

Alberta Report III

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



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Executive Summary

Benchmarking is an effective method of performance measurement and continuous improvement and has been adopted as one of the strategies for companies to improve project delivery. COAA has partnered with CII to extend the benchmarking system to COAA member companies to upload project data and compare their project performance to industry averages. The partnership also includes a team of professionals from the Schulich School of Engineering Department of Civil Engineering at the University of Calgary (U of C) which provide local support capability for the COAA benchmarking system. This support includes training and assisting the participating COAA members to gather project data and to analyze the benchmarking information.

This report presents aggregated data on some of the metrics which were collected on Alberta projects throughout Phases 1 (2006-2009), 2 (2010-2014), and 3 (2015-2019). The report also contains comparisons of metrics for SAGD and Pipeline projects, and for Alberta and U.S. projects. The findings of this report are organized into three categories – Project Characteristics, Project Performance, and Engineering/Construction Productivity.

Project characteristic trends specific to **Alberta-based projects** show that there have been a number of changes over time:

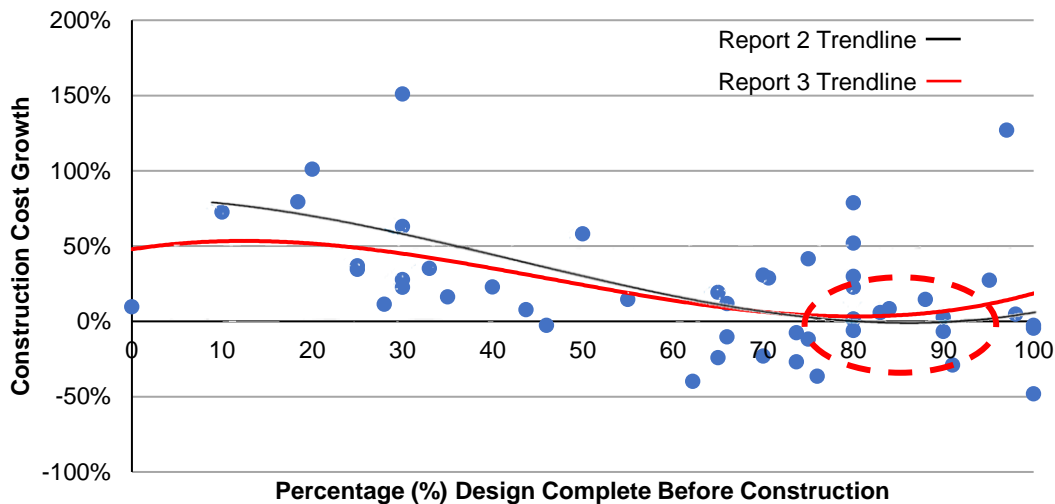
- More large projects (>\$500M) were built in Phases 1 and 3 than in Phase 2
- Phase 1 had the largest number of addition (expansion) projects, Phase 2, the largest number of brownfield projects, and Phase 3, the largest number of greenfield projects
- The preferred project delivery method in Phase 1 was Parallel Primes, Phase 2, Design-Bid-Build, Phase 3, Design-Build and Parallel Primes
- Lump sum contracts were the preferred contracting method in all three Phases

Project performance metrics on cost and schedule are also reported, with the general trend showing a noticeable improvement in the cost and schedule of Alberta projects:

- Project cost growth has increased slightly from Phase 2 to Phase 3 but remains lower than in Phase 1; *construction* cost growth has decreased consistently from Phase 1 to Phase 3
- Project schedule growth has decreased consistently from Phase 1 to Phase 3; *construction* schedule growth has increased slightly from Phase 2 to Phase 3 but remains lower than in Phase 1

- Average % contingency remains steady at 9% of the project budget but the range of contingency values is lowest in Phase 3
- Average % modularization has decreased over each phase from 16% in Phase 1 to 10% in Phase 3
- Average % design completed before construction start has improved greatly from 54% in Phase 1 to 66% in Phase 3

A major finding of this report is illustrated in Figure 22 (below), which shows the relationship between the **percentage of design complete** before construction and construction growth. It was found that projects with between 80% to 90% of design complete had on average the lowest construction cost growth.



Construction Productivity trends (for disciplines with sufficient data) show that productivity has decreased over time, however, for some disciplines, such as steel and concrete the decrease is minor.

Project performance assessment over the last fifteen 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 continue benchmarking efforts. There is ample reason to predict that tomorrow's projects will perform much better than those executed today.

Introduction

Alberta's oil and gas industry has experienced many boom and bust cycles over the past two decades. As always, the industry is seeking to continuously improve and remain competitive in the global market. Through benchmarking, it is possible to track and compare performance and productivity trends in the industry and identify areas of strength and areas requiring improvement.

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 (Fisher et al., 1992). 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. The system utilizes project cost, schedule, safety data and engineering and construction information to calculate metrics that can be further analyzed to assess project performance and engineering and construction productivity. The Construction Industry Institute (CII) at the University of Texas in Austin developed the COAA Performance Assessment System (COAA PAS). The ongoing and diversified relationship between COAA and CII provides a unique opportunity for participating COAA members to compare their projects with similar projects in their region (Alberta) but also with similar projects in other regions including Asia, Africa, Australia, North America, South America, Mexico, the Caribbean and Central America. Throughout this report, Alberta projects will be compared to projects in the United States which are part of the CII database. As both COAA and CII project data is collected using the same definitions and format, it allows for appropriate comparisons between Alberta and U.S. projects.

The COAA PAS has been developed in three phases. Phase 1 (2003-2009) included the initial development of the system and the addition of twenty-seven (27) Alberta capital projects to the database. Phase 2 (2010-2014) 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. Data on 44 projects was collected during Phase 2, however, only 33 were fully validated and ready for inclusion in Alberta Report 2. The 11 remaining projects are included in Alberta Report 3 as part of "Phase 2" data. Phase 3 (2015-2019) consisted of continued data collection to populate the PAS system,

with a total of 38 COAA projects added to the database. A team of professionals from the Schulich School of Engineering Department of Civil Engineering at the University of Calgary (U of C) provide local support capability for the COAA PAS. This support includes training and assisting the participating COAA members to gather project data and to analyze the benchmarking information. The partnership between CII, COAA, and the UofC and the role of each participant is expanded upon in Appendix A.

In this report we present and discuss a representative sample of the many project performance metrics and engineering and construction productivity metrics. 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.

Hierarchical Structure of COAA Project Types

The hierarchical structure of COAA project types is shown in Table 1. COAA projects are divided into five types (Level 1), which include upstream and downstream oil and gas, natural gas, pipeline, and well site/pads (specific to natural gas) 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 (specific to SAGD) projects. Metric values are calculated for each project and then these metrics are compared with similar projects.

Table 1: Hierarchical Structure of COAA Project Types

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

Benchmarking Database

109 Alberta projects have been established in the COAA PAS during three Phases (2006-2019). As can be seen in Table 2, the majority of submitted projects are Oil Sands SAGD and upgrading facilities. It should be mentioned that Table 2 project types do not include all of the project types shown previously in Table 1. The structure shown in Table 1 is the long-term vision of the breakdown of project types, however, there are insufficient projects to collect data at Level 3. Therefore, Table 2 shows the project types for which data was available.

Table 2: Projects in COAA Database

Project Type	Phase 1	Phase 2	Phase 3	Total
Chemical Manufacturing	0	0	1	1
Cogeneration	1	2	1	4
Electrical Distribution	0	0	2	2
Electrical Generating	0	0	3	3
Low rise Office	0	0	1	1
Natural Gas Processing	2	0	0	2
Oil and Gas Exploration	0	3	4	7
Oil Refining	1	1	5	7
Oil Sands Mining/ Extraction	3	4	5	12
Oil Sands SAGD	11	11	5	27
Oil Sands Upgrading	7	2	0	9
Other Heavy Industrial	0	2	6	8
Pipeline	2	14	1	17
Tailing	0	5	1	6
Tank Farms	0	0	2	2
Telecom Wide Area Network	0	0	1	1
Total	27	44	38	109

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 CII and 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.

Performance Assessment System (PAS)

The PAS is an online system developed by CII that allows participating COAA member companies to input project data, create summary reports, and compare project performance to industry averages.

Project data is input directly into the online system by designated Benchmarking Associates of member companies. 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 of five phases 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. The COAA safety metrics are those commonly used in Canada and the CII safety metrics are those commonly used in the U.S. Eighteen COAA-specific metrics are also included, such as comparison of direct and indirect costs, the use of modularization, overtime and peak workforce as well as overtime. Every project entered into the database undergoes an extensive validation process for the purpose of maintaining consistency between different projects and ensuring high-quality data.

The next section summarizes characteristics of projects in the COAA database.

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

Figure 1 shows the size of Alberta projects by total budgeted cost submitted in Phases 1 (2006-2009), 2 (2010-2014), and 3 (2015-2019). Figure 2 shows the size of U.S. projects compared to Alberta projects. For Phase 1, 75% of projects had a total budgeted cost greater than \$100M. This changed with Phase 2 which had smaller project budgets, and only 48% of projects were greater than \$100M. Phase 3 saw a 10% increase in the number of larger projects, with 58% of projects greater than \$100M.

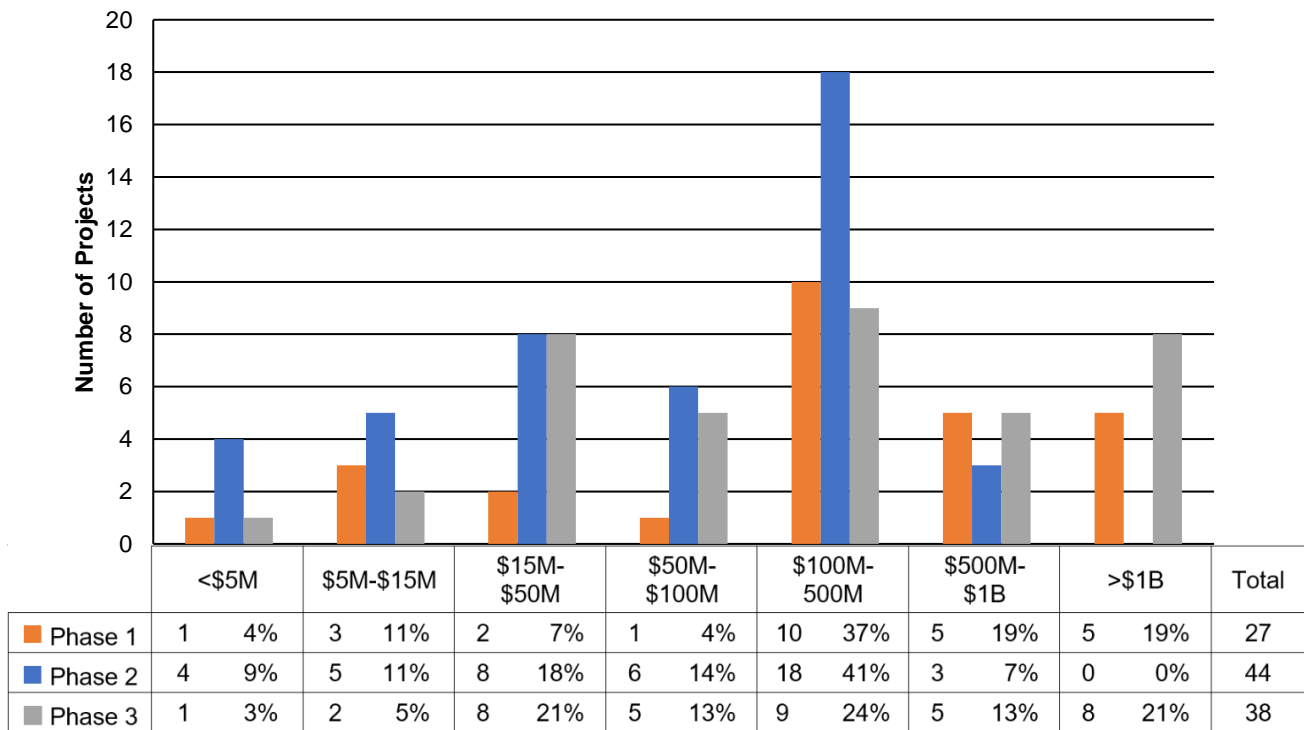


Figure 1: Alberta Phase 1, 2, and 3 Projects by Total Project Cost

Figure 2 compares the distribution of projects sizes between Alberta and U.S. projects. It can be seen that for the U.S., 59% of projects are between \$15M-\$500M, and only 4% are greater than \$500M. This contrasts with Alberta projects which are generally larger with 62% of projects between \$15M-\$500M and 24% greater than \$500M.

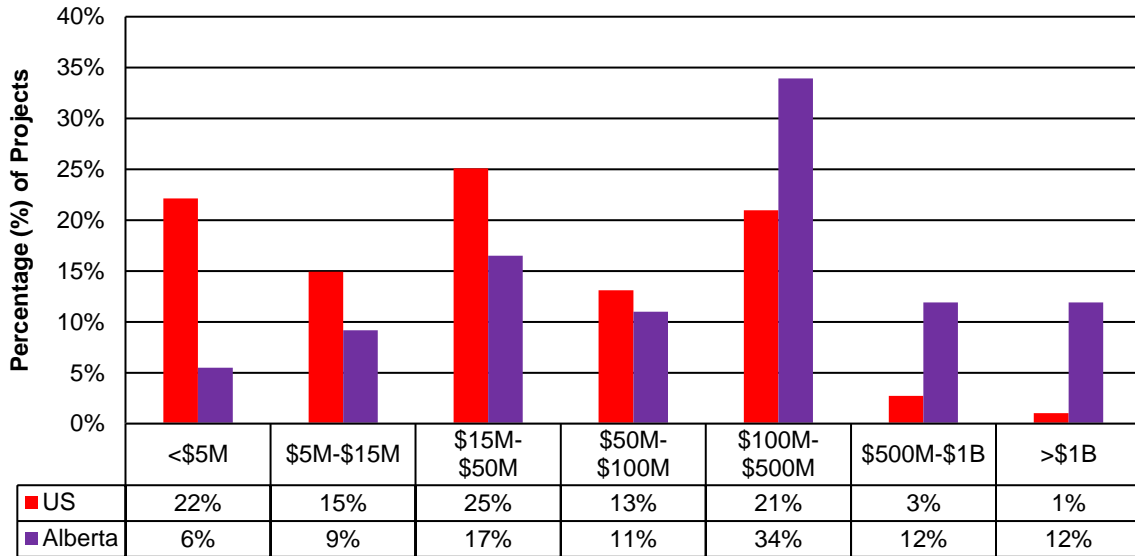


Figure 2: U.S. and Alberta Projects by Total Project Cost

Characteristics of Alberta Projects - Phase 1, 2, and 3

In Figure 3 it can be seen that the nature of projects changes throughout the three phases. Phase 1 projects were primarily Greenfield (48%), Addition (37%), and Modernization (11%). Phase 2 had the same proportion of Greenfield projects (48%), but a reduction in the number of Addition (18%) and Modernization (2%) projects, with significantly more Brownfield (32%) projects being delivered. Phase 3 had the highest proportion of Greenfield (68%) and Modernization (21%) projects compared to the previous phases.

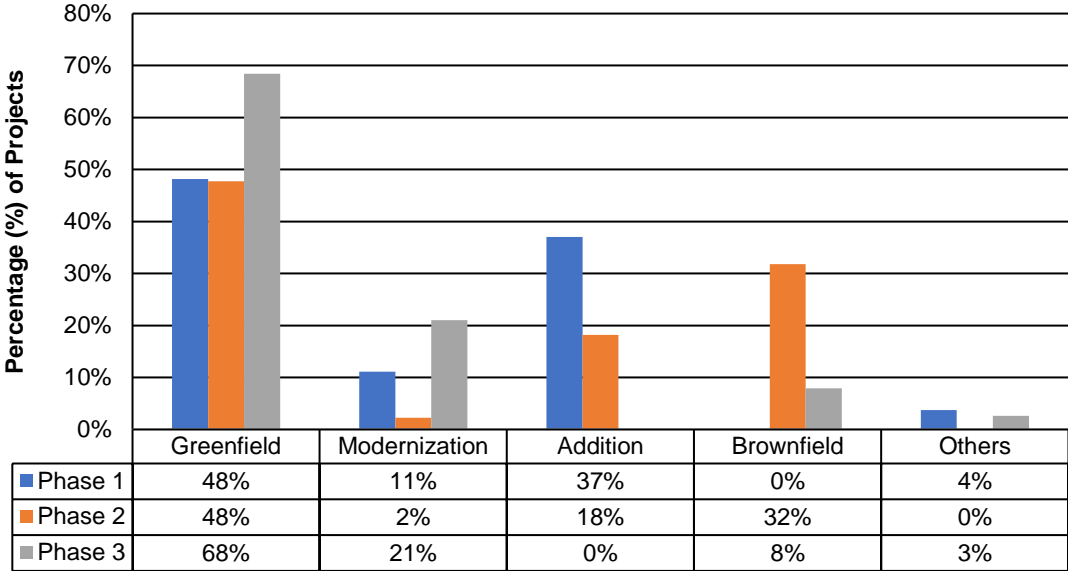


Figure 3: Alberta Phase 1, 2, and 3 Projects by Project Nature

Figure 4 shows that in Phase 1 the majority of projects were delivered by Parallel Prime (48%) and Design-Build (22%). This changed in Phase 2, which shows a decrease in the use of Parallel Primes (30%) and CM at Risk (2%) and a large increase in the use of Design-Bid-Build (50%). In Phase 3 the proportion of Parallel-Prime (32%) remained the same but saw an increase in CM at Risk (11%) and Design-Build (34%).

