Upstream Offshore-Facility Weight-Growth Study

Ray (Zhenhua) Rui and **Jason Walker,** Independent Project Analysis

Summary

Offshore-facility weight is significantly related to the cost, schedule, and complexity of offshore-facility projects. Therefore, controlling the weight growth of offshore facilities is important to project success. This paper seeks to understand weight growth and its causes among different project phases. By use of the detailed database of oil and gas projects provided by Independent Project Analysis, we conducted a rigorous statistical analysis of offshore-facility weight growth to identify the root cause(s). This paper evaluates the weight growth for 153 global offshore projects at the end of the concept selection and authorization gates. The study results show that industry weight growth is much higher than expected.

Front-end loading (FEL) is a core work process of project teams before authorization. FEL is a process to develop sufficient strategic information to address risk and make decisions to commit resources to maximize the chance of a successful project. The FEL work process is divided typically into phases or stages, with a pause for assessment and decision making about whether to process **(Fig. 1).** Although the industry typically allocates 13% of dry weight for weight contingency at the end of FEL 2 and 6% of dry weight at authorization to account for unexpected weight growth, one-half of the topsides had more than 10% weight growth from authorization to completion, and more than one in three substructures had more than 10% weight growth from authorization to completion. The data also show that estimated weight-contingency range is much narrower than that of actual required contingency. This analysis shows that the weight growth of most offshore facilities is caused by poor engineering status for the facilities at authorization. The analysis also shows that setting aggressive schedule targets erodes the benefits of good engineering definition. In general, projects with good engineering and aggressive schedule targets have an additional 9% weight growth compared with projects with good engineering and nonaggressive schedule targets. The weight growth of offshore facilities was found across many different offshore-facility concepts (e.g., fixed platforms, spars, tension-leg platforms). This research provides an understanding of industry offshore-facilities weight performance and the main causes of weight growth, and offers recommendations for improving weight predictability.

Introduction

With new technological developments, high energy demand, and existing-oilfield depletion, there has been steady growth in the discovery of offshore resources. As a result, more offshore facilities will be installed to increase oil and gas production. Given the importance of offshore weight to offshore-facility success, understanding weight growth is critical to the petroleum industry.

On the basis of our analysis and observations of projects in the database provided by Independent Project Analysis (IPA), one-half of topsides have more than 10% weight growth from authorization to completion, and more than one in three substructures have more than 10% weight growth from authorization to completion. Meanwhile, estimated contingency has a much narrower range compared with actual required contingency.

To help the industry understand offshore-facility weight predictability, IPA recently conducted a comprehensive study that sheds new light on facility weight performance and identifies the root causes of weight growth, providing guidelines for improving predictability.

Definition, Methodology, and Database

On the basis of observations of our database and documents, a few concepts are defined for this study. *Dry weight* is the weight of the components or assemblies in their dry, installed condition, without the content weight. This weight includes the basic weight and allowance, but excludes the weight contingency. *Weight contingency* is the weight addition applied to account for uncertainties and possible unforeseen occurrences. In general, weight contingency is assigned as a percentage of the dry weight.

Weight growth is the weight change across the project work-process stages. Independent Project Analysis's (IPA's) gated project work-process stages are similar to those of the industry. The most-common work process involves three front-end-loading (FEL) phases before full-funds authorization, plus execution and operation phases, as shown in Fig. 1. We will look at weight change from the end of FEL 2 to completion and weight change from the FEL 3 gate (authorization) to completion. This will allow us to observe weight change occurring between the end of FEL 2 and authorization.

Because offshore weight has many different weight definitions in the industry, such as wet weight, dry weight, and basic weight, we selected dry weight to calculate dry-weight growth as a metric to evaluate weight growth in this paper. *Dry-weight growth* measures the dry-weight growth between the different gates by use of the following formula: *dry-weight growth* = (*actual dry weight* – *estimated dry weight*)/*estimated dry weight*. It is worth noting that dry-weight growth does not include weight contingency.

