of cost and schedule growth. Although we must be cautious when comparing different project types, we can obtain learnings from one project type that we can use in other projects. All projects are managed and executed by following engineering, construction and management practices that are similar from project to project. Size, complexity and other challenges can affect performance so it is imperative to continually analyze project performance with an objective of improving outcomes on the next project.

Given the anticipated number of planned projects in Alberta over the next number of years, the proper estimation and control of cost, and schedule is paramount. We recommend a review of the estimating and control practices to identify areas for improvement. Predictability in estimating and project management best practices is needed. A review of management related aspects of planning, estimating and controlling work is recommended. This is not just a contractor issue. Owners and contractors should review the amount of engineering design that is completed prior to the start of construction. A thorough evaluation of management policies and procedures is recommended.

Given the variance in project performance and productivity numbers between Alberta projects and U.S. projects, and between different project types in Alberta, we recommend further review
and analysis of the engineering, construction, and management practices that were followed on the projects with good performance and productivity numbers. Learning from other projects is an efficient and effective way to identify areas for improvement.

The assessments of project performance and engineering, and construction productivity presented in this report demonstrate the capabilities of the COAA PAS to identify areas for improvement that participating COAA members can address as they develop and execute future projects. As noted in the report, there is a need for more detailed analysis of benchmarking data. COAA is proposing a new research study to develop new analysis techniques for benchmarking data and a new benchmarking technique that can identify areas for improvement during project execution. Based on the findings of the research study, recommendations for additions, revisions and changes to the COAA PAS would be presented to the COAA Benchmarking Committee for review. The COAA Benchmarking Committee would determine how these recommendations were implemented in the COAA PAS.

Project performance assessment over the last ten years has created an awareness of the abilities of Alberta based companies and personnel to manage the unique projects found in Alberta. One way to truly and objectively know whether or not project execution is improving is through continued measurement. Continued use of benchmarking products will generate improved intelligence concerning Alberta based projects. The value of benchmarking can only be realized with sufficient project data. Participating COAA members are encouraged to submit completed projects to the COAA PAS. There is ample reason to suspect that tomorrow’s projects will be much better than those executed today.
5.0 Acknowledgements

Funding for the COAA Performance Assessment System (PAS) was provided by the Construction Owners Association of Alberta (COAA), participating COAA members, Alberta Finance and Enterprise, Government of Alberta and the National Science and Engineering Research Council (NSERC) under NSERC Research Contract: CRDPJ 408445 10. In addition, this study would not have been possible without the endless support from the COAA Alberta Major Projects Benchmarking Committee and the many COAA members who participate in the COAA PAS. The professionals who collected and submitted their project data are greatly appreciated.

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6.0 References


# Appendix A

## Performance Metric Formulas and Definitions

### Cost Performance Metric Category

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<thead>
<tr>
<th>Metric Category</th>
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<tr>
<td>Project Cost Growth</td>
<td>Actual Total Project Cost - Initial Predicted Project Cost</td>
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<td></td>
<td>Initial Predicted Project Cost</td>
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<td>Delta Cost Growth</td>
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<tr>
<td>Project Budget Factor</td>
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<td></td>
<td>Initial Predicted Project Cost + Approved Changes</td>
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<td>Phase Cost Factor</td>
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<td>Initial Predicted Phase Cost</td>
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### Definition of Terms

**Actual Total Project Cost:**
- Owners – All actual project cost from front end planning through startup.
- Contractors – Total cost of the final scope of work.

**Initial Predicted Project Cost:**
- Owners – Budget at the time of Project Sanction.
- Contractors – Cost estimate used as the basis of contract award.

**Actual Phase Cost:**
- All costs associated with the project phase in question.
- See the Project Phase Table in Appendix C for phase definitions.

**Initial Predicted Phase Cost:**
- Owners – Budget at the time of Project Sanction.
- Contractors – Budget at the time of contract award.
- See the Project Phase Table in Appendix C for phase definitions.

**Approved Changes:**
- Estimated cost of owner-authorized changes.
## Schedule Performance Metric Category

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<td><strong>Delta Schedule Growth</strong></td>
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<td><strong>Project Schedule Factor</strong></td>
<td>Actual Total Project Duration/Initial Predicted Project Duration + Approved Changes</td>
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<td>Actual Phase Duration – Initial Predicted Phase Duration/Initial Predicted Phase Duration</td>
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### Definition of Terms

**Actual Total Project Duration:**
(Detailed Engineering through Start-up)
- Owners – Duration from beginning of detailed engineering to turnover to user.
- Contractors - Total duration for the final scope of work from mobilization to completion.

**Actual Overall Project Duration:**
(Front End Planning through Start-up)
- Unlike Actual Total Duration, Actual Overall Duration also includes time consumed for the Front End Planning Phase.

**Actual Phase Duration:**
- Actual total duration of the project phase in question. See the Project Phase Table in Appendix C for phase definitions.

**Initial Predicted Project Duration:**
- Owners – Predicted duration at the time of Project Sanction.
- Contractors - The contractor's duration estimate at the time of contract award.

**Approved Changes**
- Estimated duration of owner-authorized changes.
## Safety Performance Metric Category

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<td>Medical Aid Frequency (MAF)</td>
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<td>Total Site Work-Hours</td>
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<tr>
<td>First Aid Frequency (FAF)</td>
<td>Total Number of First Aid Cases x 200,000</td>
</tr>
<tr>
<td></td>
<td>Total Site Work-Hours</td>
</tr>
<tr>
<td>Total Recordable Injury Frequency (TRIF)</td>
<td>Total Number of Recordable Cases x 200,000</td>
</tr>
<tr>
<td></td>
<td>Total Site Work-Hours</td>
</tr>
<tr>
<td>Total Injury Frequency (TIF)</td>
<td>Total number of all injury or illness cases x 200,000</td>
</tr>
<tr>
<td></td>
<td>Total Site Work-Hours</td>
</tr>
<tr>
<td>Restricted Work Frequency (RWF)</td>
<td>Total Number of Restricted Work Cases x 200,000</td>
</tr>
<tr>
<td></td>
<td>Total Site Work-Hours</td>
</tr>
<tr>
<td>Lost Time Severity Rate (LTSR)</td>
<td>Total Number of Lost Time Workdays x 200,000</td>
</tr>
<tr>
<td></td>
<td>Total Site Work-Hours</td>
</tr>
<tr>
<td>Total Severity Rate (TSR)</td>
<td>Total Number of Recordable Lost Time Cases and all Restricted Work Cases x 200,000</td>
</tr>
<tr>
<td></td>
<td>Total Site Work-Hours</td>
</tr>
</tbody>
</table>
Safety Performance Metric Category (cont’d.)