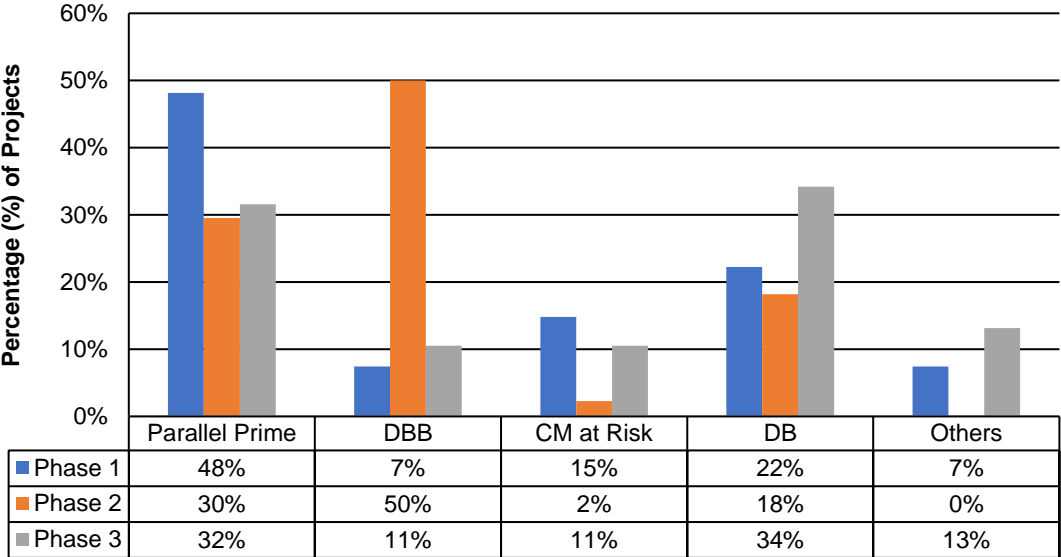


Figure 4: Alberta Phase 1, 2, and 3 Projects by Project Delivery System

In Figure 5 it can be seen that Cost Reimbursable Contracts are the main contracting method in all three phases. In Phase 1, 100% of projects in the database were completed with a cost reimbursable contract, which decreased in Phase 2 (75%) and increased in Phase 3 (91%).

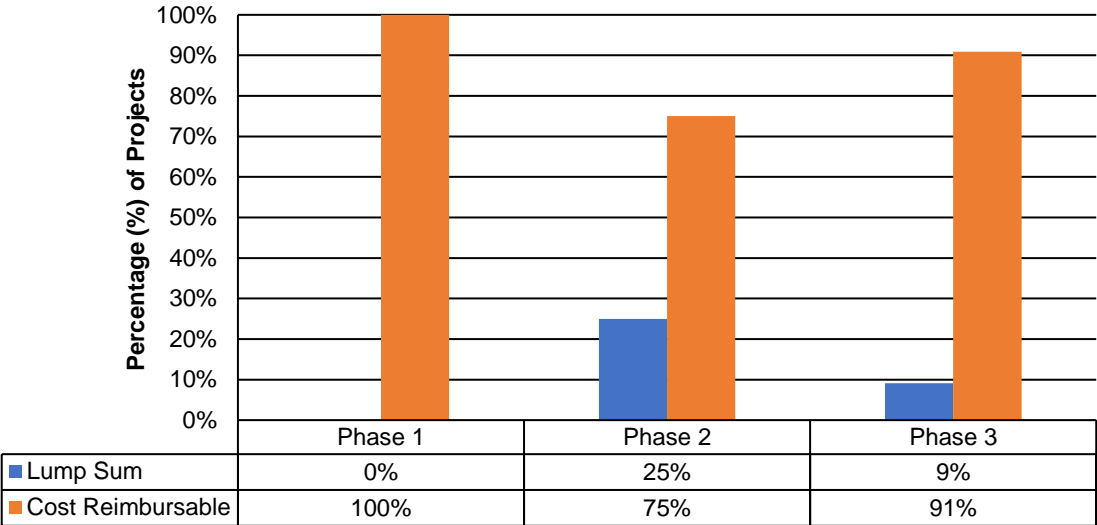


Figure 5: Alberta Phase 1, 2, and 3 Projects by Contract Type

Display of Metrics

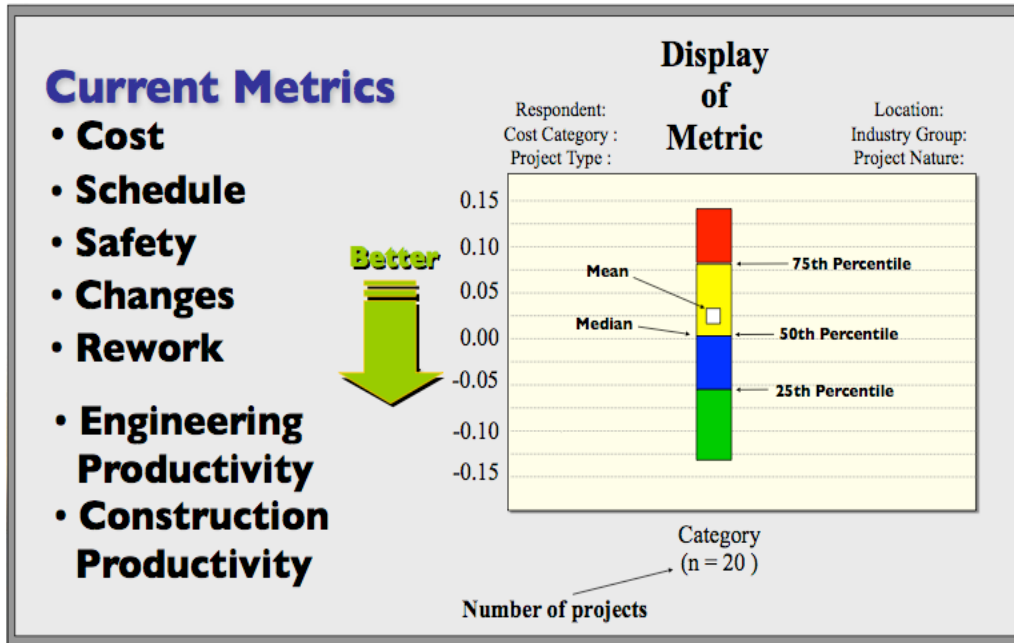


Figure 6: Visual Display of Quartiles

Project metrics are displayed as a series of quartiles as shown in Figure 6 and described below:

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

In keeping with the confidentiality policy, when fewer than 10 projects from 3 different companies are available, a capital 'C' will be displayed instead of the box plot.

In this report, extreme data points beyond 3x the Interquartile Range (25th to 75th percentile) are removed to prevent skewed graphics and means. Exceptions to this rule are for Figures 13 to 18, which had unreasonably high or low values removed.

Project Performance Assessment

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:

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

Figure 7 shows the project cost growth over the three phases. It can be seen that the mean cost growth decreased substantially from Phase 1 (27%) to Phase 2 (4%) and increased slightly in Phase 3 (9%). However, it is interesting to note that the maximum value of cost growth also decreased from Phase 1 to 3. As with all subsequent graphs, it is important to be cognizant of the fact that these means are created by aggregating data from different project types. As such, one phase may have a somewhat different composition of project types that may bias the mean cost growth either higher or lower. The next figure shows how different project types can exhibit different cost growths.

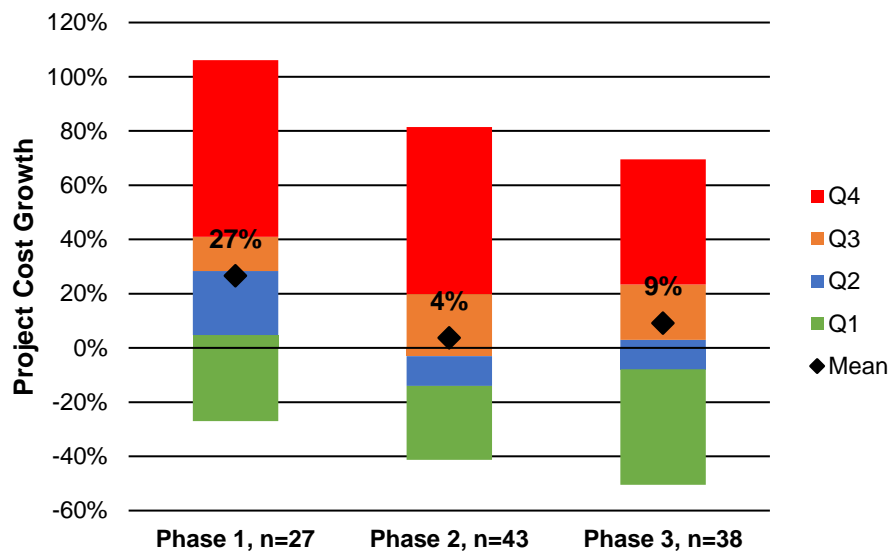


Figure 7: Project Cost Growth – Phase 1, 2, and 3

Figure 8 shows that SAGD projects tend to have a higher mean cost growth (22%) than Pipeline projects (-6%). SAGD projects also have a much wider range of cost growth (maximum value of 106%) than Pipeline projects. The negative value for Pipeline projects indicates that on average the actual project cost tends to be lower than the predicted cost, however, it should be noted that approximately 35% of pipeline projects in the sample were overbudget.

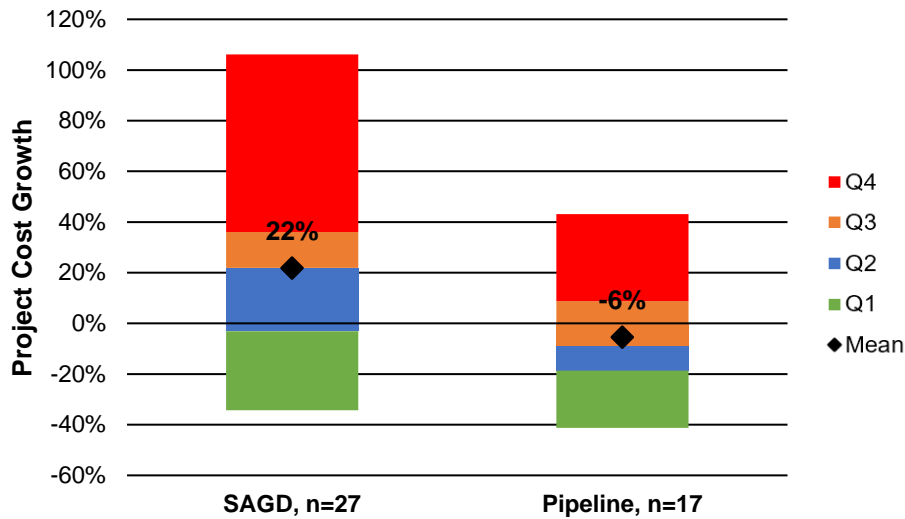


Figure 8: Project Cost Growth – Oil Sands SAGD and Pipeline Projects

Project Cost Growth comparison between Alberta and U.S. projects is shown in Figure 9. The mean cost growth for Alberta projects is 11% whereas for U.S. projects it is 1%. The fourth quartile (Q4) for Alberta projects shows that a quarter of projects have project cost growths ranging from 30% to 106%.

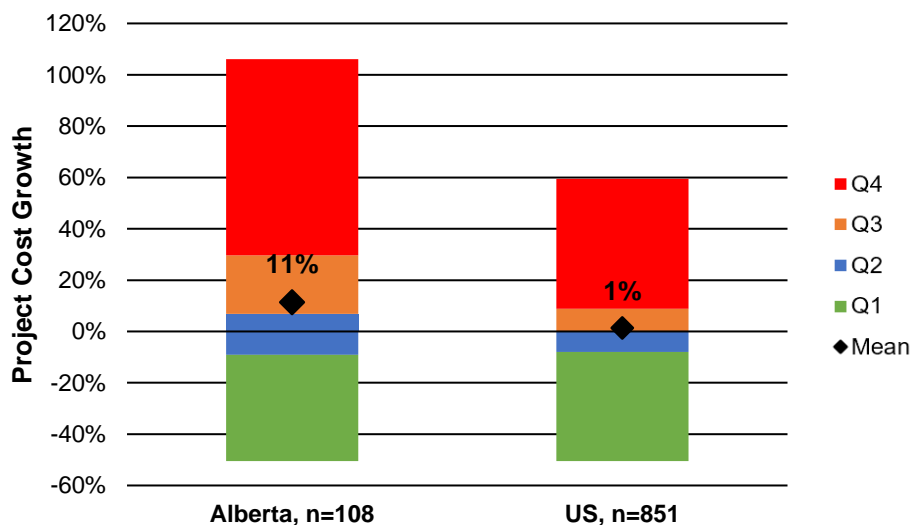


Figure 9: Project Cost Growth – Alberta and U.S. Projects

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 it can be seen that on average, Project Schedule Growth for Alberta projects has decreased over the three phases, from 18% in Phase 1 to 12% in Phase 3. The range of Project Schedule Growth is also becoming tighter with each phase. Both of these factors indicate that schedule performance for Alberta projects has improved over time.

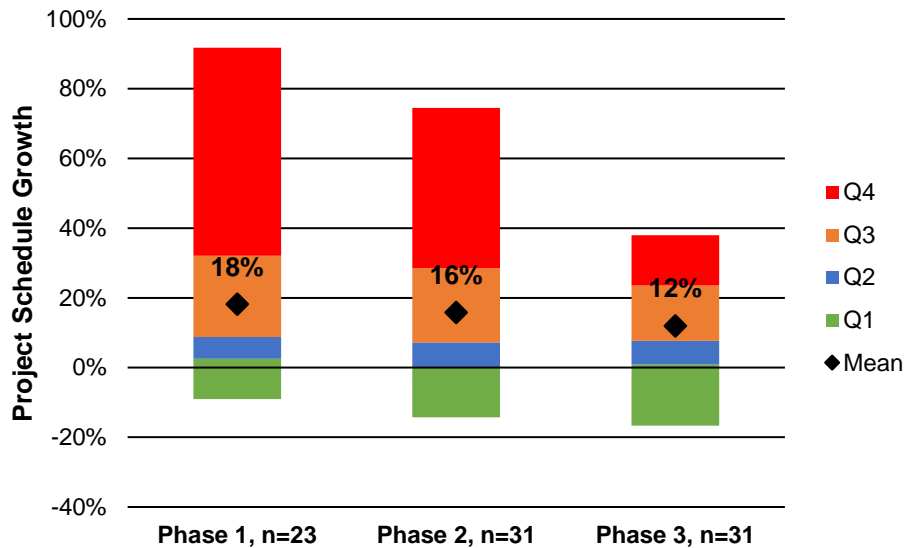


Figure 10: Project Schedule Growth – Phase 1, 2, and 3

The Project Schedule Growth of SAGD and Pipeline projects are compared in Figure 11. SAGD projects have a slightly higher mean Schedule Growth than Pipeline projects (11% vs 8%) and a wider range of growth. It is interesting to note that for Pipeline projects, 75% of projects experience a Schedule Growth between -1% and 8%, with 25% of projects having a Schedule Growth between 8% and 40%.

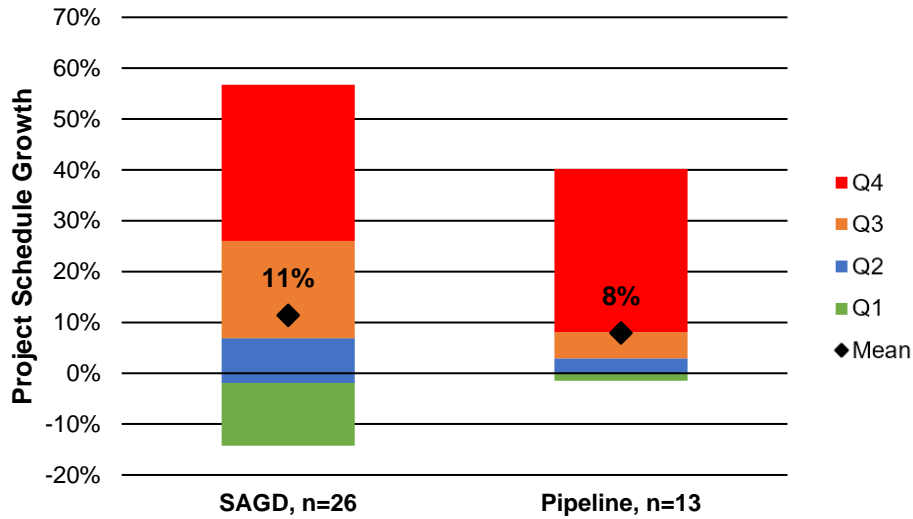


Figure 11: Project Schedule Growth – Oil Sands SAGD and Pipeline Projects

Comparing Alberta and U.S. for Project Schedule Growth in Figure 12 shows that the U.S. projects have a mean growth of 5% compared to 15% growth for Alberta projects. Furthermore, the range of the two inner quartiles (Q2 and Q3) for U.S. projects is much narrower than that of Alberta projects.