To increase our understanding of the pattern of data and the differences between the groups, standard statistical techniques (t-tests for testing the equality of means for two groups and sd-tests for testing the equality of standard deviations for two groups) were used. The statistical significance (p-value) was reported through the use of common rules; IPA generally uses a 5% criterion, but most of the test results in this study are much stronger than this threshold—much lower than 5%. For this study, we used an offshore-facility data set developed and maintained by IPA. **Table 1** describes the data set composition.

The average facility cost of the selected projects is (2014) USD 650 million, with a range from less than (2014) USD 11 million to more than (2014) USD 2 billion. The average authorization year is 2006, with a range from 2001 to 2012. Twenty-three global

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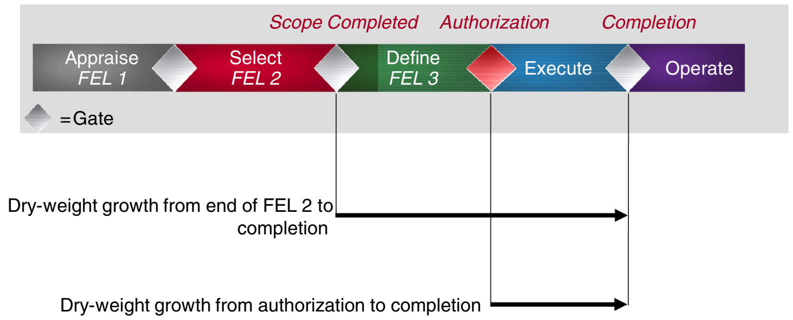

Fig. 1—Exploration- and production-stage gate process.

Number of facilities	153
Number of companies	23
Average authorization year	2006
Range of authorization year	2001–12
Average facility cost (2014 USD)	650 million
Range of facility costs (2014 USD)	<11 million to >2 billion
Average topsides weight (1,000 t)	8581
Range of topsides weight (1,000 t)	<200 to >40 000
Average substructure weight (1,000 t)	7900
Range of substructure weight (1,000 t)	<200 to >40 000
Region distribution	Europe 22%, Asia 24%, Latin America 17%, North America 16%, Africa and Middle East 14%, Australia 7%
Facility-concept distribution	SPJ 69%; FPSO 19%; FSS 5%; TLP 4%; spar 3%

Table 1—Composition of study data set.

companies are associated with these projects, including international oil companies, independent oil companies, and national oil companies. Meanwhile, the offshore facilities are evenly distributed around the globe and include most of the oil- and gas-production locations. The data set also includes five major offshore-facility concepts: steel-piled jacket (SPJ), tension-leg platform (TLP), semisubmersible (FSS), spar platform, and floating production, storage, and offloading system (FPSO). In summary, the offshore-facility industry's broad range of characteristics is well-represented in the data set.

Offshore-Facility Weight Performance

Exploration-and-production offshore facilities include two major components: topsides and substructure. *Topsides* is a common term for facilities placed above the sea level that are supported by a fixed, compliant, or buoyant *substructure*, the most-important component of the offshore facility. **Table 2** lists the typical topsides and substructure weight components.

Topsides	Substructure
Deck	
Equipment	
Bulks	
Quarters	Jacket and piles (SPJ)
Helideck	
Crane	Hull (spar, TLP, FSS, FPSO)
Vent flare	
Buildings	
Auxiliaries	

Table 2—Offshore-facility topsides and substructure components.

Fig. 2 shows topsides dry-weight growth from the end of front-end loading (FEL) 2 to completion and from the FEL 3 gate (authorization) to completion. As shown, the average topsides weight growth is 21% from the end of FEL 2 to completion, with one-standard-deviation variance ranging from –20 to 62%, indicating significant weight growth and high uncertainty. From authorization to completion, the topsides experience an average weight growth of 10%, with one standard deviation from –9 to 30%. The average weight growth and variance from authorization to completion is less than that from the end of FEL 2 to completion, which is in line with our expectation that weight estimation becomes more accurate with more engineering work being performed through FEL 3.