Definition of Terms

- **Lost Time Days**: Equals the number of scheduled work days away from work as a result of an occupational injury or illness, disabling injury or illness which prevents a worker from reporting to work on next regularly scheduled.

- **Medical Aid Case**: Any occupational injury or illness requiring medical treatment administered by a physician, not including first aid treatment.

- **First Aid Case**: Any one time treatment which does not require medical care or further medical aid e.g. minor scratches, cuts, burns, splinters.

- **Recordable Case**: A work event or exposure that is the discernable cause of an injury or illness or of a significant aggravation to a pre-existing condition. A recordable case requires medical aid, restricted work in relation to either medical aid or lost time, or fatality.

- **Total number of all injury or illness cases**: Equals the number of lost time (LT) cases, medical aid (MA) cases, first aid (FA) cases and the number of restricted work cases for lost time (RWLT), medical aid (RWMA) and first aid (RWFA).

- **Total Number of Restricted Work Cases**: Equals the number of restricted work lost time cases, restricted work medical aid cases and restricted work first aid cases.

- **Lost Time Case**: Lost Time cases are the result of an occupational injury or illness including any disabling injury which prevents a worker from reporting to work on his/her next regularly scheduled.

- **Restricted Work Case**: Includes restricted work lost time cases, restricted work medical aid cases and restricted work first aid cases.

- **Restricted Work Days**: Equals the number of scheduled work days that the worker was unable to work their regular duties as a result of an injury or illness as defined in restricted work.

- **Total Number of Recordable Lost Time Cases and all Restricted Work Cases**: Includes the number of lost workdays plus the number of restricted work days for all lost time, medical aid and first aids.
### Change Performance Metric Category

| Scope Change Cost Factor | Formula: \[
\frac{\text{Total Cost of Scope Changes}}{\text{Actual Total Project Cost}}
\] |
|--------------------------|--------------------------------------------------|
| Project Development Change Cost Factor | Formula: \[
\frac{\text{Total Cost of Project Development Changes}}{\text{Actual Total Project Cost}}
\] |

#### Definition of Terms

- **Total Cost of Scope Changes**: Total cost impact of scope and project development changes.
- **Total Cost of Project Development Changes**: Total cost impact of project development changes.

**Actual Total Project Cost**:

- **Owners** –
  - O All actual project cost from front end planning through startup
  - O Exclude land costs but include in-house salaries, overhead, travel, etc.
- **Contractors** – Total cost of the final scope of work.

### Field Rework Performance Metric Category

| Total Field Rework Factor | Formula: \[
\frac{\text{Total Direct Cost of Field Rework}}{\text{Actual Construction Phase Cost}}
\] |
|---------------------------|--------------------------------------------------|

#### Definition of Terms

- **Total Direct Cost of Field Rework**: Total direct cost of field rework regardless of initiating cause.
- **Actual Construction Phase Cost**: All costs associated with the construction phase. See the Project Phase Table in Appendix C for construction phase definition.
## Construction Productivity Metrics Categories

<table>
<thead>
<tr>
<th>Concrete</th>
<th>Electrical</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Total Concrete</td>
<td>- Total Electrical Equipment (Each)</td>
</tr>
<tr>
<td>- Slabs (CM)</td>
<td>- Panels and Small Devices (Each)</td>
</tr>
<tr>
<td>- On-Grade (CM)</td>
<td>- Electrical Equipment below 1kV (Each)</td>
</tr>
<tr>
<td>- Elevated Slabs/On Deck (CM)</td>
<td>- Electrical Equipment over 1kV (Each)</td>
</tr>
<tr>
<td>- Area Paving (CM)</td>
<td>- Conduit (LM)</td>
</tr>
<tr>
<td>- Foundations (CM)</td>
<td>- Exposed or Above Ground Conduit (LM)</td>
</tr>
<tr>
<td>- &lt; 4 CM</td>
<td>- Underground, Duct Bank or Embedded Conduit (LM)</td>
</tr>
<tr>
<td>- 4 – 15 CM</td>
<td>- Cable Tray (LM)</td>
</tr>
<tr>
<td>- 15 –38 CM</td>
<td>- Wire and Cable (LM)</td>
</tr>
<tr>
<td>- ≥ 38 CM</td>
<td>- Control Cable (LM)</td>
</tr>
<tr>
<td>- Concrete Structures (CM)</td>
<td>- Power and Control Cable below 1kV (LM)</td>
</tr>
<tr>
<td>Structural Steel</td>
<td>- Power Cable above 1kV (LM)</td>
</tr>
<tr>
<td>- Total Structural Steel (MT)</td>
<td>- Transmission Line (LM)</td>
</tr>
<tr>
<td>- Structural Steel (MT)</td>
<td>- High Voltage above 25kV (LM)</td>
</tr>
<tr>
<td>- Pipe Racks &amp; Utility Bridges (MT)</td>
<td>- Other Electrical Metrics</td>
</tr>
<tr>
<td>- Miscellaneous Steel (MT)</td>
<td>- Lighting (Each)</td>
</tr>
<tr>
<td>Instrumentation</td>
<td>- Grounding (LM)</td>
</tr>
<tr>
<td>- Loops (Count)</td>
<td>- Electrical Heat Tracing (LM)</td>
</tr>
<tr>
<td>- Devices (Count)</td>
<td></td>
</tr>
</tbody>
</table>

## Piping

- Small Bore (2-1/2” & Smaller) (LM)
  - Carbon Steel (LM)
  - Stainless Steel (LM)
  - Chrome (LM)
  - Other Alloys (LM)
  - Non Metallic (LM)

## Insulation

- Equipment
  - Insulation Equipment (SM)
  - Piping
    - Insulation Piping (ELM)

## Module Installation

- Pipe Racks (MT)
- Process Equipment Modules (MT)
- Building (SM)

## Scaffolding

- Scaffolding Work-Hours/ Total Direct Hours

## Construction Work-Hours

- Construction Indirect/ Direct Work-Hours

### Notes

Construction Productivity Unit Rate = Direct Work hours
Installed Quantity
## Construction Direct and Indirect Work