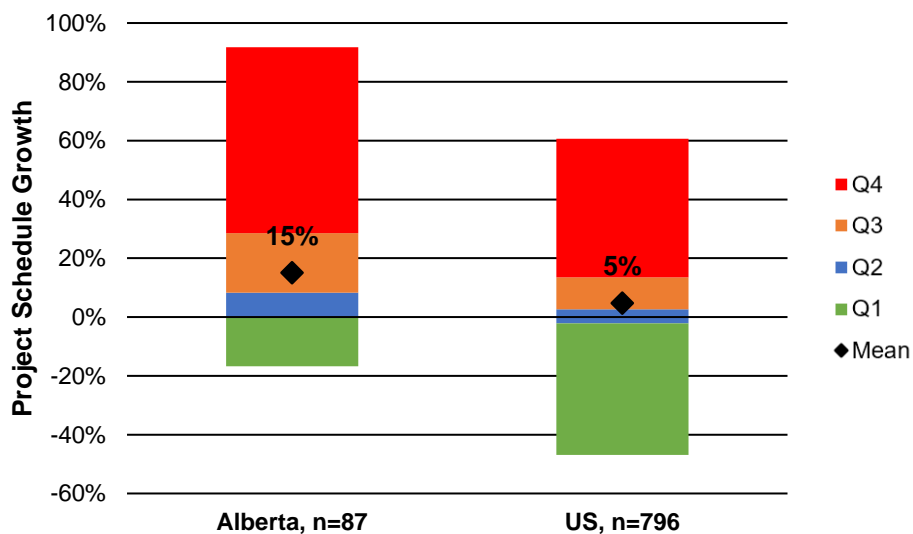


Figure 12: Project Schedule Growth – Alberta and U.S. Projects

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:

$$\text{Construction Cost Growth} = \frac{\text{Actual Construction Cost} - \text{Initial Predicted Construction Cost}}{\text{Initial Predicted Construction Cost}}$$

Figure 13 shows that Construction Cost Growth has decreased over time. Phase 1 has the highest mean growth (28)%, which decreased in Phase 2 (21%) and decreased slightly again in Phase 3 (20%). Despite this improvement, the upper quartile shows that in Phase 3, 25% of projects still experience cost growths between 36% and 127%.

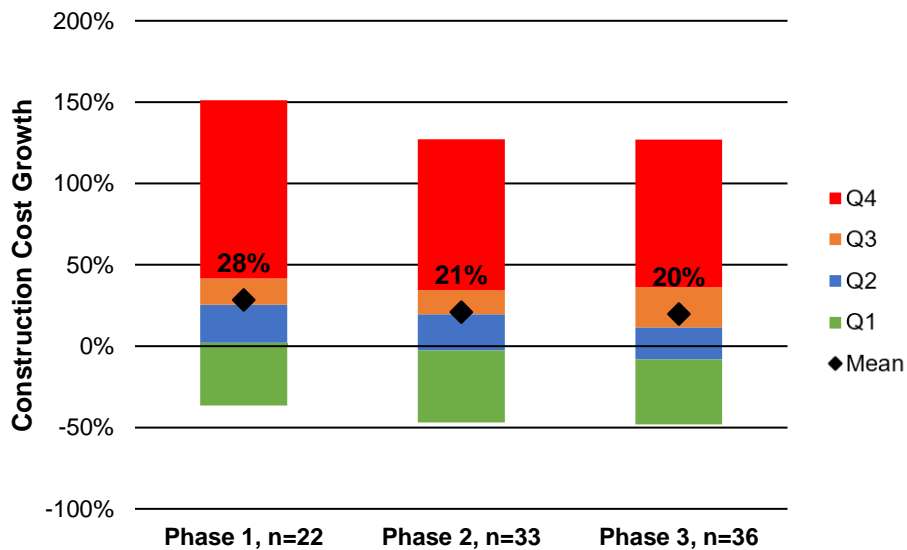


Figure 13: Construction Cost Growth – Phase 1, 2, and 3

In Figure 14 we see that SAGD projects experience much higher Construction Cost Growths than Pipeline projects (26% versus 15%). It should be noted that there is one SAGD project experiencing high cost growth, without which the mean Construction Cost Growth would be 19%.

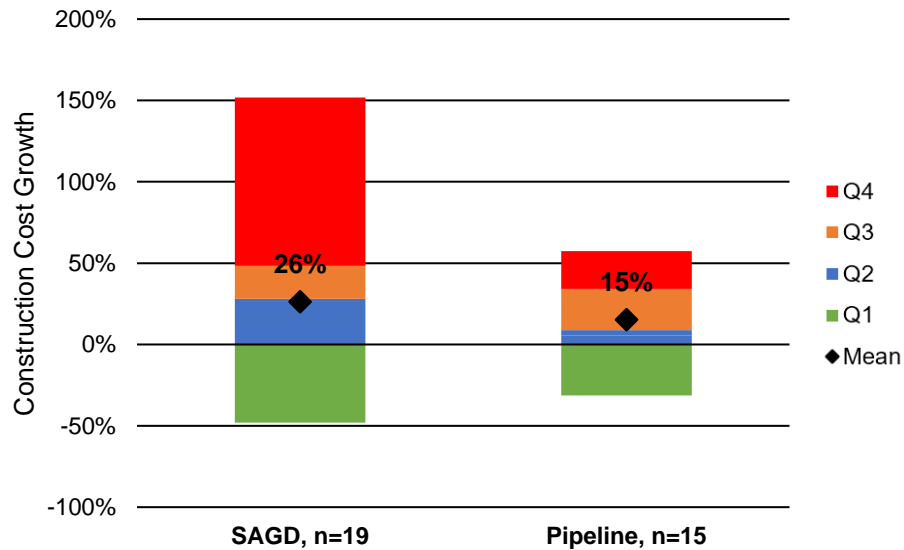


Figure 14: Construction Cost Growth – SAGD and Pipeline Projects

Figure 15 shows that U.S. projects tend to have a lower mean Construction Cost Growth (4%) than Alberta projects (22%).

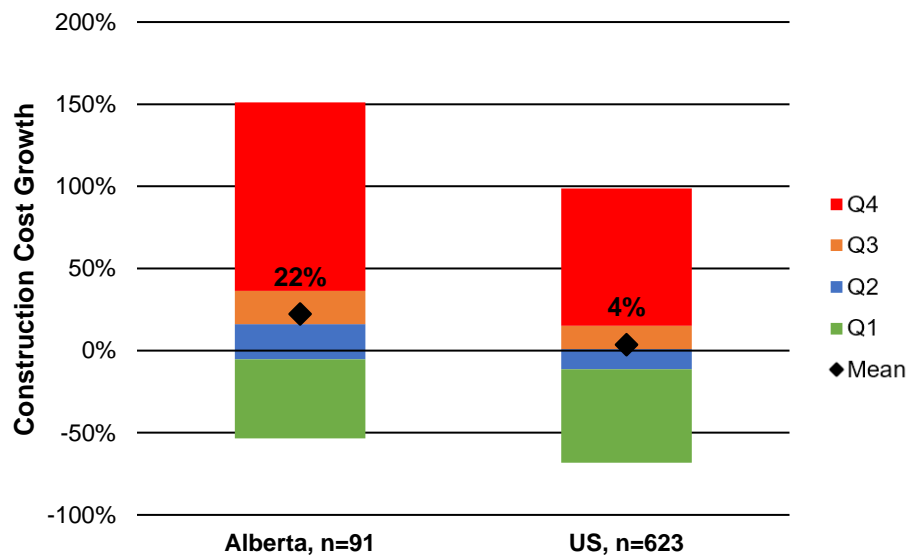


Figure 15: Construction Cost Growth – Alberta and U.S. Projects

Construction Cost Factor

The cost of the construction phase of a project can also be analyzed 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:

$$\text{Construction Cost Factor} = \frac{\text{Actual Construction Phase Cost}}{\text{Actual Total Project Cost}}$$

Figure 16 shows that the average actual cost of construction as a portion of the total project cost decreases from Phase 1 (64%) to Phase 2 (63%) and Phase 3 (59%). As construction is an area where a considerable portion of project funds are spent, it is important to focus on controlling the cost of this phase and applying the appropriate best practices to manage its cost.

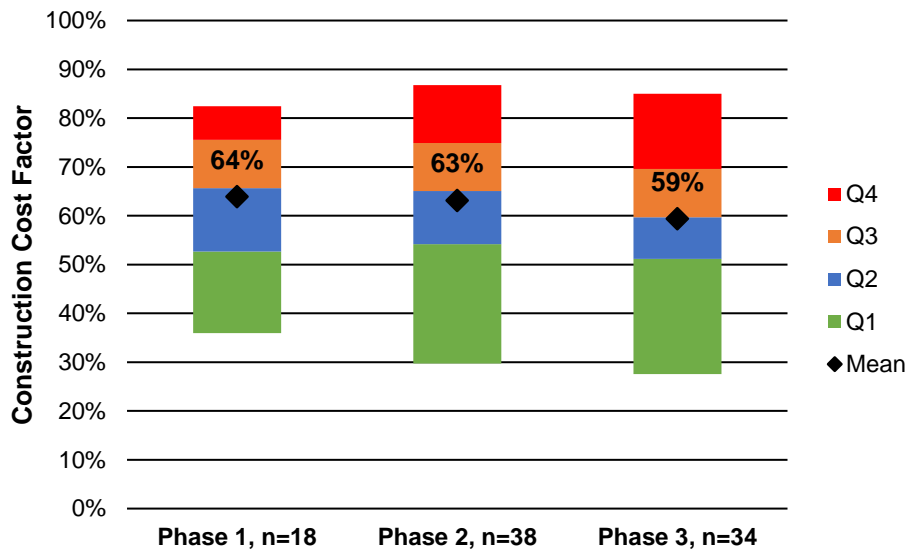


Figure 16: Construction Cost Factor – Phase 1, 2, and 3

Figure 17 shows that on average, Pipeline projects expend 70% of the actual total project cost on construction, whereas for SAGD projects the average is 63%. Pipeline projects in the first quartile Q1 exhibit a range of cost factors (42% to 67%) greater than the other three quartiles, Q2, Q3, Q4, which contain 75% of projects (67% to 86%).

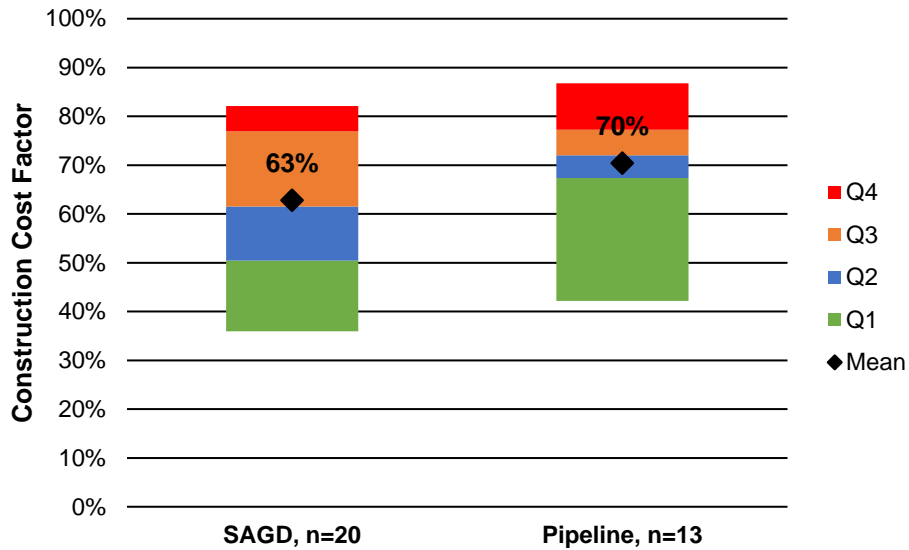


Figure 17: Construction Cost Factor – SAGD and Pipeline Projects

In Figure 18 it can be seen that U.S. projects on average spend less on the construction phase relative to the overall project cost than Alberta projects (53% vs 62%).

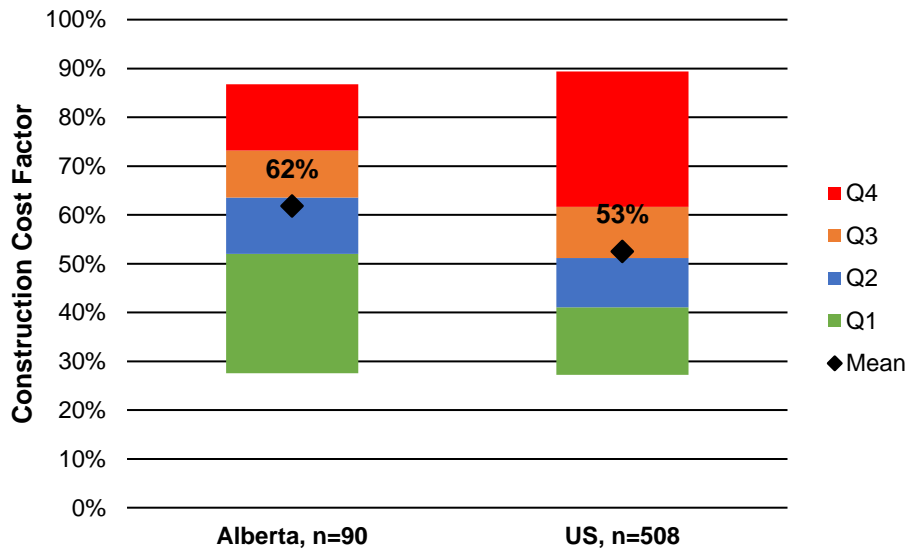


Figure 18: Construction Cost Factor – Alberta and U.S. Projects

Engineering Design

Researchers continue to examine the effect of engineering design completeness before the start of construction on construction cost and other metrics (Akinsola et al., 1997; Chanmeka et al., 2012; Chua et al., 1997; Chua et al., 1999; Cho et al., 2009; Jaselskis and Ashley, 1991; Konchar and Sanvido, 1998; Ling and Liu, 2004; Molenaar and Songer, 1998; Pedwell et al., 1998; Suk et al. 2016). 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. It can be seen in Figure 19 that on average, U.S. projects have a higher percentage of design complete before construction than Alberta projects (74% versus 60%). It is also interesting to note that the upper quartile, Q4, for U.S. projects has a very small range – indicating that 25% of the projects in the U.S. sample had 95% to 100% design complete before the start of construction.

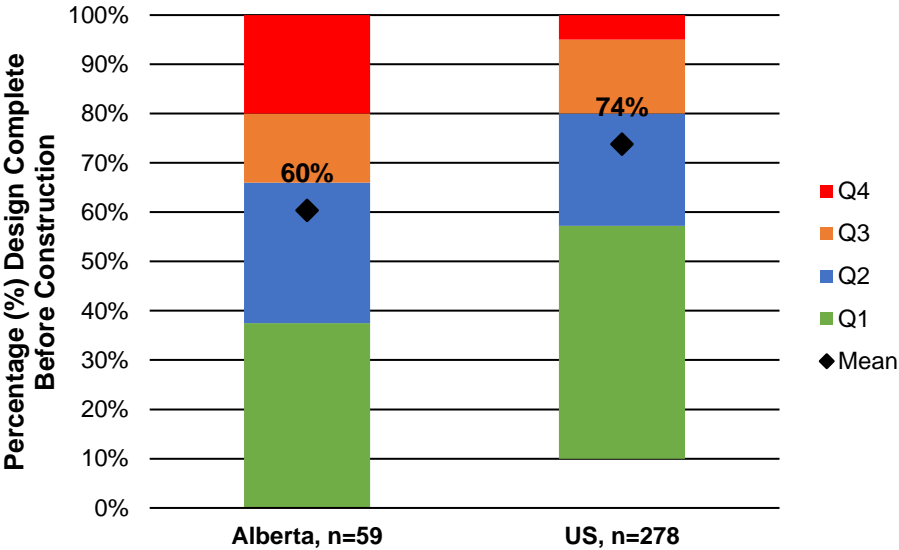


Figure 19: % Design Complete before Construction – Alberta and U.S. Projects

Figure 20 shows that, for Alberta projects, the mean percentage of design complete before construction has increased 12% from Phase 1 (54%) to Phase 3 (66%). Furthermore, in Phase 3, the top two quartiles (Q3 and Q4) which represent half of the projects in the sample have at least 75% of the design complete before start of construction. The trend over time suggests that, for Alberta projects, more emphasis is being placed on finishing a greater portion of the design prior to the start of construction.

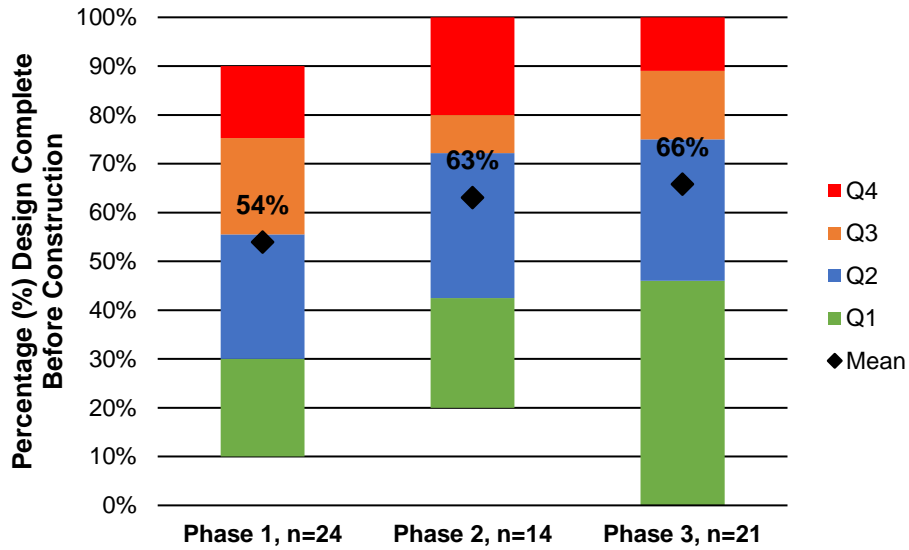


Figure 20: % Design Complete before Construction – Alberta Projects

In Figure 21 an attempt was made to show the percentage of design complete before construction for SAGD and Pipeline projects. As there are only two Pipeline projects, the data does not meet the required minimum of 10 projects from 3 different companies and values cannot be displayed for Pipeline projects. For SAGD projects, however, metrics can be displayed, and the average percentage design complete before construction is 57%.

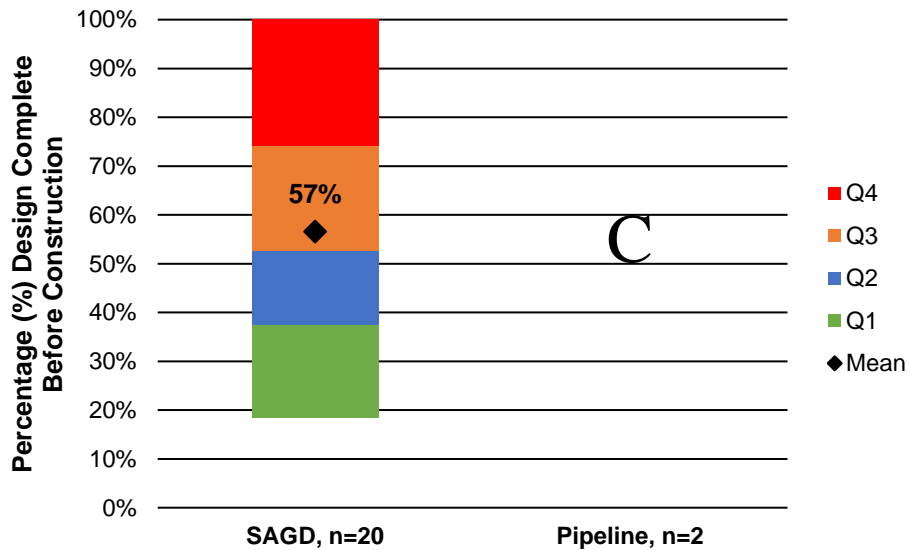


Figure 21: % Design Complete before Construction – SAGD/Pipeline Projects

The relationship between percent engineering design completed before construction and construction cost growth is shown in Figure 22. A cubic polynomial function is used to fit the data points which represent projects. It can be seen from the trendline that the more design is completed before construction, the less cost growth is experienced. By inspection it can be seen that an optimum value range between 80% and 90% design complete exists in which projects on average have almost no cost growth. While there are some projects with high percentage design complete and high construction cost growth (data point on the upper right of the graph, for example), the high cost growth may be attributed to different factors that may impact construction.

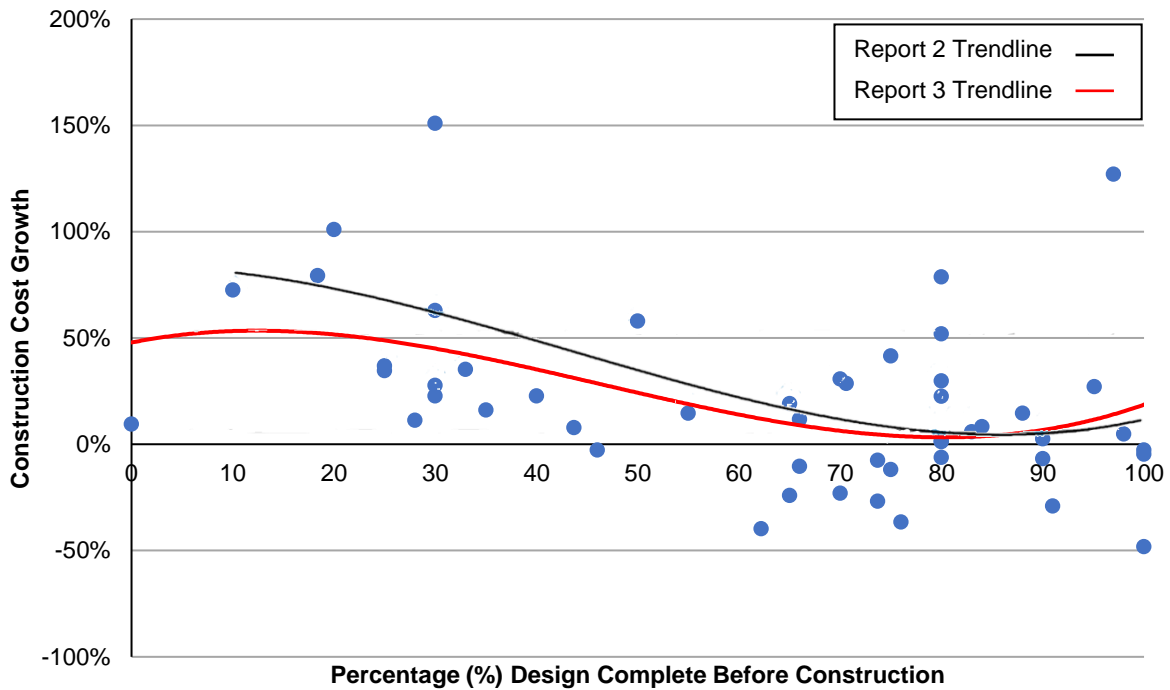


Figure 22: % Design Complete before Construction Start

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:

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

Changes in Construction Schedule Growth from Phase 1 to Phase 3 are shown in Figure 23. It can be seen that while the mean Construction Schedule Growth is highest in Phase 1 (26%), the range of growth is much smaller than in Phase 2 and Phase 3. Therefore, while the average schedule growth in construction is less in Phase 2 (13%) and Phase 3 (19%), more projects exhibit higher (and lower) cost growths than in Phase 1.

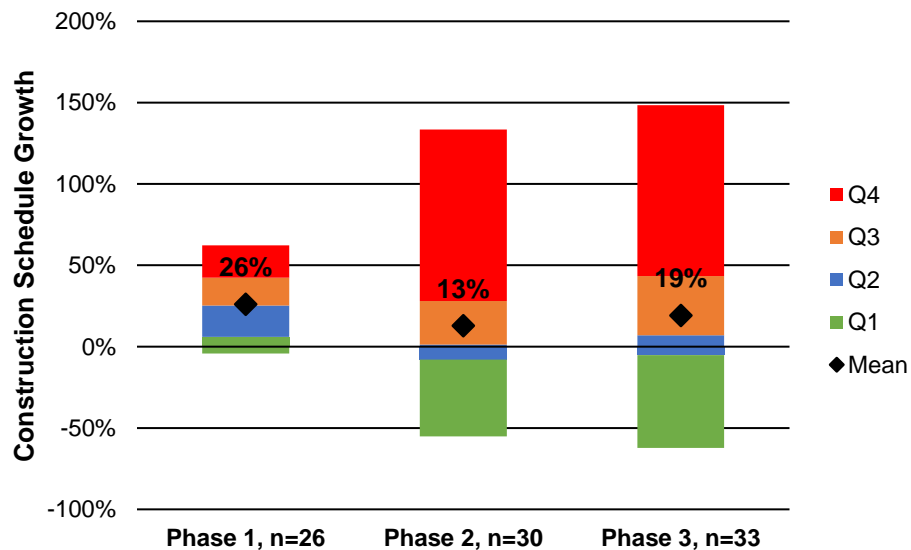


Figure 23: Construction Schedule Growth – Phase 1, 2, and 3

Figure 24 compares the Construction Schedule Growth of SAGD and Pipeline projects. The mean construction schedule growth for SAGD projects (15%) is higher than that of Pipeline projects (-2%). While Pipeline projects have a mean value that indicates projects finish earlier than planned, it is important to note that the range of construction schedule growth is also quite large (from -46% to 75%). In fact, half of Pipeline projects (Q3 and Q4) in this sample have a positive construction schedule growth.

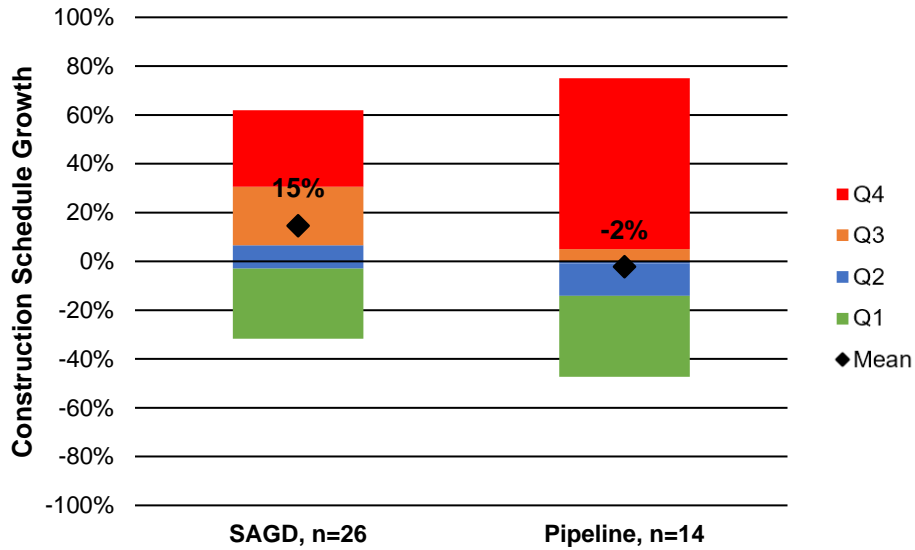


Figure 24: Construction Schedule Growth – SAGD and Pipeline Projects

In Figure 25 it can be seen that on average U.S. projects experience approximately 13% less schedule growth in construction than for Alberta (6% versus 19%). The range of construction schedule growth for Q2 and Q3 (representing half of projects in the sample) in the U.S. is also smaller (-4% to 17%) than that for Alberta (-4 to 38%).

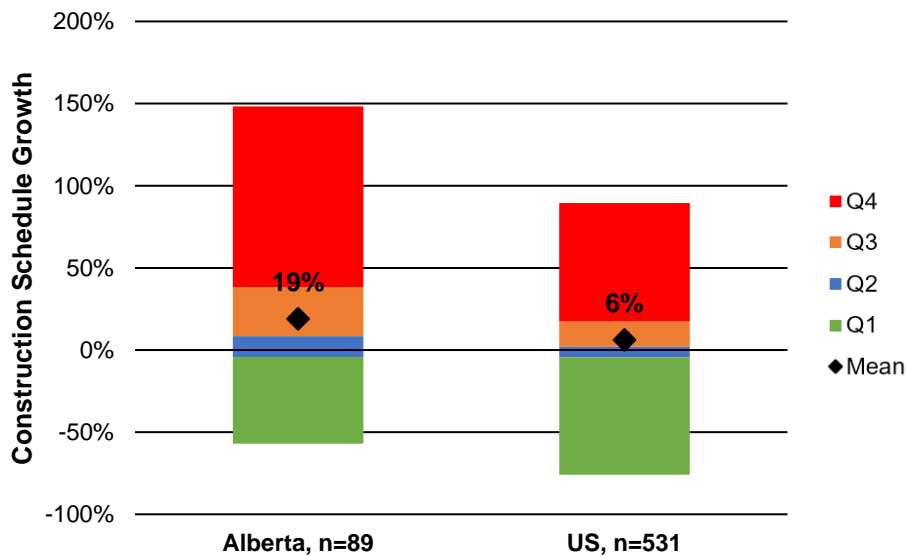


Figure 25: Construction Schedule Growth – Alberta and U.S. Projects

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 shows that on average, the Contingency percent has not changed from Phase 1 to Phase 3, however, the range of contingency is quite different in each phase. Phase 1 ranges from 3% to 13%, Phase 2 has the largest range from 1% to 17.5%, and Phase 3 has the smallest range from 5% to 14.5%.

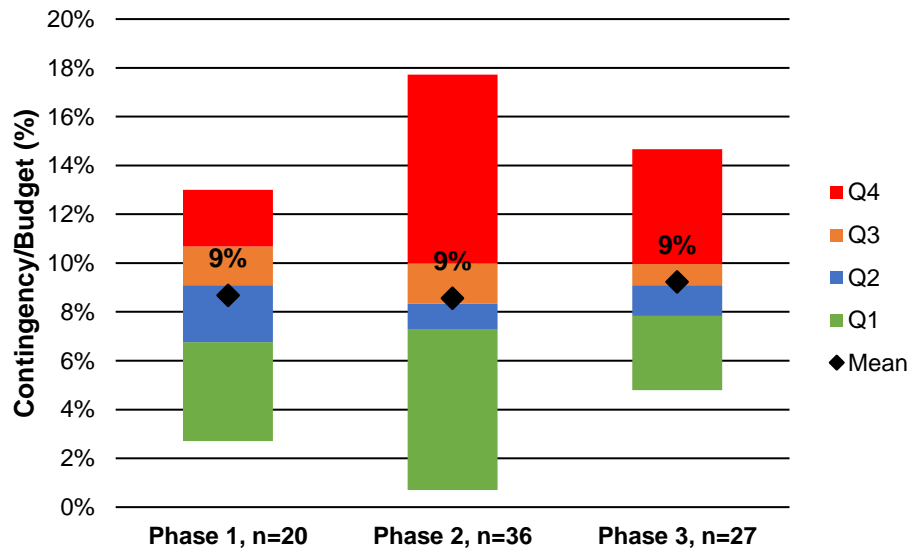


Figure 26: Contingency/Budget (%) – Phase 1, 2, and 3

Comparing the mean contingencies of SAGD (8%) and Pipeline (9%) projects in Figure 27 shows that a similar portion of funds are allocated for both project types.

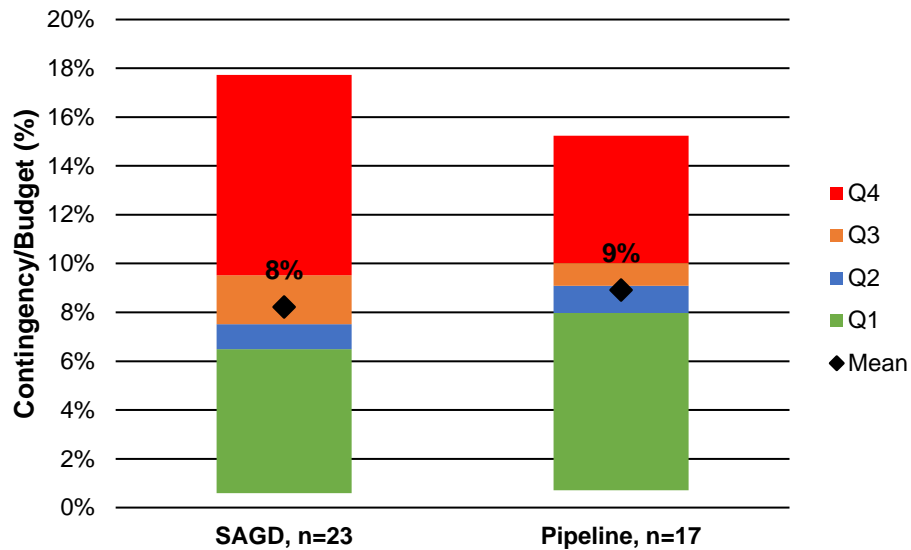


Figure 27: Contingency/Budget (%) – SAGD and Pipeline Projects

Figure 28 shows the percent of contingency allocated in for Alberta and U.S. projects. The mean percent of contingency allocated is similar between the Alberta (9%) and U.S. (8%) projects. The range of contingency percentage for Alberta projects is smaller, with the maximum contingency reached being 18% in Alberta as opposed to 25% in the U.S.

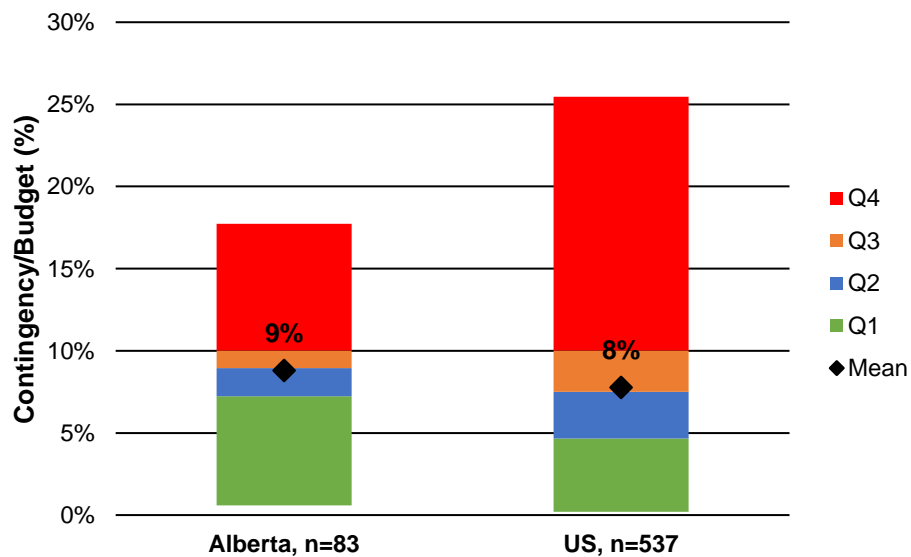


Figure 28: Contingency/Budget (%) – Alberta and U.S. Projects

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. The Percentage of Modularization is calculated as follows:

$$\text{Modularization} = \frac{\text{Cost of All Modules}}{\text{Total Installed Cost}}$$

The percentage of modularization on projects over the three phases is shown in Figure 29. Phase 3 contains a project with a much higher percent of modularization which, when removed, reduces the mean to 10%. This would then show a trend of decreasing modularization from Phase 1 (16%) to Phase 2 (11%) and Phase 3 (12%→10%). The low average percent modularization in Phase 3 can be attributed to a number of “electrical generating” and “other heavy industrial” projects which have 0% modularization. It is important to recall that the percentage of modularization may depend on the type of projects being executed, and therefore the averages in each phase could be influenced by the project composition of the sample.