<table>
<thead>
<tr>
<th>Direct</th>
<th>Indirect</th>
</tr>
</thead>
<tbody>
<tr>
<td>Direct Craft Labour</td>
<td>Accounting</td>
</tr>
<tr>
<td>Foreman</td>
<td>Procurement</td>
</tr>
<tr>
<td>General Foreman</td>
<td>Area Superintendent</td>
</tr>
<tr>
<td>Load and Haul</td>
<td>Process Equipment Maintenance</td>
</tr>
<tr>
<td>Oilers</td>
<td>Assistant Project Manager</td>
</tr>
<tr>
<td>Operating Engineer</td>
<td>Project Controls</td>
</tr>
<tr>
<td>Safety Meetings</td>
<td>Bus Drivers</td>
</tr>
<tr>
<td>Scaffolding</td>
<td>Project Manager</td>
</tr>
<tr>
<td>Truck Drivers Direct</td>
<td>Clerical</td>
</tr>
<tr>
<td></td>
<td>QA/QC</td>
</tr>
<tr>
<td></td>
<td>Craft Planners</td>
</tr>
<tr>
<td></td>
<td>Quantity Surveyors</td>
</tr>
<tr>
<td></td>
<td>Craft Training</td>
</tr>
<tr>
<td></td>
<td>Recruiting</td>
</tr>
<tr>
<td></td>
<td>Crane Setup/take down</td>
</tr>
<tr>
<td></td>
<td>Safety</td>
</tr>
<tr>
<td></td>
<td>Document Control</td>
</tr>
<tr>
<td></td>
<td>Safety Barricades</td>
</tr>
<tr>
<td></td>
<td>Drug Testing</td>
</tr>
<tr>
<td></td>
<td>Security</td>
</tr>
<tr>
<td></td>
<td>Equipment Coordinator</td>
</tr>
<tr>
<td></td>
<td>Show-up/Travel Time</td>
</tr>
<tr>
<td></td>
<td>Evacuation Time</td>
</tr>
<tr>
<td></td>
<td>Site Construction Manager</td>
</tr>
<tr>
<td></td>
<td>Field Administration Staff</td>
</tr>
<tr>
<td></td>
<td>Site Maintenance</td>
</tr>
<tr>
<td></td>
<td>Field Engineer-Project</td>
</tr>
<tr>
<td></td>
<td>Subcontract Administrator</td>
</tr>
<tr>
<td></td>
<td>Field Staff (Hourly)</td>
</tr>
<tr>
<td></td>
<td>Supervision (Hourly)</td>
</tr>
<tr>
<td></td>
<td>Field Staff (Salary)</td>
</tr>
<tr>
<td></td>
<td>Surveying Crews</td>
</tr>
<tr>
<td></td>
<td>Fire Watch</td>
</tr>
<tr>
<td></td>
<td>Temporary Facilities</td>
</tr>
<tr>
<td></td>
<td>Flag Person</td>
</tr>
<tr>
<td></td>
<td>Temporary Utilities</td>
</tr>
<tr>
<td></td>
<td>General Superintendent</td>
</tr>
<tr>
<td></td>
<td>Test Welders</td>
</tr>
<tr>
<td></td>
<td>Hole Watch</td>
</tr>
<tr>
<td></td>
<td>Tool Room</td>
</tr>
<tr>
<td></td>
<td>Janitorial</td>
</tr>
<tr>
<td></td>
<td>Truck Drivers Indirect</td>
</tr>
<tr>
<td></td>
<td>Job Clean-Up</td>
</tr>
<tr>
<td></td>
<td>Warehouse</td>
</tr>
<tr>
<td></td>
<td>Master Mechanic</td>
</tr>
<tr>
<td></td>
<td>Warehousing</td>
</tr>
<tr>
<td></td>
<td>Material Control</td>
</tr>
<tr>
<td></td>
<td>Water Hauling</td>
</tr>
<tr>
<td></td>
<td>Mobilization</td>
</tr>
<tr>
<td></td>
<td>Workface Planner (WFP)</td>
</tr>
<tr>
<td></td>
<td>Nomex Distribution</td>
</tr>
<tr>
<td></td>
<td>Orientation Time</td>
</tr>
<tr>
<td></td>
<td>Payroll Clerks/ Timekeepers</td>
</tr>
</tbody>
</table>

---

52
## Engineering Direct and Indirect Work

<table>
<thead>
<tr>
<th></th>
<th>Direct</th>
<th>Indirect</th>
</tr>
</thead>
<tbody>
<tr>
<td>Discipline Engineer</td>
<td>Document Control</td>
<td></td>
</tr>
<tr>
<td>Designer</td>
<td>Reproduction Graphics</td>
<td></td>
</tr>
<tr>
<td>Technician</td>
<td>Project Management</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Project Controls (cost/schedule/estimating)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Project Engineer</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Secretary/clerk</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Procurement (supply management)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Quality Assurance</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Accounting and Legal</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Construction Support</td>
<td></td>
</tr>
</tbody>
</table>
# Engineering Productivity Metrics Categories

## Concrete
- Total Concrete (CM)
  - Total Slabs (CM)
    - Ground and Supported Slab (CM)
    - Area Paving (CM)
  - Total Foundations (except Piling) (CM)
    - Foundation (<4CM) (CM)
    - Foundation (≥4CM) (CM)
  - Concrete Structures (CM)
  - Total Piling (Each)

## Structural Steel
- Total Steel (MT)
  - Combined Structural Steel / Pipe Racks & Utility Bridges (MT)
    - Structural Steel (MT)
    - Pipe Racks & Utility Bridges (MT)
  - Miscellaneous Steel (MT)

## Electrical
- Total Electrical Equipment (Each)
  - Electrical Equipment 600V & Below (Each)
  - Electrical Equipment Over 600V (Each)
- Conduit
  - Conduit (LM)
  - Conduit (Number of Runs)
- Cable Tray (LM)
- Wire & Cable
  - Wire & Cable (LM)
  - Wire & Cable (Number of Terminations)
- Other Electric Metric
  - Lighting (Each Fixtures)
  - Electrical Heat Tracing (LM)

## Piping
- Total Piping (LM)
  - Small Bore (2-1/2” and Smaller) (LM)
  - Large Bore (3” and Larger) (LM)
  - Engineered Hangers and Supports (Each)
- Heat Tracing Tubing (LM)

## Instrumentation
- Loops (Count)
- Tagged Devices (Each)
- I/O (Count)

## Equipment (Individual Design and Total Quantity)
- Total Equipment (Each)
  - Pressure Vessels (Each)
  - Atmospheric Tanks (Each)
  - Heat Transfer Equipment (Each)
  - Boiler & Fired Heaters (Each)
  - Rotating Equipment (Each)
  - Material Handling Equipment (Each)
  - Power Generation Equipment (Each)
  - Other Process Equipment (Each)
  - Vendor-Designed Modules & Pre-Assembled Skids (Each)