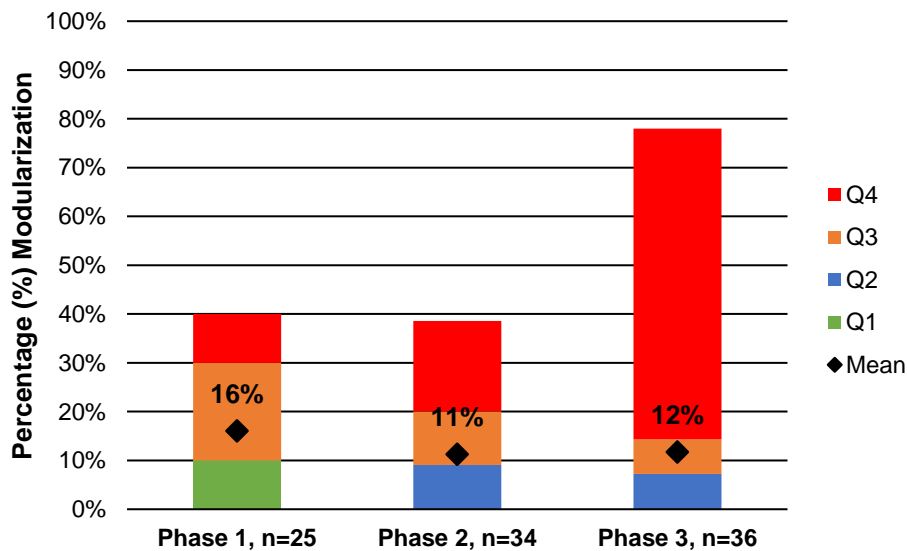


Figure 29: Percent Modularization – Phase 1, 2, and 3

Project Productivity Assessment

We present and discuss both engineering and construction productivity metrics and make comparisons between Alberta and U.S. projects, and between different types of projects in a similar manner to what was presented for project performance assessment metrics. 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 publication 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:

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

Engineering Productivity – Structural Steel

Figure 30 shows that U.S. projects used 6.2 engineering work hours/ton. Structural steel includes, for example, trusses, columns and girders, but excludes steel structures outside the physical boundaries of a major structure like pipe racks and utility bridges. As there are fewer than ten projects with data on structural steel engineering productivity, metrics for Alberta projects could not be produced.

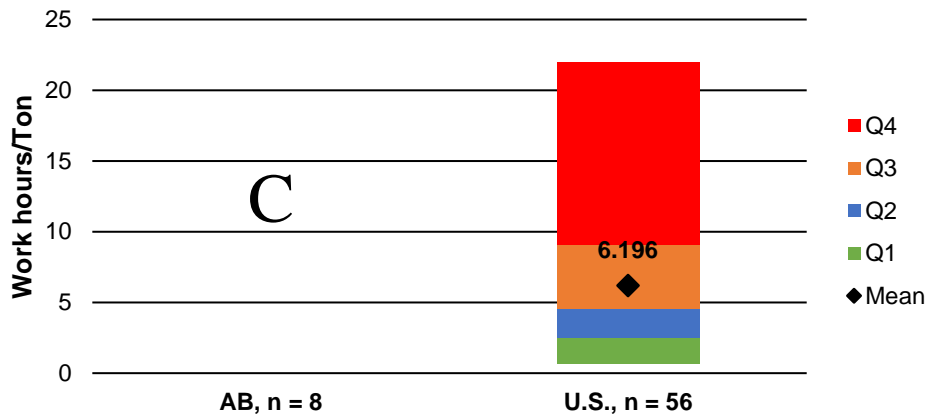


Figure 30: Structural Steel Engineering Productivity – Alberta and U.S. Projects

We can also assess engineering productivity for a combination of steel elements to create a customized steel metric. In Figure 31, we add engineering work hours per ton for pipe racks and utility bridges to the work hours for structural steel. Here we see approximately double the engineering work hours per ton for Alberta projects when compared to the U.S. – Alberta projects used 16.7 engineering work hours per ton of combined structural steel while U.S. projects only used 7.9 work hours per ton for the same work. The range of engineering work hours is similar for Alberta and U.S.

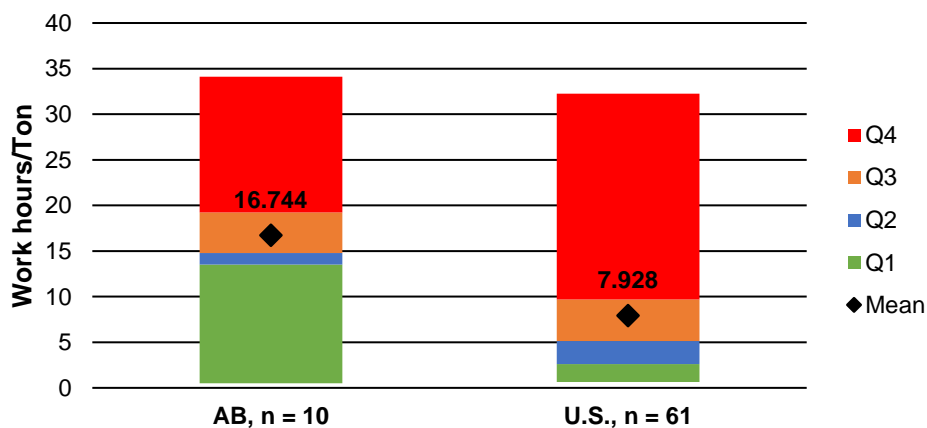


Figure 31: Combined Steel Productivity – Alberta and U.S. Projects

Engineering Productivity – Piping

In Figure 32 we see that engineering work hours per linear foot of piping is 23% higher for Alberta projects as compared U.S. projects. Alberta projects use 0.97 engineering work hours per linear foot of piping, while U.S. projects use only 0.80 engineering hours were required for the same work.

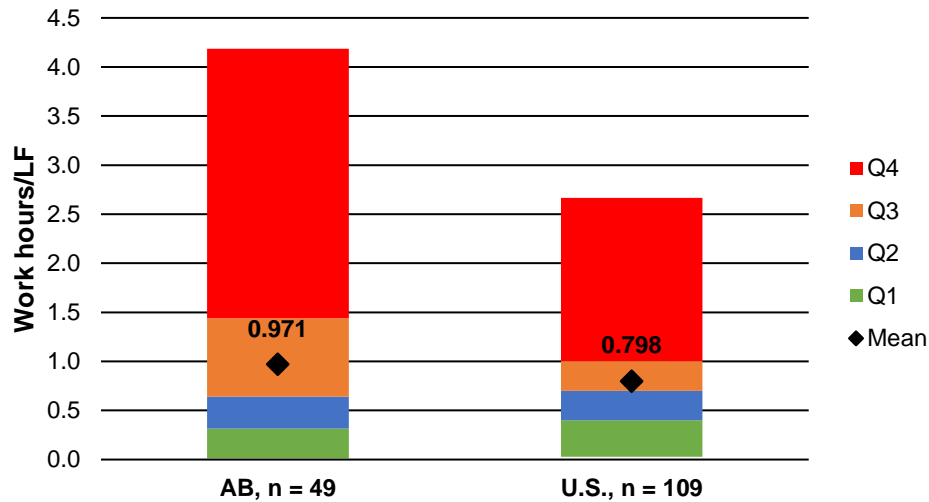


Figure 32: Piping Engineering Productivity – Alberta and U.S. Projects

For some disciplines, there is sufficient data to break out productivity for Alberta projects over all three phases. Figure 33 shows how engineering productivity for piping has changed in Alberta projects over the three phases. In Phase 1, Alberta projects required 0.68 engineering work hours per linear foot of piping. This increased to 1.21 engineering workhours per linear foot in Phase 2 and decreased slightly in Phase 3 to 1.12.

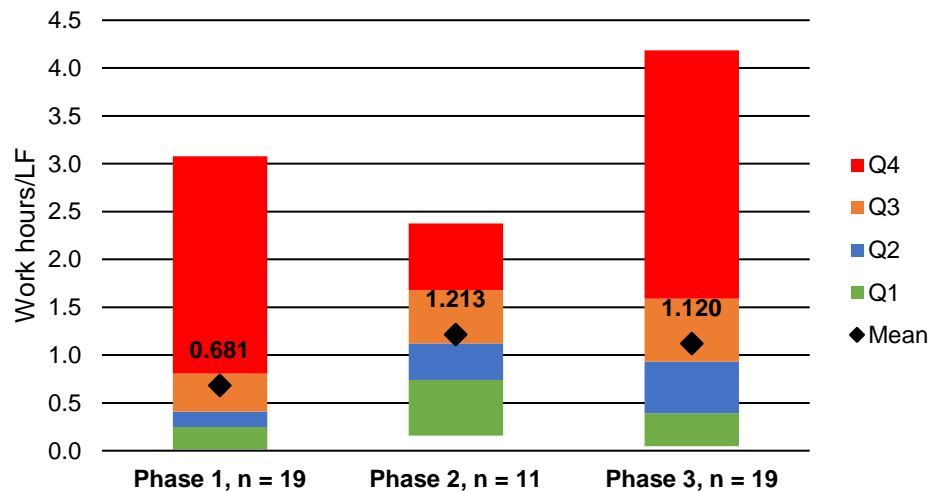


Figure 33: Piping Engineering Productivity – Phase 1, 2, and 3

When the metric in Figure 34 is restricted to only large bore piping, it can be seen that engineering work hours per linear foot of piping decrease for Alberta projects while they increase in for U.S. projects. Alberta projects use 0.24 engineering work hours per linear foot of large bore piping, while U.S. projects use 4.3x this amount (1.1 engineering work hours for the same work). No Alberta project required more than 1.0 engineering hour of work per linear foot of large bore piping, while some U.S. projects required more than 3.0 engineering work hours for the same work.

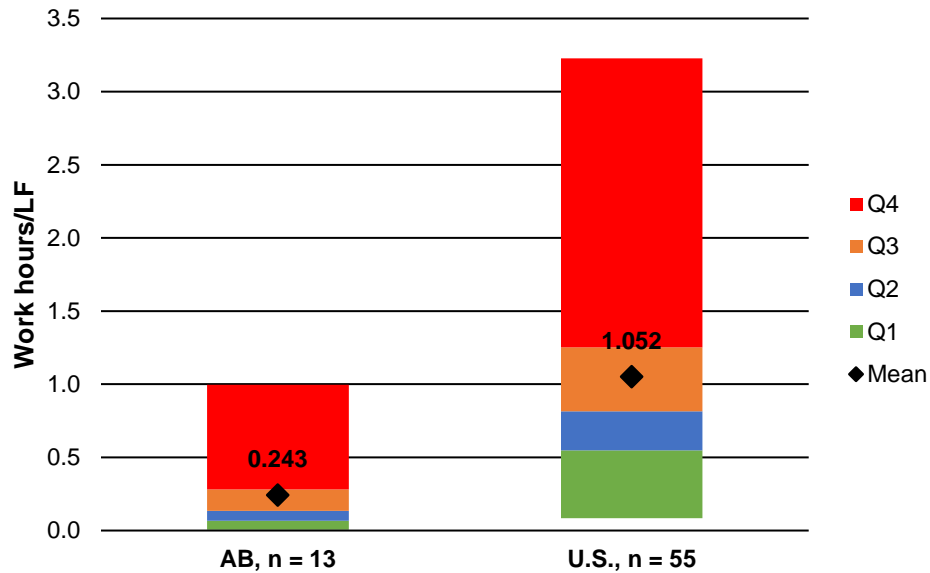


Figure 34: Piping (Large Bore) Engineering Productivity – Alberta & U.S. Projects

Engineering Productivity – Wire and Cable

Figure 35 shows that engineering work hours required per linear foot is much higher for Alberta projects than for U.S. projects. Alberta projects require 0.16 engineering work hours per linear foot of wire and cable, while U.S. projects require only 0.03 hours for the same work. This work includes the design of power, control and grounding cables.

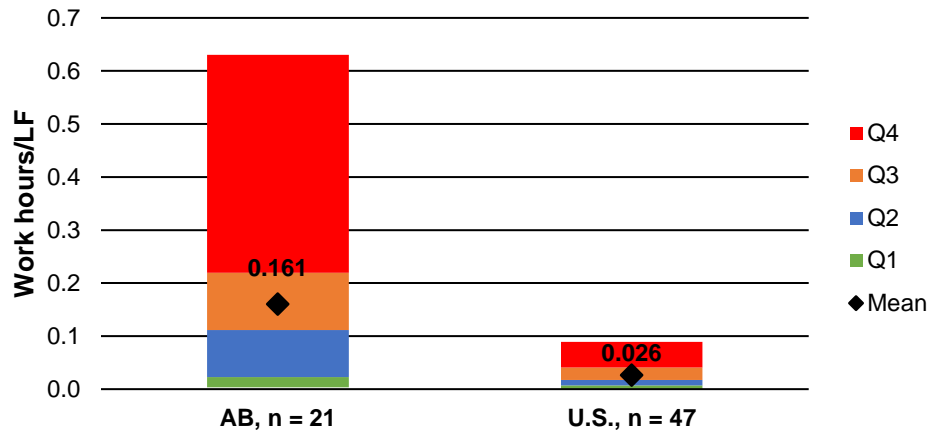


Figure 35: Wire and Cable Engineering Productivity – Alberta and U.S. Projects

Engineering Productivity – Equipment

As seen in Figure 36, Alberta projects require slightly more engineering work hours per piece of equipment than U.S. projects. Alberta projects required 158 work hours per piece of equipment while U.S. projects required 124 work hours. Despite these differences in averages, some Alberta and U.S. projects required over 600 hours of engineering work per piece of equipment. Like all engineering metrics, engineering work hours are reported per IFC quantity. Equipment is made up of all tagged items and vendor designed skids which are each counted as single items.

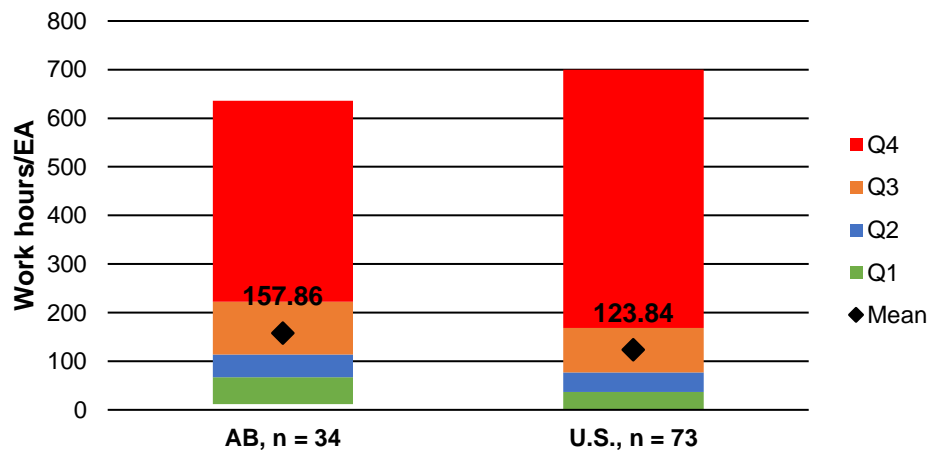


Figure 36: Equipment Engineering Productivity – Alberta and U.S. Projects

Construction Productivity Metrics

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:

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

Construction Productivity – Structural Steel

In Figure 37, structural steel requires more work hours to be installed for Alberta projects than for U.S. projects. Alberta projects require 52.7 work hours to install each ton of structural steel while this same work is accomplished in only 36.7 hours for U.S. projects. This work includes things like trusses, columns and girders, but excludes pipe racks, utility bridges and miscellaneous steel such as stairs, grating and miscellaneous platforms.

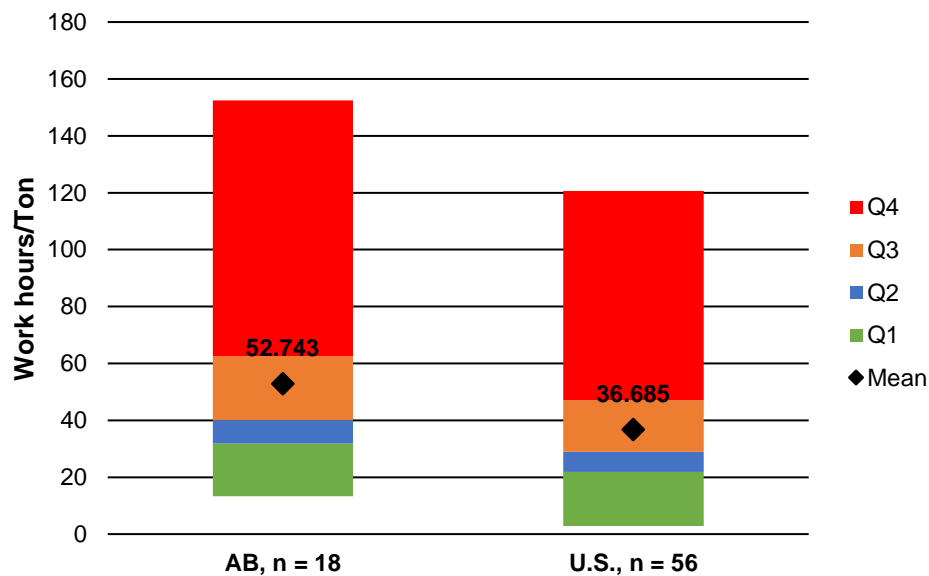


Figure 37: Structural Steel Construction Productivity – Alberta and U.S. Projects

Similar to engineering productivity, we can also assess construction productivity for a combination of steel elements to create a customized steel metric as shown in Figure 38. With the inclusion of work on pipe racks, utility bridges and miscellaneous steel, construction productivity for Alberta projects remains the same as for structural steel, while productivity for U.S. projects reduces by 15% compared to just structural steel. Alberta projects require, on average, 52.7 work hours per ton of total steel, while U.S. projects require only 42.3 hours for the same work. It is also of interest to note that 25% of both Alberta and U.S. projects require less than 27 hours of work per ton of total steel.

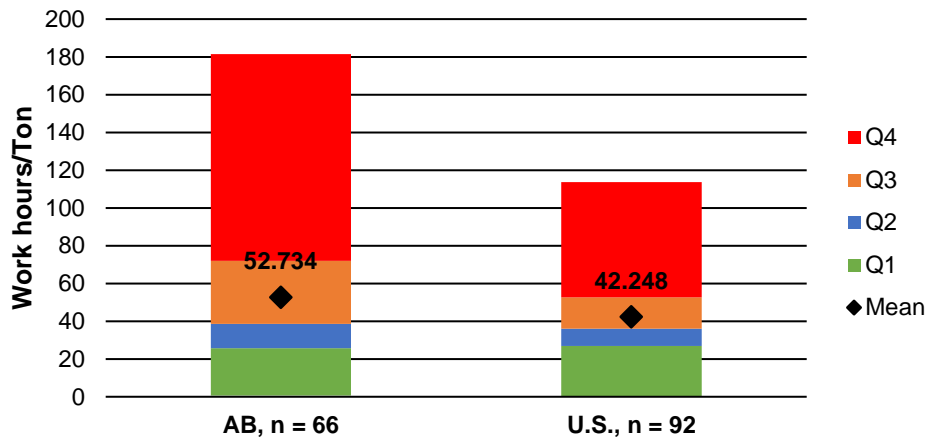


Figure 38: Total Steel Construction Productivity – Alberta and U.S. Projects

Figure 39 shows how construction productivity for total steel has changed for Alberta projects from Phase 1 to Phase 3. Total steel productivity changed from 49.0 workhours per ton of steel in Phase 1 to 61.7 workhours per ton in Phase 2. Productivity then improved in Phase 3, back to 48.7 workhours per ton (similar to Phase 1).

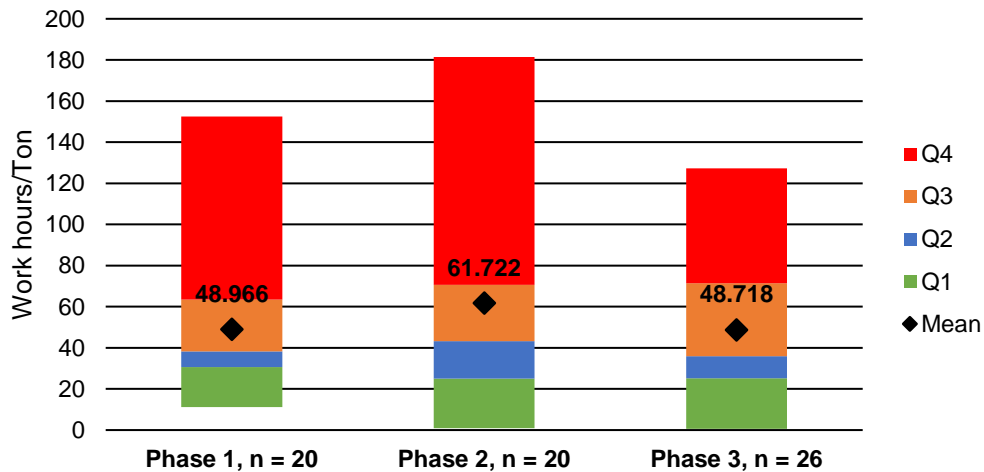


Figure 39: Total Steel Construction Productivity – Phase 1, 2, and 3

Construction Productivity – Piping

In Figure 40, construction productivity for Large Bore Piping inside the battery limits is slightly slower for Alberta projects when compared to U.S. projects. While some data was collected on the percentage of this piping that was shop fabricated and the weighted average diameter of piping, there is not enough information to make a useful comparison which might account for this difference. For both Alberta and U.S., some projects require over 13 hours per linear foot of piping while other projects only require less than 1 hour for the same work.

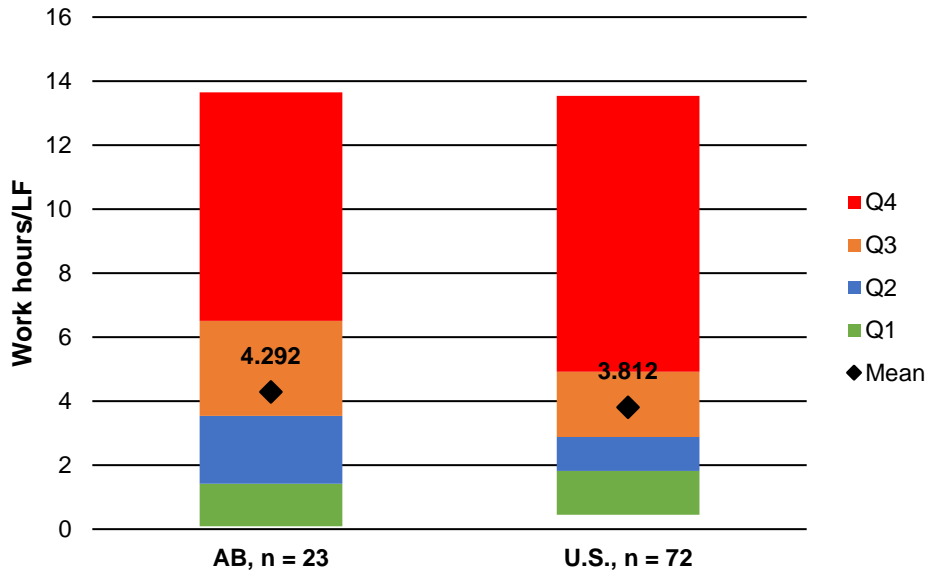


Figure 40: Total Large Bore Piping ISBL Construction Productivity Alberta and US Projects

Construction Productivity – Concrete

As seen in Figure 41, Alberta and U.S. projects have similar construction productivity in terms of work hours required for each cubic yard of concrete installed. Some U.S. projects required over 35 hours of work per cubic yard of concrete installed which is at least 10 hours more than even the least efficient Alberta project. Also, it appears that 25% of Alberta and U.S. projects required less than 5 work hour per cubic yard of concrete installed.

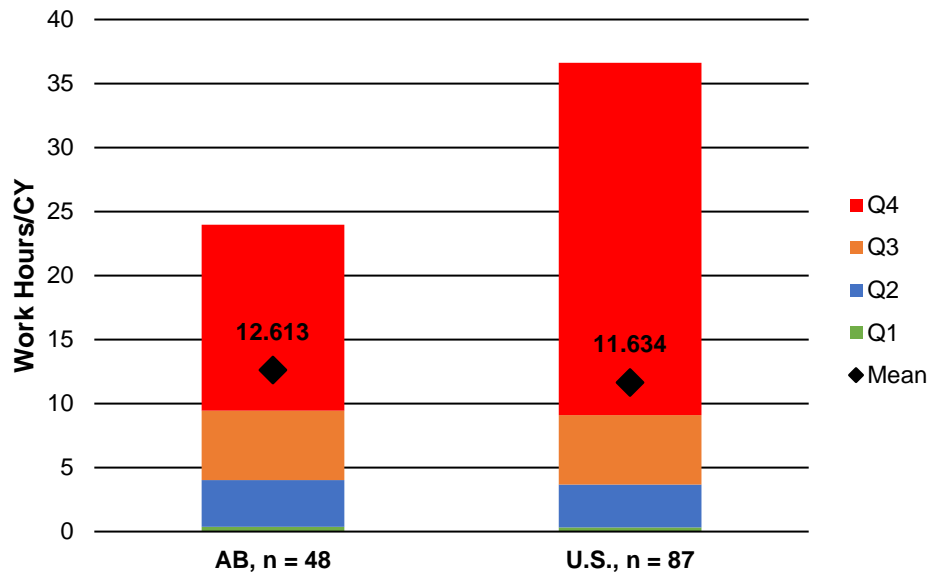


Figure 41: Concrete Construction Productivity – Alberta and U.S. Projects

Figure 42 shows that for Alberta projects there was an improvement in concrete productivity from Phase 1 (14.4 Whrs/CY) to 2 (11.2 Whrs/CY), and a slight decrease in productivity from Phase 2 (11.2 Whrs/CY) to 3 (12.5 Whrs/CY).

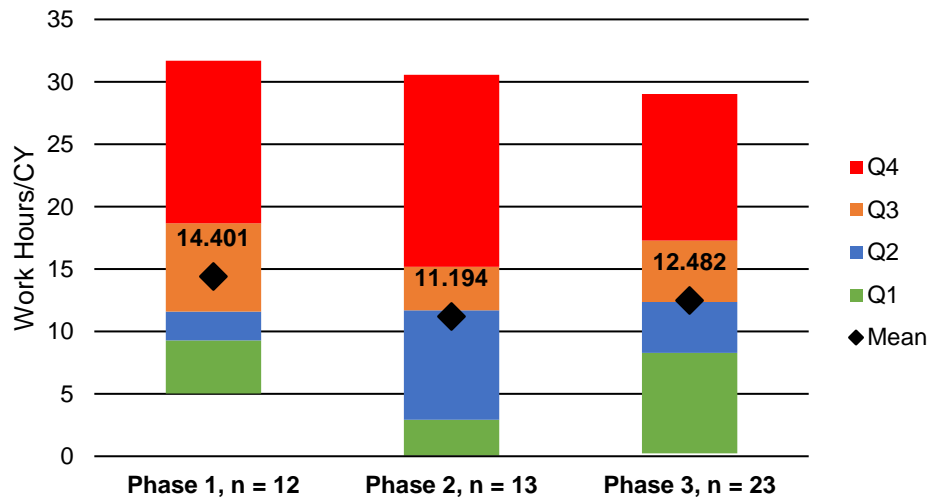


Figure 42: Concrete Construction Productivity – Phase 1, 2, and 3

Construction Productivity – Insulation (Piping)

Figure 43 demonstrates that Alberta and U.S. projects have similar construction productivity for work hours required per linear foot of piping insulation. The most labour intensive 25% of projects required between 1-3 work hours per linear foot of piping insulation in both Alberta and U.S. projects.

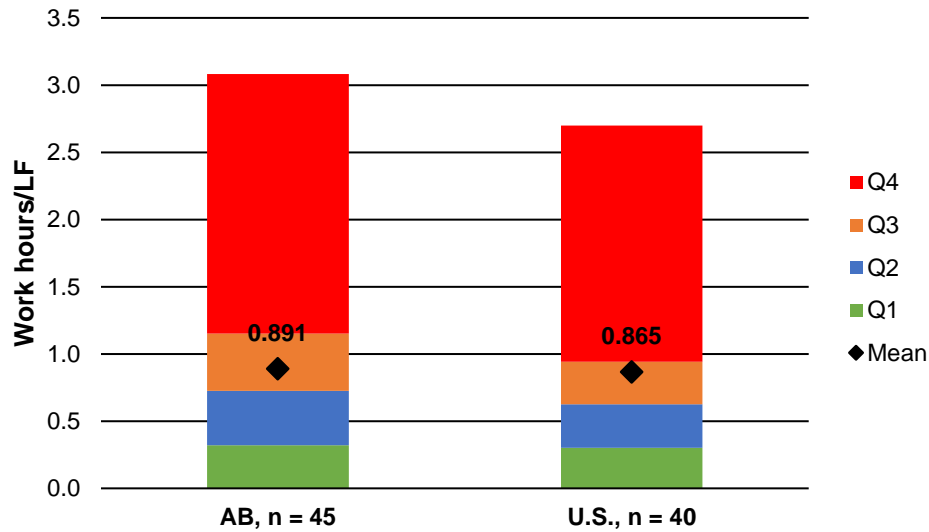


Figure 43: Insulation (Piping) Construction Productivity – Alberta and U.S. Projects

Figure 44 shows that for Alberta projects there is a consistent decrease in piping insulation productivity from Phase 1 to 3, with projects in each subsequent phase requiring more workhours per linear foot.

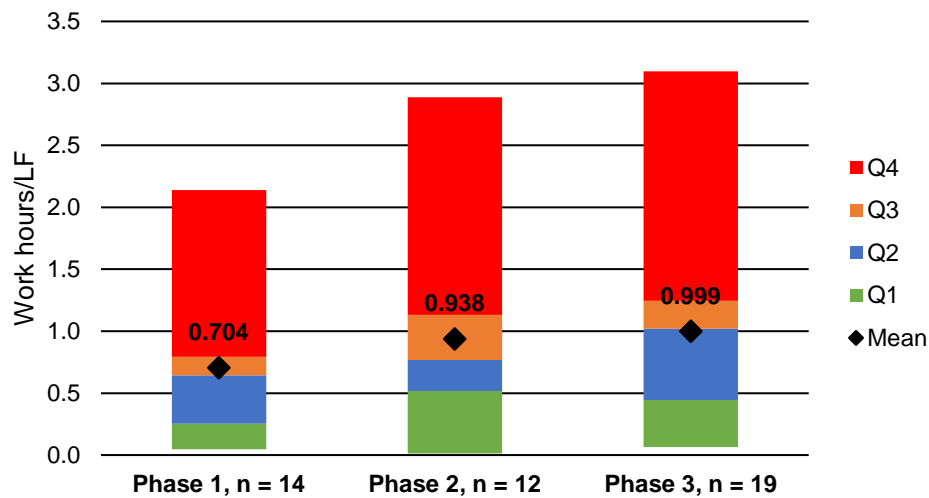


Figure 44: Insulation (Piping) Construction Productivity – Phase 1, 2, and 3

Construction Productivity – Electrical Equipment

In Figure 45, Alberta projects require more hours to install each piece of electrical equipment than U.S. projects. This work includes all labour for the installation of transformers, switchgears, UPS systems and other electrical equipment. Some Alberta and U.S. projects require as low as 5 work hours per piece of equipment or greater than 300 hours.

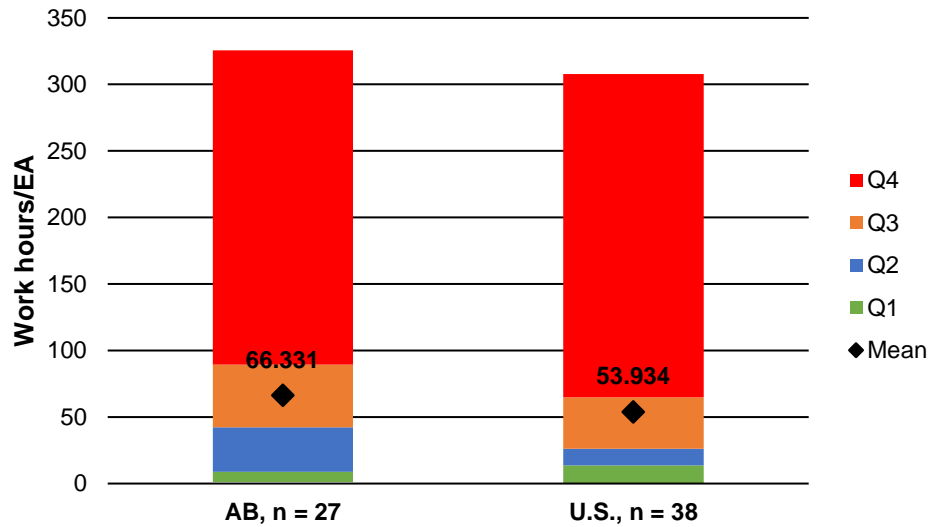


Figure 45: Electrical Equipment Construction Productivity – Alberta & U.S. Projects

Construction Productivity – Instrumentation Devices

Figure 46 shows that Alberta projects require more work hours to install instrumentation devices than U.S. projects. Additionally, some Alberta projects required over 80 hours to install instrumentation devices while no U.S. project required over 40 hours. Some highly efficient projects saw work on installing each instrumentation device take as little as 3-7 hours.

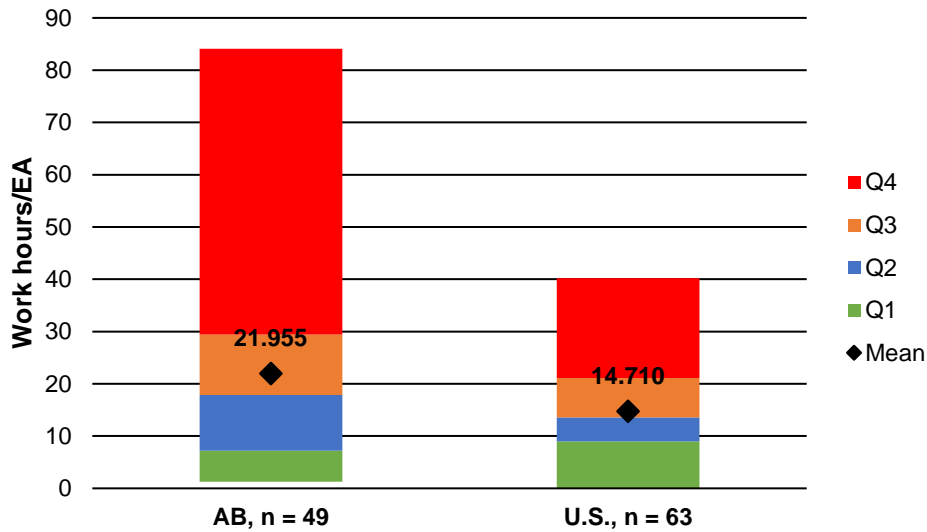


Figure 46: Instrumentation Devices Construction Productivity – Alberta and US Projects

Figure 47 shows that for Alberta projects there is a consistent decrease in instrumentation device installation productivity from Phase 1 to 3, with projects in each subsequent phase requiring more workhours per device installed.