## Engineering Productivity

\[
\text{Engineering Productivity} = \frac{\text{Direct Design-Hours}^*}{\text{IFC Quantity}^{**}}
\]

* Per Design Component
** IFC (Issued for Construction)
# Project Phase Definition

<table>
<thead>
<tr>
<th>Project Phase</th>
<th>Start/Stop</th>
<th>Typical Activities &amp; Products</th>
<th>Typical Cost Elements</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Front End Planning</strong></td>
<td>Start: Single project adopted and formal project team established Stop: Project Sanction</td>
<td>Options Analysis Life-cycle Cost Analysis Project Execution Plan Appropriation Submittal Pkg P&amp;IDs and Site Layout Project Scoping Procurement Plan Arch. Rendering</td>
<td>Owner Planning Team Personnel Expenses Consultant Fees &amp; Expenses Environmental Permitting Costs Project Manager / Construction Manager Fees Licensor Costs</td>
</tr>
<tr>
<td><strong>Typical Participants:</strong></td>
<td>Owner Personnel Planning Consultants Constructability Consultant Alliance / Partner</td>
<td><strong>Detail Engineering</strong> Start: Contract award to engineering firm Stop: Release of all approved drawings and specs for Construction (or last package for fast-track)</td>
<td>Drawing &amp; spec. preparation Bill of material preparation Procurement Status Sequence of operations Technical Review Definitive Cost Estimate</td>
</tr>
<tr>
<td><strong>Typical Participants:</strong></td>
<td>Owner Personnel Design Contractor Constructability Expert Alliance / Partner</td>
<td><strong>Procurement</strong> Start: Procurement plan for engineered equipment Stop: All major equipment has been delivered to site</td>
<td>Vendor Qualification Vendor Inquiries Bid Analysis Purchasing Expediting Engineered Equipment Transportation Vendor QA/QC</td>
</tr>
<tr>
<td><strong>Typical Participants:</strong></td>
<td>Owner personnel Design Contractor Alliance / Partner</td>
<td><strong>Procurement</strong> Start: Procurement plan for engineered equipment Stop: All major equipment has been delivered to site</td>
<td>Vendor Qualification Vendor Inquiries Bid Analysis Purchasing Expediting Engineered Equipment Transportation Vendor QA/QC</td>
</tr>
<tr>
<td><strong>Typical Cost Elements:</strong></td>
<td>Owner project management personnel Project Manager / Construction Manager fees Procurement &amp; Expediting personnel Engineered Equipment Transportation Shop QA / QC</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Note:** The demolition / abatement phase should be reported when the demolition / abatement work is a separate schedule activity (potentially paralleling the design and procurement phases) in preparation for new construction. Do not report the demolition / abatement phase if the work is integral with modernization or addition activities.
## Project Phase Definition (cont’d.)

<table>
<thead>
<tr>
<th>Project Phase</th>
<th>Start/Stop</th>
<th>Typical Activities &amp; Products</th>
<th>Typical Cost Elements</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Construction</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Typical Participants:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Owner personnel</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Design Contractor (Inspection)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Construction Contractor and its subcontractors</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Start:</strong></td>
<td>Commencement of foundations or driving piles</td>
<td>Set up trailers Procurement of bulks Issue Subcontracts Construction plan Build Facility &amp; Install Engineered Equipment Complete Punch list Demobilize construction equipment Warehousing</td>
<td>Owner project management personnel Project Manager / Construction Manager fees Building permits Inspection QA/QC Construction labour, equipment &amp; supplies Bulk materials (including freight) Construction equipment (including freight) Contractor management personnel Warranties</td>
</tr>
<tr>
<td><strong>Stop:</strong></td>
<td>Mechanical Completion</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Commissioning Start-up</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Note: Does not usually apply to infrastructure or building type projects</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Typical Participants:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Owner personnel</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Design Contractor</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Construction Contractor</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Training Consultant</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Equipment Vendors</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Start:</strong></td>
<td>Mechanical Completion</td>
<td>Testing Systems Training Operators Documenting Results Introduce feed stocks and obtain first product Hand-off to user/operator Operating System Functional Facility Warranty Work</td>
<td>Owner project management personnel Project Manager / Construction Manager fees Consultant fees &amp; expenses Operator training expenses Wasted feed stocks Vendor fees</td>
</tr>
<tr>
<td><strong>Stop:</strong></td>
<td>Custody transfer to User/Operator</td>
<td>Steady-state operation</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Steady-state operation</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Appendix B

Glossary

General Terms

Addition (Add-on) – A new addition that ties in to an existing facility, often intended to expand capacity.

Grass Roots, Green Field – A new facility from the foundations and up. A project requiring demolition of an existing facility before new construction begins is also classified as grass roots.

Modernization, Renovation, Upgrade – A facility for which a substantial amount of the equipment, structure, or other components is replaced or modified, and which may expand capacity and/or improve the process or facility.

Per Cent Offsite Construction Labour Hours – The level of offsite labour hours for building modules. This value should be determined as a ratio of the offsite labour hours of all modules divided by total construction hours.

Rework - is defined as activities in the field that have to be done more than once in the field or activities which remove work previously installed as part of project.

Total Construction Hours – The summation of all direct and indirect hours associated with the construction phase.

Project Delivery System

Design-Bid-Build – Serial sequence of design and construction phases; Owner contracts separately with designer and contractor.

Design-Build (or EPC) – Overlapped sequence of design and construction phase; procurement normally begins during design; owner contracts with Design-Build (or EPC) contractor.

CM at Risk – Overlapped sequence of design and construction phases; procurement normally begins during design; owner contracts separately with designer and CM at Risk (constructor). CM holds the contracts.

Multiple Design-Build – Overlapped sequence of design and construction phases; procurement normally begins during design; owner contracts with two Design-Build (or EPC) contractors, one for process and one for facilities.

Parallel Primes – Overlapped sequence of design and construction phases; Procurement normally begins during design. Owner contracts separately with designer and multiple prime constructors.

Cost Definition

Construction Costs – include the costs of construction activities from commencement of foundation or driving piles to mechanical completion. The costs include construction project management, construction labour, and also equipment & supplies costs that are used to support construction operations and removed after commissioning. See “Instruction for Construction Direct and Indirect Costs” for detail of typical cost element.

Contingency – Contingency is defined as an estimated amount included in the project budget that may be required to cover costs that result from project uncertainties. These uncertainties may result from incomplete design, unforeseen and unpredictable conditions, escalation, or lack of project scope.
definition. The amount of contingency usually depends on the status of design, procurement and construction, and the complexity and uncertainties of the component parts of the project.

**Direct Costs** – Direct costs are those that are readily or directly attributable to, or become an identifiable part of, the final project (e.g., piping labour and material) [AACE].

**Direct Cost of Field Rework** – The sum of those costs associated with actual performance of tasks involved in rework. Examples include: Labour, Materials, Equipment, Supervisory personnel, Associated overhead cost.

**Modularization** – Modularization refers to the use of offsite construction. For the purposes of the benchmarking data, modularization includes all work that represents substantial offsite construction and assembly of components and areas of the finished project. Examples that would fall within this categorization include:

- Skid assemblies of equipment and instrumentation that naturally ship to the site in one piece, and require minimal on-site reassembly.
- Super-skids of assemblies of components that typically represent substantial portions of the plant, intended to be installed in a building.
- Prefabricated modules comprising both industrial plant components and architecturally finished enclosures.

Modularization does not include offsite fabrication of components. Examples of work that would be excluded from the definition of modularization include:

- Fabrication of the component pieces of a structural framework
- Fabrication of piping spool-pieces

**Indirect Costs** – Indirect costs are all costs that cannot be attributed readily to a part of the final product (e.g., cost of managing the project) [AACE].

**Schedule Definition**

**Project Sanction** – is defined as the milestone event at which the project scope, budget, and schedule are authorized. Project Sanction is the start of the execution phase of the project.

**Commissioning and Startup** – The transitional phase between construction and commercial operations; major steps include turnover, checkout, commissioning, and initial operations. Commissioning is the integrated testing of equipment and facilities that are grouped together in systems prior to the introduction of feedstocks.

**Detail Engineering** – Detail engineering is the project phase initiated with a contract to the firm providing detail engineering for the project. The typical activities included in this phase are: preparation of drawings, specifications, bill of materials, development of a definitive cost estimate, technical reviews, and engineering procurement functions. The detail engineering phase terminates with release of all approved drawings and specifications for construction.

**Mechanical Completion** - The point in time when a plant is capable of being operated although some trim, insulation, and painting may still be needed. This occurs after completion of pre commissioning.

**Changes Definition**

**Change** - A change is any event that results in a modification of the project work, schedule or cost. Owners and designers frequently initiate changes during design development to reflect changes in project scope or preferences for equipment and materials other than those originally specified. Contractors often initiate changes when interferences are encountered, when designs are found to be not constructable, or other design errors are found.
Change Order - A contractual modification executed to document the agreement and approval of a change (See definition of Change above).

Project Development Changes – Project Development Changes include those changes required to execute the original scope of work or obtain original process basis. Examples include:
1) Unforeseen site conditions that require a change in design / construction methods
2) Changes required due to errors and omissions
3) Acceleration
4) Change in owner preferences
5) Additional equipment or processes required to obtain original planned throughput
6) Operability or maintainability changes. (See Change above)

Scope Changes – Scope Changes include changes in the base scope of work or process basis. Examples include: 1) Feedstock change, 2) Changed site location, 3) Changed throughput, 4) Addition of unrelated scope

Best Practice Definitions

Front End Planning– is the essential process of developing sufficient strategic information with which owners can address risk and make decisions to commit resources in order to maximize the potential for a successful project. Front End Planning is also known as pre-project planning, front end loading, feasibility analysis, conceptual planning/ schematic design, and early project planning.

Project Risk Assessment – Project risk assessment is the process to identify, assess and manage risk. The project team evaluates risk exposure for potential project impact to provide focus for mitigation strategies.

Team Building – is a project- focused process that builds and develops shared goals, interdependence, trust and commitment, and accountability among team members and that seeks to improve team members' problem- solving skills.

Alignment during Front End Planning– is the condition where appropriate project participants are working with acceptable tolerances to develop and meet a uniform defined and understood set of project objectives.

Constructability – is the effective and timely integration of construction knowledge into the conceptual planning, design, construction, and filed operations of a project to achieve the overall project objectives in the best possible time and accuracy at the most cost- effective levels.

Design for Maintainability– Design for maintainability is the optimum use of facility maintenance knowledge and experience in the design/engineering of a facility to pertain the ease, accuracy, safety and economy in the performance of maintenance action; a design parameter related to the ability to maintain.

Material Management – the planning, controlling, and integrating of the materials takeoff, purchasing, economic, expediting, transportation, warehousing, and issue functions in order to achieve a smooth, timely, efficient flow of materials to the project in the required quantity, the required time, and at an acceptable price and quality, and the planning and controlling of these functions (CII Publication SP-4)

Project Change Management– is the process of incorporating a balanced change culture of recognition, planning, and evaluation of project changes in an organization to effectively manage project changes. Practices related to the management and control of both scope changes and project changes.

Zero Accident Techniques– include the site- specific safety programs and implementation, auditing, and incentive efforts to create a project environment and a level of that embraces the mind-set that all accidents are preventable and that zero accidents is an obtainable goal.
**Quality Management**—Quality management incorporates all activities conducted to improve the efficiency, contract compliance and cost effectiveness of design, engineering, procurement, QA/QC, construction and startup elements of construction projects.

**Automation/Integration (AI) Technology**—the Automation and Integration Technology practice addresses the degree of automation/level of use and integration of automated systems for predefined tasks/work functions common to most projects.

**Planning for Startup**—is the effectiveness of planning on startup activities that facilitate the implementation of the transitional phase between plant construction completion and commercial operations, including all of the activities bridging these two phases. Critical steps within the startup phase include systems turnover, checkout of systems, commissioning of systems, introduction of feed stocks, and performance testing.

**Prefabrication/ Preassembly/ Modularization**—Prefabrication/Preassembly/Modularization (PPMOF) is defined as several manufacturing and installation techniques, which move many fabrication and installation activities from the plant site into a safer and more efficient environment. For each technique, more specific definitions are provided below.

- **Prefabrication**: a manufacturing process, generally taking place at a specialized facility, in which various materials are joined to form a component part of a final installation. Prefabricated components often involve the work of a single craft.

- **Preassembly**: a process by which various materials, prefabricated components, and/or equipment are joined together at a remote location for subsequent installation as a sub-unit: generally focused on a system.

- **Module**: a major section of a plant resulting from a series of remote assembly operations and may include portions of many systems: usually the largest transportable unit or component of a facility.

- **Offsite Fabrication**: the practice of preassembly or fabrication of components both off the site and onsite at a location other than at the final installation location.