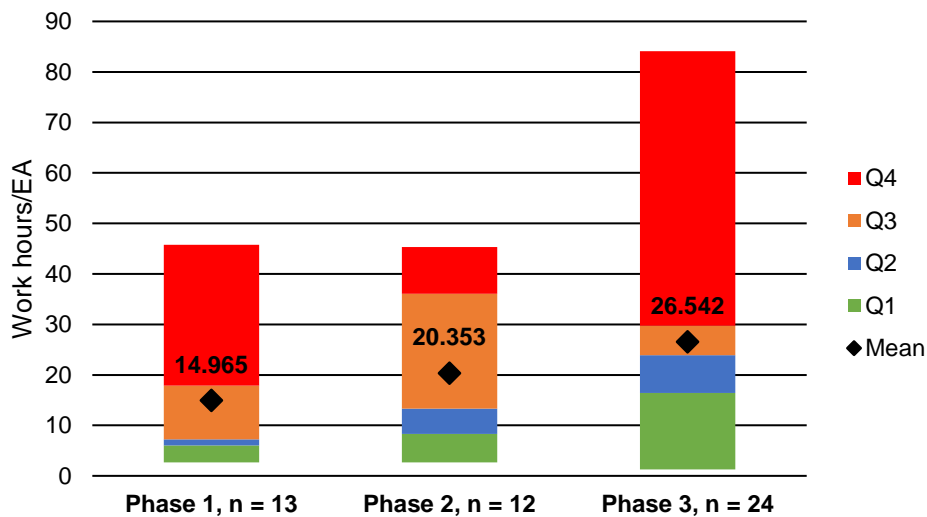


Figure 47: Instrumentation Devices Construction Productivity – Phase 1, 2, and 3

Construction Productivity – Cable Tray

It can be seen in Figure 48 that the installation of cable trays is faster for Alberta projects than for U.S. projects. Some Alberta and U.S. projects saw each linear foot of cable tray take as little as 0.1 hours or as much as 3.8 hours. 75% of Alberta projects installed cable tray faster than 1.0 work hours per linear foot.

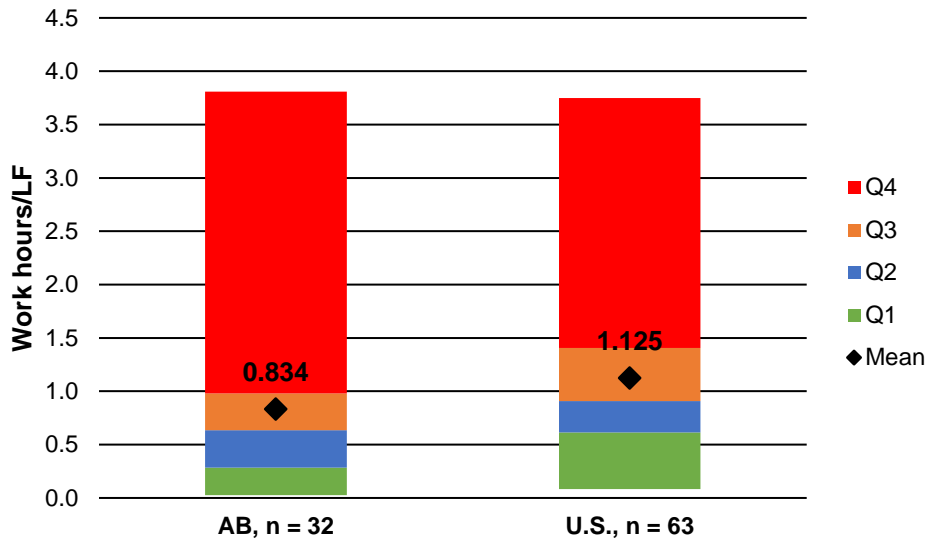


Figure 48: Cable Tray Construction Productivity – Alberta and U.S. Projects

Construction Productivity – Wire and Cable

Figure 49 shows that the installation of wire and cable is much slower for Alberta projects (0.233) than for U.S. projects (0.066).

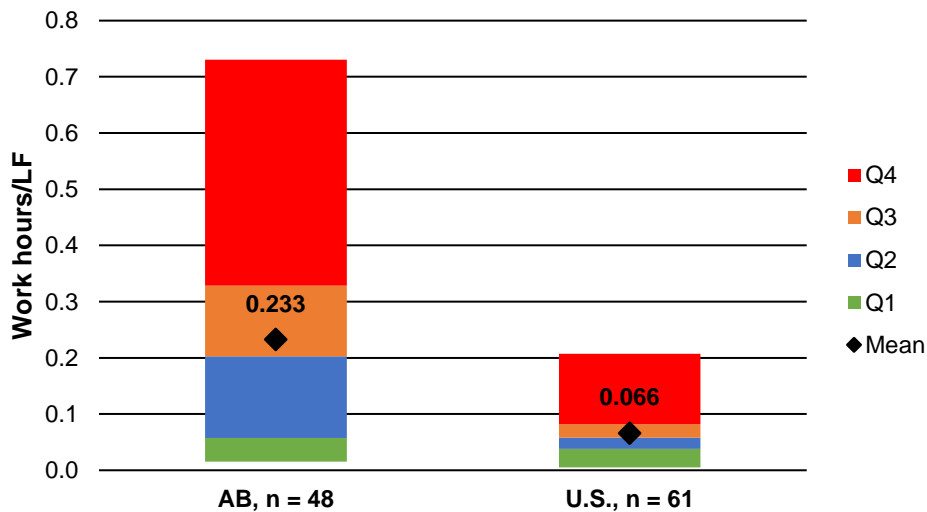


Figure 49: Wire and Cable Construction Productivity – Alberta and U.S. Projects

Construction Productivity – Electrical Heat Tracing

Figure 50 shows that for the same quantity of electrical heat tracing, Alberta projects required 3.5x more hours than U.S. projects. 25% of Alberta projects required over 2.2 hours to install each linear foot of electrical heat tracing while no U.S. project required over 1.8 hours for the same work.

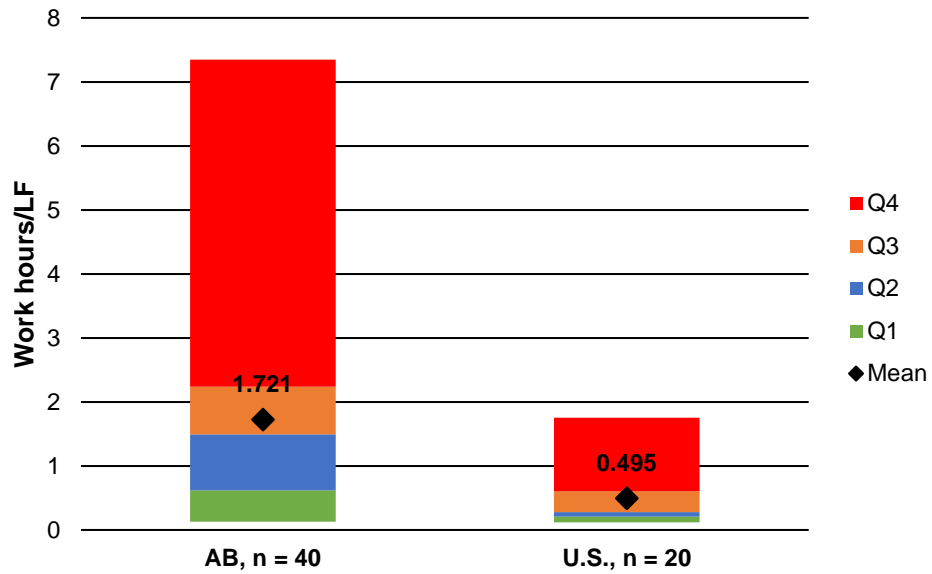


Figure 50: Electrical Heat Tracing Construction Productivity – Alberta and U.S. Projects

Construction Productivity – Scaffolding

In Figure 51 it can be seen that Alberta projects require approximately twice as many work hours on scaffolding as U.S. projects. For some Alberta projects, up to 40% of the construction work hours may be used for scaffolding work. Note that projects without any scaffolding work were excluded from this analysis.

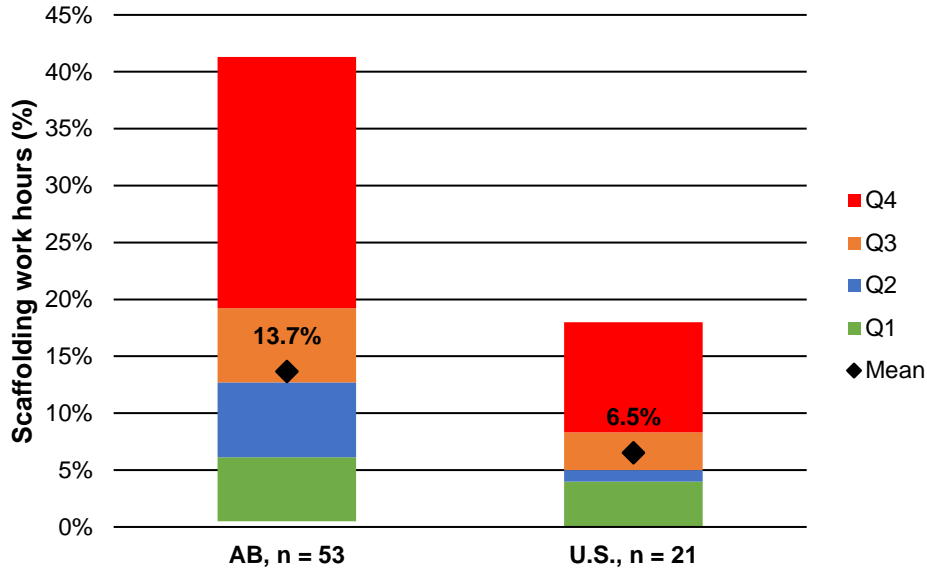


Figure 51: Scaffolding Construction Productivity – Alberta and U.S. Projects

Figure 52 shows that for Alberta projects there is a consistent increase in the percentage of work hours required for scaffolding from Phase 1 (11.9%) to Phase 3 (15.4%).

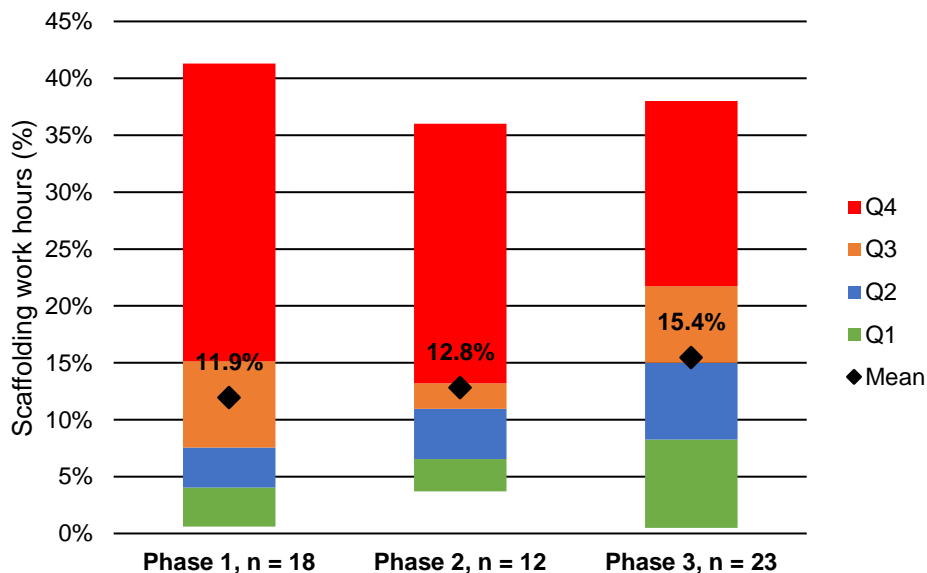


Figure 52: Scaffolding Construction Productivity – Phase 1, 2, and 3

Construction Indirect and Direct Work Hours

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 specific engineering and construction work activities as direct and indirect (Appendix C) to assist participating COAA members to input project work hours that are consistent from project to project allowing for valid comparisons to be made.

As shown in Figure 53, for Alberta projects the average ratio of indirect to direct work hours is 37%. This information was not collected on U.S. projects. For some Alberta projects, the number of indirect hours closely approached the number of direct work hours with the largest amount being around 90% of direct work hours.

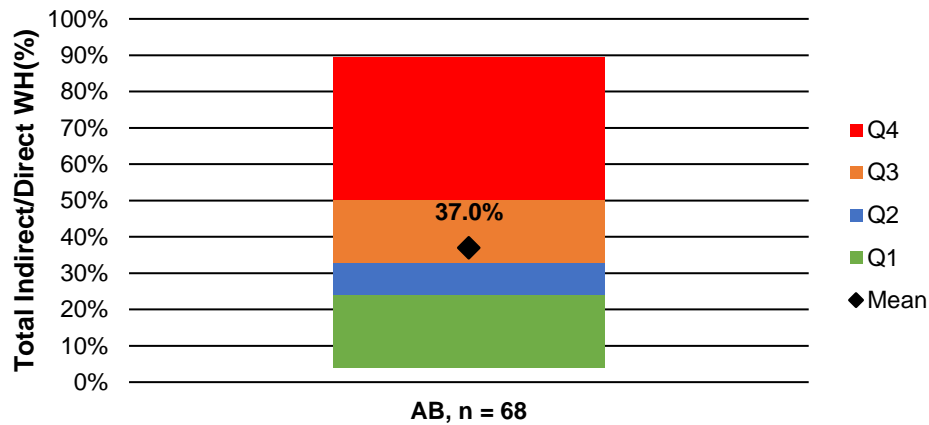


Figure 53: Construction Indirect and Direct Work Hours - Alberta Projects

Figure 54 shows that for Alberta projects there is a consistent increase in the percentage of total indirect to direct workhours from Phase 1 (34.4%) to Phase 3 (38.5%).

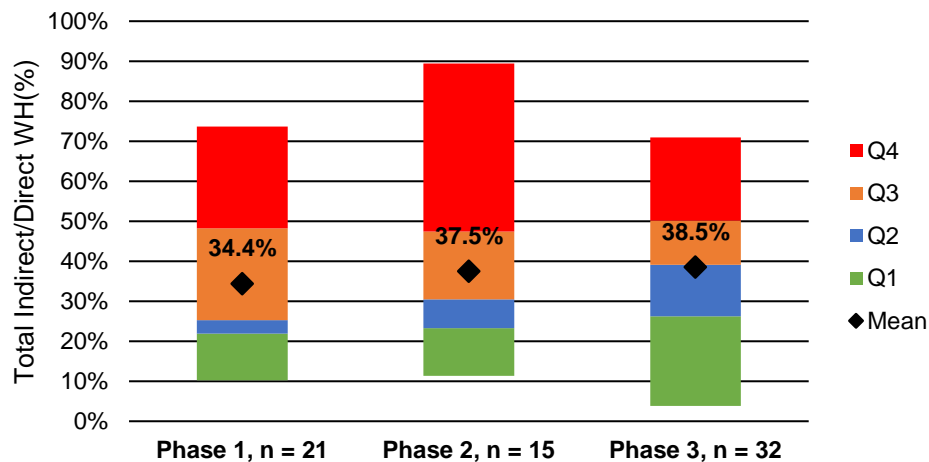


Figure 54: Construction Indirect and Direct Work Hours – Phase 1, 2, and 3

Conclusions and Recommendations

Numerous global and national forces continue to dramatically alter the worldwide marketplace for energy. These forces have led to significant annual fluctuations in the amount of investment and project activity in Alberta surrounding oil sands and other energy resources. Some Owner companies have accelerated the development of specific energy projects while others have delayed, modified or completely abandoned projects. In light of all these challenges, the COAA Performance Assessment System (PAS) is still able to objectively quantify the performance of observed projects.

Project characteristics summarized in the report, such as project size, nature and delivery method underwent some changes over the three phases. Phase 3 indicated a shift towards larger projects which reversed the trend towards smaller projects seen in Phase 2. The projects submitted during Phase 3 indicate that 68% of these projects are greenfield while projects submitted during Phase 2 indicate that many were additions and brownfield. Delivery methods also changed in Phase 3, with the majority of projects being Parallel Prime and Design-Build. This may have been influenced by the challenges that projects continue to face. Cost reimbursable continues to be the preferred contract type with a small number of contracts being lump sum.

The cost and schedule performance of projects were also shown for Phases 1, 2, and 3. A comparison of project performance and productivity metrics of the two most recent phases is shown below in Figure 55.