   This practice consists of two part, constructability at AFE phase and constructability at mechanical completion. Please fill out one part of this practice according to your current project phase.

**Workface Planning**—The process of organizing and delivering all elements necessary, before work is started, to enable craft persons to perform quality work in a safe, effective and efficient manner

**Engineering Productivity**

**Engineering Direct Work hours**—should include all detailed design hours used to produce deliverables including site investigations, meetings, planning, constructability, RFIs, etc., and rework. Specifically exclude work hours for operating manuals and demolition drawings.

- Engineering work hours reported should only be for the categories requested and may not equal the total engineering work hours for the project. (See “Instructions for Computation of Work hours and Rework-Hours” reference table)

- Exclude the following categories: architectural design, plumbing, process design, civil/site prep, HVAC, insulation and paint, sprinkler/deluge systems, etc. Within a category, direct work hours that cannot be specifically assigned into the provided classifications, and have not been excluded, should be prorated based on known work hours or quantities as appropriate.

**IFC Drawing** — Issued for Construction drawings.

**Construction Productivity**

**Actual Quantities and Work hours**—are all quantities and work hours of actual installation and include rework hours for these quantities and work-hours.
**Estimated Productivity** – are the estimated productivity of direct labour work hours required for installation according to the estimated quantity.

For owners: Estimated Quantity, Work hours and Total Installed Unit Cost **at the time of Project Sanction** (or as soon as available following sanction)

For contractors: Estimated Quantity, Work hours and Total Installed Unit Cost used **as the basis of Contract Award**.

**Estimated Quantities and Work hours** – are the estimated quantity to be installed, the estimated work hours required for the installation and include all change orders.

**Estimated Total Installed Unit Cost** – including labour and material cost at the time of project sanction (or as soon as available following sanction).

**Estimated Total Installed Unit Costs** (TIUC) – is the burdened direct cost of labour, material and equipment by pro rata share which are directly attribute to, or become a part of the final product including overhead and profit at the time of project sanction (or as soon as available following sanction).

**Actual Total Installed Unit Costs** (TIUC) – the burdened direct cost of labour, material and equipment by pro rata share which are directly attribute to, or become a part of the final product including overhead and profit from both direct hire and subcontract.

- The direct labour costs are considered as the costs of the labours listed as Direct in the “Instructions for Computation of Actual Work-Hours, Rework-Hours, and Installed Costs” table in Construction Productivity Section.
Appendix C

COAA Project Assessment System Background

Performance and Productivity Metrics

The COAA PAS program measures five aspects of project performance, namely: cost, schedule, safety, change and field rework. Safety, change, and rework are measured in terms of overall project performance at project completion. Project cost and schedule performance metrics evaluate the amount of variation from planned cost and schedule estimates at project sanction.

These performance metrics are further decomposed to address five primary phases of capital project execution. Known as phase cost and schedule factors, these metrics portray the proportion of total project time and money expended during each phase of the project, namely: front end planning, engineering, procurement, construction, and commissioning and start-up.

The only aspect of project performance metrics that differs between the CII PAS and the COAA PAS concerns safety metrics. For the COAA projects, the safety metrics commonly used in Canada are included. The definitions of these metrics are described in Appendix B.

Engineering and Construction Productivity Metrics

The productivity metrics used in the COAA PAS are based on the engineering and construction productivity measurements used in the CII PAS. Metrics are defined as ratios of work hours (WH) to quantities. For these metrics, a lower productivity rate is generally preferred.

Engineering productivity metrics are defined as actual engineering work hours per Issued for Construction (IFC) quantities that are the number of actual direct work hours to design a particular unit of work. Engineering productivity metrics are captured for significant work activities for the following design disciplines, namely: concrete, structural, piping, electrical, instrumentation and equipment.

Construction productivity metrics are defined as actual direct work hours required to install a unit quantity. Construction productivity metrics are captured for significant work activities for the following disciplines, namely: concrete, structural steel, piping, electrical, instrumentation, equipment, module installation, insulation and scaffolding.

Key Report

The project Key Report provides feedback to a participating COAA member regarding how their selected project(s) performed. It compares the project against the most comparable set of projects available for each individual metric. Importantly, each participating COAA member can use their Key Report(s) to identify performance gaps in order to set objectives for future projects.
and to initiate improvements to key work processes. A sample Key Report is shown in Figure 48.

![Owner COAA Sample Key Report](image)

**Figure 48: Owner COAA Sample Key Report**
Data Miner

The Data Miner, which can be seen in Figure 49, was launched in May 2012 at the COAA Best Practices Conference in Edmonton. This followed several years of development at CII to create a first-of-its-kind data-mining engine for capital project benchmarking.

Figure 49: Screenshot of COAA Data Miner

There are two critical reasons why this approach to benchmarking data visualization has been so successful:

1. Data can be seen in a user-defined format. This is atypical since other benchmarking outlets process the data using proprietary models, and present charts and results in the format of their choosing. The COAA Data Miner is different. The user starts by selecting a primary metric of interest and a quartile chart appears in colour. This chart includes all projects in the combined COAA and CII databases containing the specific metric. Then, the user can begin a process of ‘filtering’ the comparison cohort by filters including, for example: contract type, per cent of modularization, specific range of changes and range of year of project completion.

2. Aggregate data can be seen for any metric contributed by any participating COAA or CII member. Prior to the COAA/CII Data Miner, benchmarks were only available for similar
projects submitted by a specific COAA member (i.e. contractors could only see contractor projects, owners could only see owner projects, and metrics were only reported when questions were asked for a specific project). While this can be viewed as a weakness of the COAA Key Report, the advantage of the Key Report is the standardized comparison across all COAA projects. The advantage of being able to mine both owner and contractor-submitted metrics from any project type provides an added level of insight about current and future projects that, before the Data Miner, was unavailable.

Arrows (see arrow pointing to the second (blue) quartile) are used to indicate the specific metric value for a project that a participating COAA member has entered into the database. All projects submitted by the participating COAA member can be selected from the window on the right side of Figure 49.