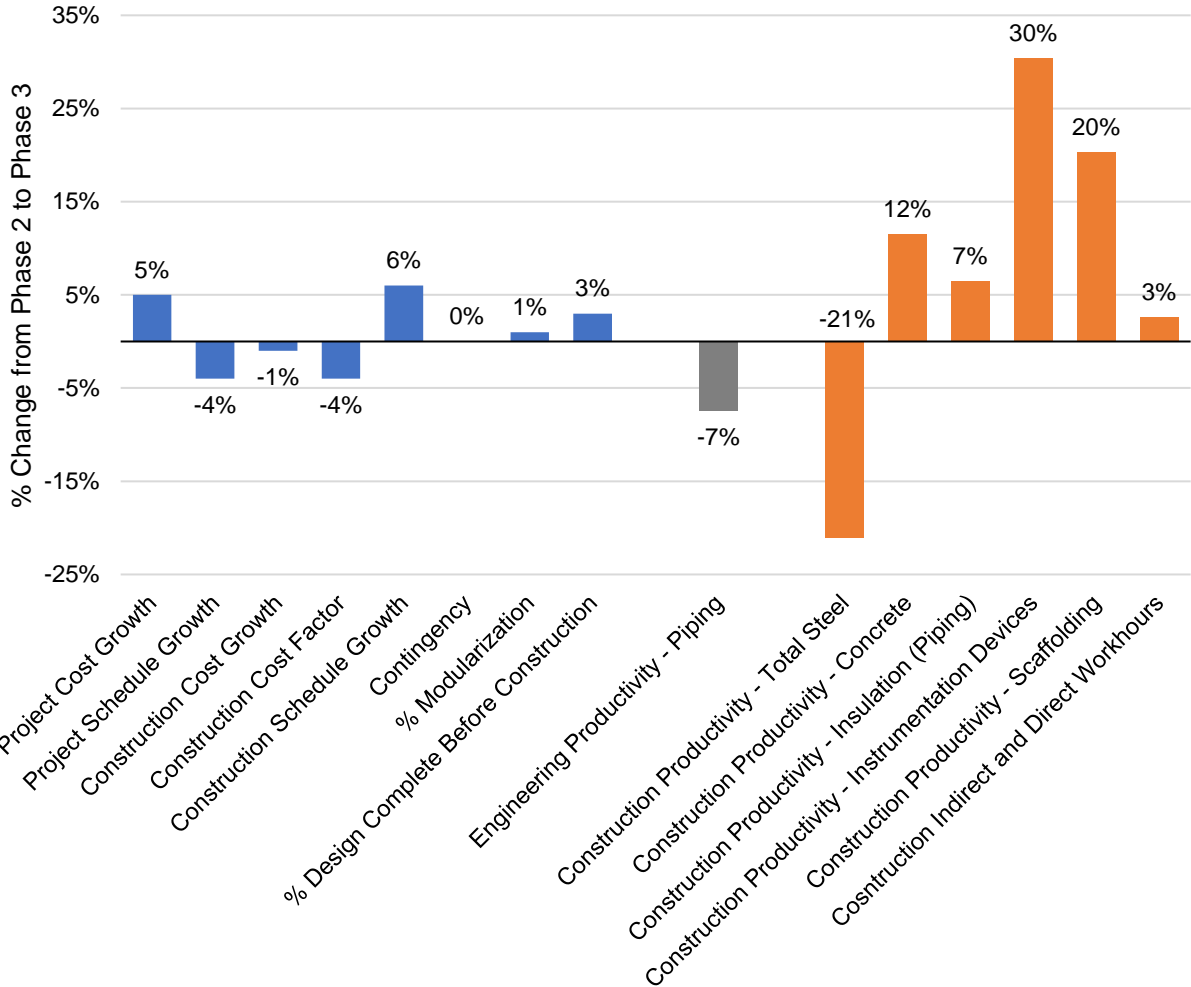


Figure 55: Performance and Productivity Changes - Alberta Phase 2 to Phase 3

The data shows that project schedule performance has improved in Phase 3. The overall project cost growth has increased since Phase 2 but is still considerably lower than that of Phase 1. The increase in cost growth from Phase 2 to Phase 3 may be influenced by the higher proportion of large projects in Phase 3 compared to Phase 2. Interestingly, construction cost growth and the average construction cost factor has decreased over time.

The decrease in construction cost growth may be linked to the increase in amount of engineering design complete before construction (54% in Phase 1 to 66% in Phase 3). This trend of higher engineering design complete indicates that more emphasis is being placed on finishing a greater portion of engineering design prior to the start of construction. As shown in Figure 22 of this report, the recommended percentage of detailed engineering for minimal construction cost growth is between 80% to 90% design complete prior to construction start.

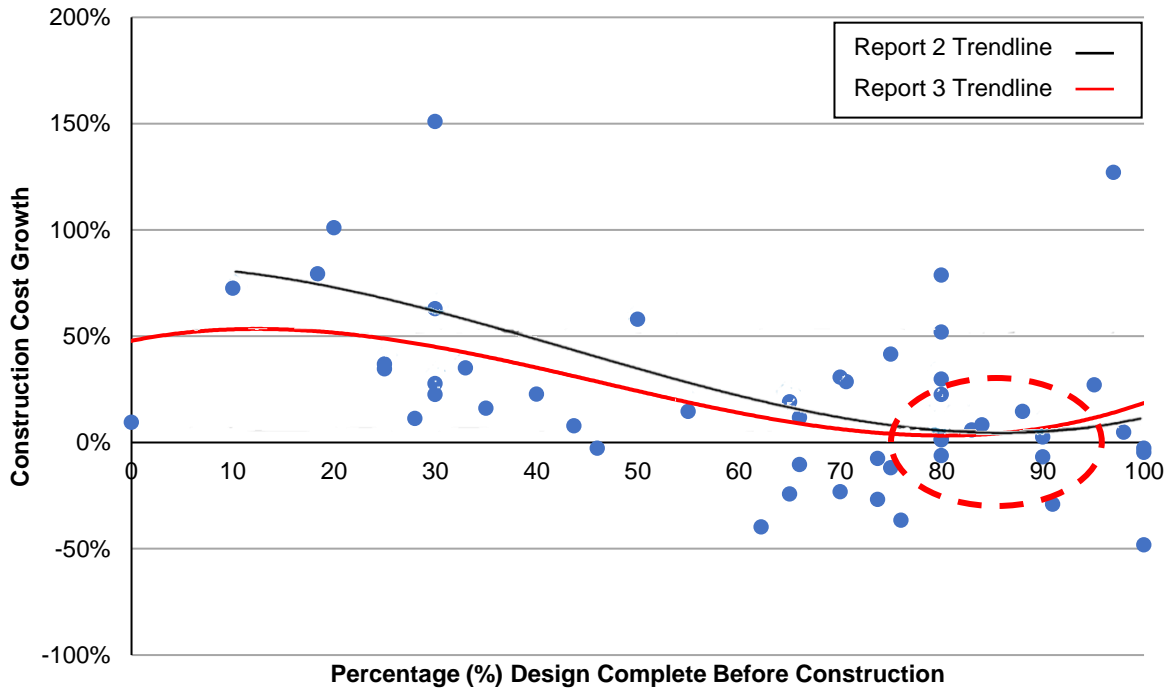


Figure 22 (Repeat): % Design Complete before Construction Start

While the trends from Phase 1 to Phase 3 indicate a general improvement in cost and schedule performance, there is still opportunity for further savings in cost and schedule. Industry professionals involved in project execution should watch for early warning signs such as:

- Delays in early schedule milestones without adjustment to the final completion date, resulting in the fast-tracking of already fast-tracked projects
- Large number of scope changes and extras without proper adjustment of the schedule
- The fast rate at which contingencies and allowances are consumed during execution

There are many studies and reports investigating factors impacting project performance and actions that can be taken to improve project performance. The findings of some of these studies are summarized in “Performance Challenges of Mega Capital Projects” (Jergeas and Lozon, 2014). The findings emphasize the importance of leadership, governance, stakeholder alignment, comprehensive front-end planning, strong cost and schedule monitoring and control, interface management, proper management of engineering, clear scope definition.

Given the anticipated number of planned projects in Alberta over the next number of years and high expectations from project sponsors, the proper estimation and control of project cost and schedule remains paramount. As such, project sponsors are encouraged to consider a stronger

risk management program which includes proper contingencies, scope allowances, and management reserves added to the project estimate among other measures.

With regards to the construction productivity of Alberta projects, the data shows a decrease or consistent level of productivity over the three phases. When compared to projects in the U.S., productivity for Alberta projects is typically lower (more time spent per unit), though for some disciplines the difference is minor. Due to the decreasing productivity of Alberta projects and continued differences in performance between Alberta and U.S. projects, further review and analysis of the root causes of these trends should be studied. Learning from other projects can be an efficient and effective way to identify areas for improvement. To improve project performance, lessons learned processes should be institutionalized by changing existing policies, standards, specification and procedures.

The assessments of project performance, engineering, and construction productivity presented in this report demonstrate the capability of the benchmarking process to identify areas for improvement that participating COAA members can address as they develop and execute future projects. The oil and gas industry in Alberta is capable of developing a new strategy to improve project predictability. As discussed in a report by Lynch and Jergeas (2014), an approach that addresses the entire system and multiple success criteria is required as opposed to addressing individual pieces of the problem. This new approach must be studied and developed through new collaborations between academia and industry, and by building on previous collaborations between the University of Calgary, CII, and COAA.

Project performance assessment over the last fifteen 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 continue benchmarking efforts. There is ample reason to predict that tomorrow's projects will perform much better than those executed today.

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). 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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Participating COAA Members

Bantrel Constructors	Imperial Oil	Shell Canada Ltd.
Capital Power	Jacobs Engineering	StatOil
Cenovus	JV Driver Group	Suncor Energy Inc.
ConocoPhillips Canada Ltd.	Nexen Energy ULC	Supreme Steel
Enbridge Inc.	North West Redwater Partnership	Syncrude Canada Ltd.
Fluor	NOVA Chemical Corporation	Teck Resources

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Further reading on metrics definitions, the data collection instrument, and CII/COAA benchmarking can be found at:

<https://www2.construction-institute.org/nextgen/learn.cfm>

Appendices

Appendix A: 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 heavy industrial 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 26 years of experience in benchmarking capital project delivery and best practices. Today, there are 144 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. Over the years, an online benchmarking system 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.

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.

In this study, the responsibilities of CII included:

- 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 2019, 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 3 Benchmarking Project in September 2016 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 2019, the U of C has trained over 240 Benchmarking Associates (participating COAA members).

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

In addition to this report, this collaboration resulted in a number of studies conducted by the University of Calgary on topics related to:

- Pipeline projects
- SAGD projects
- Well Site and Well Pad projects
- Benchmarking techniques
- Impact of Best Practices on Cost and Schedule Performance
- Factors Impacting Project Performance of Heavy Industrial Projects

A highlight of the two studies conducted in Phase 3 under the supervision of Dr. Farnaz Sadeghpour and Dr. George Jergeas can be found in Appendix D.

Participating COAA Members

There are currently 18 participating COAA members who provide project data for the COAA PAS. These industry partners include Owner organizations (industrial and pipeline) and Contractor organizations.

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

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.

Percent 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 constructor.

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: Construction and Engineering Direct and Indirect Work

Construction

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

Engineering

Direct	Indirect
Discipline Engineer	Document Control
Designer	Reproduction Graphics
Technician	Project Management
	Project Controls (cost/schedule/estimating)
	Project Engineer
	Secretary/clerk
	Procurement (supply management)
	Quality Assurance
	Accounting and Legal
	Construction Support

Appendix D: Research Conducted at University of Calgary

In addition to this report, the collaboration between COAA and the research team at the University of Calgary resulted in a number of research projects. A highlight of the two studies conducted in Phase 3 are brought below. These projects have emerged directly from research collaboration between University of Calgary and COAA on Benchmarking Heavy Industrial Projects in Alberta under the supervision of **Dr. Farnaz Sadeghpour** and **Dr. George Jergeas** at the Center for Project Management Excellence at University of Calgary. Research interest and inquiries can be directed via email to farnaz@ucalgary.ca and jergeas@ucalgary.ca.

The researchers would also like to acknowledge the support of Natural Sciences and Engineering Research Council of Canada (NSERC) in this project.



Impact of Best Practices on Cost and Schedule Performance

Lead Researcher: **Mihai Robu**, University of Calgary

One of the areas of research conducted by the University of Calgary is on the impact of Best Practices (as defined by CII) on project performance in terms of cost and schedule. Statistical analysis was conducted on 1,015 heavy industrial projects from Canada and the United States to determine: 1) if the impact of Best Practices is different across project phases; and 2) the magnitude of the impact of each Best Practice on phase cost and schedule. Pairwise inferential tests were used to determine if the relationship between Best Practices and phase cost and schedule performance are statistically significant. It was found that Best Practices impacted different phases differently. This could be due to the different nature of activities conducted in each phase.

Tables 3 and 4 below summarize the findings of this study and show the impact of Best Practices on the Cost Growth and Schedule Growth of the 5 phases of a project: Front-End Planning, Detailed Engineering, Procurement, Construction, and Commissioning. In Table 3, for example, projects which invited contractors and consultants to participate in front-end planning (Front-End Participation) on average had 7.8% less cost growth than projects that did not. The last column (Weighted Magnitude) weighs the magnitude by the cost factor of each phase in order to rank the overall impact of each Best Practice. Overall, cost performance can benefit most from the implementation of **scope definition, partnering agreements, and risk mitigation**.

Table 3: Impact of Best Practices on Cost Growth of Phases

Best Practice	Phase					Weighted Magnitude
	FEP	ENG	PRO	CON	COM	
Front-End Participation		-7.8 %				-1.0 %
Scope Definition		-15.9 %	-27.8 %			-11.2 %
Partnering Agreement			-11.5 %	-17.0 %		-11.5 %
Team Building		-3.9 %				-0.5 %
Risk Mitigation				-26.8 %		-12.2 %

On the other hand, schedule performance (Table 4) can see the most overall improvement from the implementation of **scope definition**, **risk assessment**, and a documented and well understood **change management plan**.

Table 4: Impact of Best Practices on Schedule Growth of Phases

Best Practice	Phase					Weighted Magnitude
	FEP	ENG	PRO	CON	COM	
Front-End Participation	+10.6%	-9.5%			-12.0%	-1.9 %
Scope Definition				-39.7%		-16.8 %
Partnering Agreement				-13.9%		-5.9 %
Team Building	+6.7%	-7.5%				-1.0 %
Risk Assessment				-29.4%		-12.4 %
Constructability Plan			-11.0%			-4.8 %
Change Mgmt Documented		-27.6%		-18.3%		-18.4 %
Change Mgmt Understood				-14.4%		-6.1 %

The highest impacting practices for cost and schedule performance were proper scope definition, risk management, change management plans, and partnering agreements. These findings support the recommendations of this report which encourage proper planning and scope definition, and risk management which can aid in the allocation of sufficient contingency. Further details and findings can be found in Robu et al. (2018), Robu et al. (2019), and Robu (2019)

Factors Impacting Cost Growth of Heavy Industrial Projects

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Further research was conducted by the University of Calgary on other factors that may influence the cost growth of heavy industrial projects in Alberta. The effect of different factors on cost growth was compared between projects in Alberta and the United States to see if the effect of some factors is more pronounced in Alberta. The research determined the size and direction of this impact using correlation analysis and two-way ANOVA tests. These inferential statistical methods determine where the relationship is statistically significant, meaning that the relationship is supported by a commonly accepted amount of evidence.

Table 5 and Figure 56 below summarize the findings of this study and show the impact of factors on the cost growth of heavy industrial projects in Alberta and the United States. This work studied the impact of nine variables, namely project budget, planned construction duration, complexity, timeliness and accuracy of engineering deliverables, the percentage of engineering complete before authorization and construction, contract type, and project nature on cost growth. In Table 5 it can be seen that **larger, longer and more complex projects** have higher cost growth in Alberta, but not the United States. **High quality engineering done before construction** reduces cost growth in Alberta, but not in the United States. Figure 56 shows that **Cost Reimbursable, greenfield** projects have higher cost growth in Alberta, but these factors don't impact cost growth in the United States. These results show that in general, the analyzed variables have a much higher impact on projects in Alberta while projects in the United States have relatively low cost growth in all scenarios. While cost growth is higher in Alberta, this study can shed light on the ways that project teams can effectively reduce cost growth on these projects.

Table 5: Impact of Various Factors on Cost Growth in Alberta and the United States

Factor	Alberta		United States	
	r	n	r	n
Budget amount	0.27*	92	0.02	812
Planned Construction Duration	0.54*	64	0.05	518
Complexity	0.26*	92	0.09*	638
Eng. Deliverables Timely	-0.47*	61	-0.17	84
Eng. Deliverables Accurate	-0.32*	57	-0.09	84
% Eng. before authorization	-0.23	48	-0.08	257
% Eng. before construction	-0.54*	52	-0.07	265

r = strength of relationship, n = sample size, * = statistically significant relationship

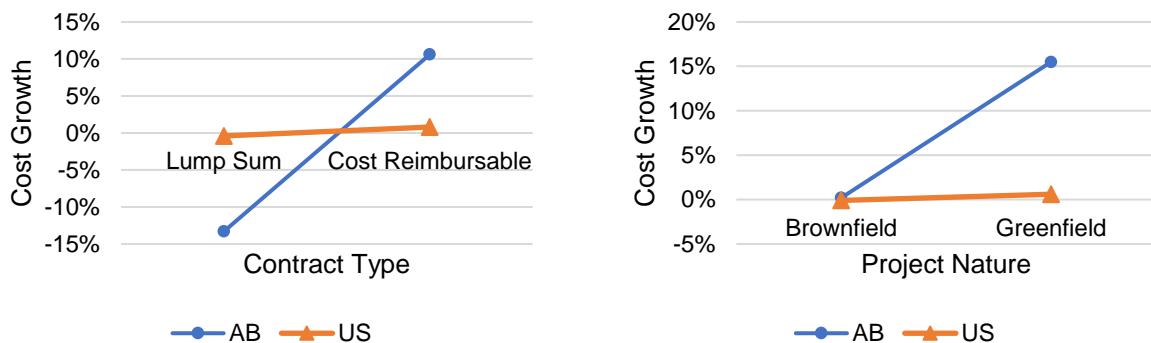


Figure 56: Comparison of Impact of Contract Type and Project Nature on Cost Growth – Alberta and U.S. Projects

More details and findings can be found in Haines et al. (2019).