**COAA-Specific Metrics**

The COAA PAS includes additional COAA-specific metrics to quantify Alberta project performance and productivity. These metrics are listed in Table 3. Many of these additional metrics relate to indirect and direct construction costs, mechanical and equipment costs, scaffolding work hours, the use of offsite modules, as well as various workforce metrics. The additional metrics were developed to evaluate suspected major causes of cost overruns and schedule delays common to large projects (Flyvberg 2003; COAA 2005). The COAA-specific metrics are described in Appendix A.
Table 3: Additional COAA-Specific Performance Metrics

<table>
<thead>
<tr>
<th>Metrics Related to Project Cost</th>
<th>Direct Construction Cost</th>
<th>= Direct Construction Costs Total Construction Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Indirect Construction Cost</td>
<td>= Indirect Construction Costs Total Construction Cost</td>
<td></td>
</tr>
<tr>
<td>Indirect/Direct</td>
<td>= Indirect Construction Costs Direct Construction Costs</td>
<td></td>
</tr>
<tr>
<td>Major Equipment</td>
<td>= Major Equipment Cost Total Project Cost</td>
<td></td>
</tr>
<tr>
<td>Mechanical &amp; Process Equipment</td>
<td>= Mech. and Process Equipment Costs Total Project Cost</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Metrics Related to Workforce</th>
<th>Direct-Indirect Workhours</th>
<th>= Total Construction Indirect Work-Hours Total Construction Direct Work-hours</th>
</tr>
</thead>
<tbody>
<tr>
<td>% Offsite Construction WH</td>
<td>= Offsite Construction WH of Modules x 100 Total Construction Hours</td>
<td></td>
</tr>
<tr>
<td>% Overtime Work-hours</td>
<td>= Overtime Craft Work-hours x 100 Total Construction Field Work-hours</td>
<td></td>
</tr>
<tr>
<td>Peak Construction Workforce</td>
<td>= Actual Peak Workforce Planned Peak Workforce</td>
<td></td>
</tr>
<tr>
<td>Mode of Travel to Worksite</td>
<td></td>
<td></td>
</tr>
<tr>
<td>% Workers Living in Camps and Living Out Allowance</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Metrics Related to Construction Productivity</th>
<th>Scaffolding WH Factor</th>
<th>= Scaffolding WH Total Direct WH</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scaffolding Cost Factor</td>
<td>= Total Scaffolding Cost Total Direct Cost</td>
<td></td>
</tr>
<tr>
<td>Modules Installation: Pipe Rack, Process Equipment, and Building Modules</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total Installed Unit Cost ( $/ Unit Quantity)</td>
<td>= Estimated Productivity Rate Actual Productivity Rate</td>
<td></td>
</tr>
<tr>
<td>Productivity Estimate Accuracy</td>
<td>= Estimated Total Installed Unit Cost Actual Total Installed Unit Cost</td>
<td></td>
</tr>
<tr>
<td>Cost Estimate Accuracy</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

| Practices | Workface Planning |

History of the COAA Performance Assessment System (PAS)

Benchmarking has long been used to improve the process of manufacturing. It is the continuous and systematic process of measuring one’s own performance against the results of recognized leaders for the purpose of finding best practices that lead to superior performance when implemented. In the capital projects industry, benchmarking is primarily used at the project level to help participants identify gaps in their work processes that can compromise performance. For a given company, benchmarking provides sets of external comparisons to its peer group that can be used to establish improvement goals and objectively understand what “best in class” practices could be applied.
The execution of capital projects in Alberta is truly unique. It is one of few geographic areas that have such a great prevalence of capital projects. At last estimate, over 240,000 people were engaged in the development of the oil sands resources in Alberta (OSDG, 2008). In fact, construction comprised 9.0% of Alberta’s gross domestic product (GDP) in 2007 (AFE, 2008). Spending on the Athabasca Oil Sands resource in particular rose to $37.7 Billion (CDN) in 2007 (ibid.). However, this dramatic amount of growth has also brought its challenges. Increasing pressures on capital projects have been created due to significant worldwide cost escalations and labour shortages. This has led to the creation of many perceptions regarding the potential loss of productivity or excessive indirect costs.

The purpose of Phase 2 (2010-2014) of the COAA Performance Assessment System (COAA PAS) was to quantitatively assess the performance of capital projects in Alberta. The combined resources of COAA, CII and U of C were directed to objectively measure the performance of actual projects planned and executed in Alberta within the past eight years. While it was not possible to obtain measures of every aspect of project performance, the COAA PAS does provide data necessary to gain new insights to the results of Alberta’s heavy industrial sector projects. It directly addresses many common perceptions regarding engineering and construction productivity, and it provides a baseline of project data that can be used to help improve the work processes used by participating COAA members that develop and execute capital projects in Alberta.

In Phase 1 (2006-2009), the Construction Industry Institute (CII) was selected by COAA to explore the performance and productivity concerning the execution of capital projects in Alberta. This selection was premised on the extensive experience of CII in researching and benchmarking industrial facilities in the United States and around the world. Extending CII’s reach into Alberta permitted tremendous understanding of the performance of these projects, especially when compared with similar projects in the United States.

Following the completion of Phase 1 of the COAA PAS, COAA AND CII analyzed the results of the benchmarking activities, and determined that there was a need for new metrics and modifications to current metrics to expand performance measurements tailored to projects in Alberta. As a result, COAA embarked on Phase 2 development to expand and extend the system to add new metrics for pipeline and SAGD projects, and to review the system for a better performance. New user interfaces, customized reporting and enhanced data analysis are also part of Phase 2 development. To provide local support for participating COAA members and to conduct research into benchmarking techniques, COAA invited a team of professionals from the Schulich School of Engineering at the University of Calgary to participate in Phase 2.
COAA / CII / U of C / Industry Benchmarking Partnership

Construction Owner’s Association of Alberta (COAA)

COAA represents a broad cross-section of owners’ interests, which are associated with many sectors of the Alberta construction community. COAA also includes associate members, which provide construction services and other activities. COAA’s mission is to assist its members in achieving excellence in the execution of capital projects by:

- Creating and promoting Best Practices in the construction industry
- Serving as a voice for owners to stakeholders that can make a difference
- Providing a forum for dialogue and debate among owners, contractors, labour providers and government
- Bringing new ideas to the construction industry and to government leaders

The responsibilities of the COAA Benchmarking Committee include:

- Provide oversight and management of the COAA PAS
- Create policies, and procedures for the ongoing development and operation of the COAA PAS
- Recruit new industry partners (participating COAA members) to participate in the COAA PAS

Construction Industry Institute (CII)

Headquartered at the University of Texas in Austin, CII is a consortium of leading owners, engineering and construction contractors, and suppliers that have come together to improve the cost effectiveness of capital projects. As the major public benchmarking resource in the capital projects industry, CII has over 21 years of experience in benchmarking capital project delivery and best practices. Today, there are over 130 CII members around the world engaged in capital projects.

CII started its Performance Assessment (PA) program in 1993 (formerly Benchmarking and Metrics Program) with an initial purpose to validate the benefit of best practices and to support CII research. Today, CII’s PA program employs 8 staff members to advance project performance through benchmarking research. Over the years, an online benchmarking system known as Project Central has been developed to allow benchmarking participants known as Benchmarking Associates (BA’s) to enter project data and get real-time feedback 24 hours per day. BA training is provided three times a year to ensure understanding of CII metrics and compliance with standard data definitions. CII continues to develop and manage their Performance Assessment System (PAS) to benchmark global capital projects.

Building on the collective expertise of COAA and CII, a contract was established in 2005 between the two organizations for the purpose of benchmarking capital projects in Alberta. The relationship between COAA and CII has been very productive, and has yielded many
discoveries regarding Alberta’s heavy industry sector capital projects, many of which are presented in this report.

The responsibilities of CII include:

- Manage access to the COAA PAS and CII PAS to protect the security, and quality of the data contained in these databases
- Operate and maintain the performance assessment system
- Extend, revise and update the performance system

Schulich School of Engineering University of Calgary (U of C)

From 2009 to 2012, a team of professionals from the Schulich School of Engineering at the University of Calgary (U of C) worked as volunteers with the COAA Benchmarking Committee and CII. The U of C team officially began work on the COAA Phase 2 Benchmarking Project in March 2012 under the COAA, participating COAA members, NSERC and Alberta Government funding agreements. The U of C team was asked to support the participating COAA members using the benchmarking system. This support includes training and assisting the industry partners to gather project data, and to analyze the benchmarking information. As of March 2014 the U of C has trained over 200 Benchmarking Associates (participating COAA members). The U of C team was also asked to conduct research into what other benchmarking techniques might be incorporated into the COAA PAS to enhance its performance assessment capabilities.

The responsibilities of the U of C include:

- Review, validate and verify projects in the COAA PAS
- Assist participating COAA members with data collection and input to the COAA PAS
- Present training sessions to all participating COAA members in large groups, in small groups within a company or one-on-one with industry professionals
- Conduct research into benchmarking techniques to enhance the assessment of project performance including:
  - Pipeline projects
  - SAGD projects
  - Well site and well pad projects
  - Benchmarking techniques

Participating COAA Members

There are currently 17 participating COAA members who provide project data for the COAA PAS. These industry partners include owner organizations (industrial and pipeline) and contractor organizations:

- Bantrel
- ConocoPhillips Canada
- Devon Energy
- Enbridge
• Fluor Canada
• JV Driver Projects
• Laricina Energy
• MEG Energy
• Nexen
• Pembina Pipeline
• Shell Canada
• Statoil
• Steeplejack Industrial Group
• Suncor Energy
• Syncrude
• TransCanada Corporation
• WorleyParsons Canada

Each participating COAA member designates professionals who are responsible for data input and retrieval of information from the COAA PAS. These professionals have assigned roles and responsibilities according to a hierarchy. The responsibilities of the participating COAA members include assigning professionals to collect project data, to input this data to the COAA PAS and to retrieve benchmarking information according to the following hierarchy:

**Benchmarking Manager (BM)**
- Manages the participating COAA member’s benchmarking efforts
- Sets benchmarking goals
- Determines the internal benchmarking hierarchy
- Coordinates the benchmarking efforts of the participating COAA member

**Benchmarking Associate (BA)**
- Data submission and retrieval of information from the COAA PAS
- Receive training to become familiar with the COAA PAS and to learn how to:
  - Collect meaningful project data
  - Verify the completeness and accuracy of the data
  - Input project data into the COAA PAS
  - Retrieve and interpret benchmarking information from the COAA PAS

**Project Manager (PM)**
- Work with project teams
- Collect and review data for selected projects
- Submit projects to a Benchmarking Associate

**Phase 2 Research by U of C**

The purpose of the research is to assess the performance of Alberta major projects considering factors unique to their execution, to permit analysis of this performance over time, and to include measures of engineering and field productivity. In particular, specific research objectives include:
- Include more project data into the existing data base
• Develop new benchmarking metrics for Pipeline projects
• Review how performance is assessed
• Develop new benchmarking metrics for SAGD projects

This research program used the principal components of CII’s benchmarking program as its foundation. CII’s existing large project questionnaire for heavy industry sector projects was used as a basis for the COAA questionnaire.

Throughout the study period, U of C conducted several training sessions for COAA member participants in this study. COAA Benchmarking Associates (BA’s) are given access to the COAA PAS and Key Reports.

Pipeline Project Research

In partnership with COAA, the U of C conducted research in cooperation with participating COAA members into how pipeline projects could be benchmarked.

The goal of the pipeline research was to develop a framework for benchmarking metrics and also to define a set of parameters specifically for pipeline projects that would assist participating COAA members and others in examining, and comparing their projects in the pipeline industry. In the study, fifty-three (53) benchmarking metrics specifically for pipeline projects were developed. In addition to this, the environment, context, barriers and boundaries in the pipeline industry that can affect project results were identified. A definition of pipeline projects was developed and validated. New categorizations based on pipeline size were developed. Risks associated with pipeline construction were identified and categorized. Industry practices regarding data collection were identified.

The findings of the pipeline research include:

Definition of a pipeline:
• A pipeline moves products or raw materials from point A to point B which is outside the battery limit and needs right of way

• Two categories of pipeline projects
  o Large pipeline > 20 inch diameter
  o Small pipeline < 20 inch diameter

• Customized questionnaire and metrics
  o Large pipeline – 53 metrics
  o Small pipeline – 25 metrics

Recommendations for additions, revisions and changes to the performance assessment of pipeline projects have been presented to the COAA Benchmarking Committee for review. The
COAA Benchmarking Committee will determine how these recommendations may be implemented in the COAA PAS.

**SAGD Project Research**

The U of C continues to conduct research in cooperation with participating COAA members to determine what changes or improvements might be made to benchmark SAGD type projects. The purpose of the SAGD project research is to expand and extend the previous benchmarking of this type of project, focusing on activities and methods utilized by engineering, procurement, and construction (EPC) owners and contractors to design and build a SAGD project. The objectives of the SAGD project research include:

- Better understanding of SAGD projects
- How SAGD projects may be benchmarked efficiently
- Establish SAGD benchmarking metrics

A PhD candidate is conducting the SAGD project research that is scheduled for completion by year-end 2014. Recommendations for additions, revisions and changes to the performance assessment of SAGD projects will be presented to the COAA Benchmarking Committee for review. The COAA Benchmarking Committee will determine how these recommendations may be implemented in the COAA PAS.