Fig. 3 shows a similar trend for substructure weight. Substructures experience 24% weight growth from the end of FEL 2 to completion, with a large variance ranging from –12 to 65%. Substructures experience 7% weight growth from authorization to completion, with a relatively small variance ranging from –10 to 22%.

Fig. 4 shows weight growth for the five offshore-facility concepts. As shown, all five concepts see weight growth, and it appears

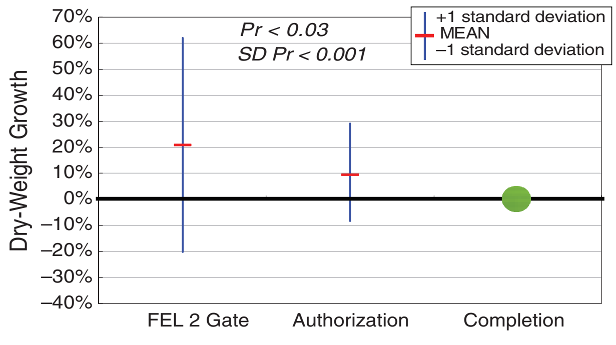

Fig. 2—Topsides weight-estimate progression.

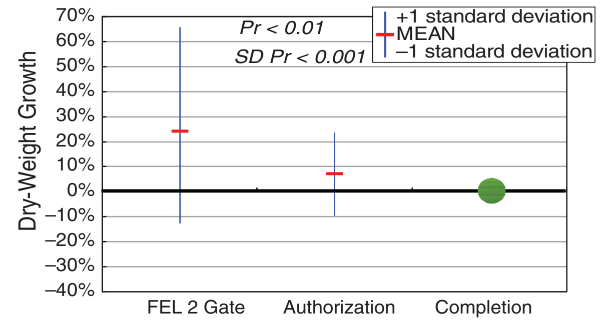

Fig. 3—Substructure weight-estimate progression.

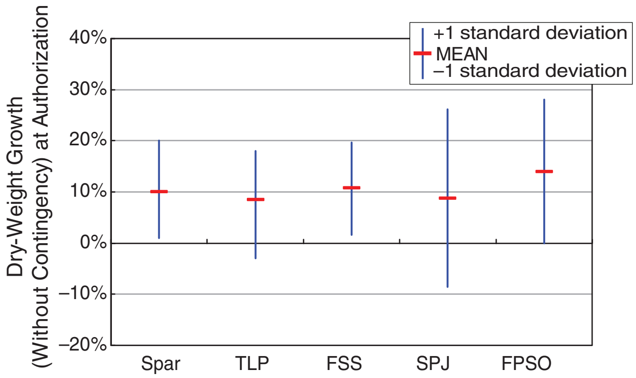

Fig. 4—Weight growth for the five offshore-facility concepts.

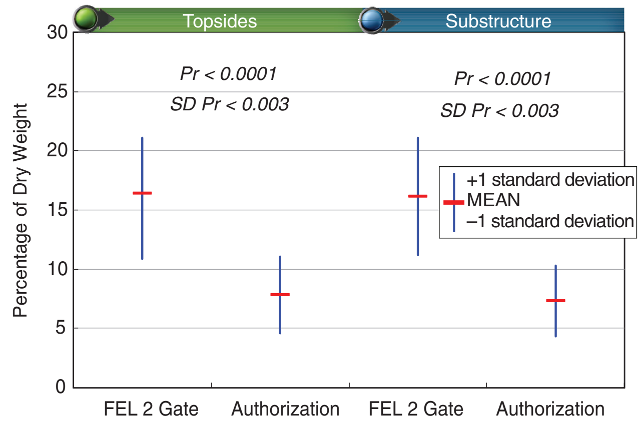

Fig. 5—Industry-estimated contingency.

that FPSO systems tend to have the highest weight growth. However, statistical analysis shows that the weight-growth difference among the five concepts is not significant. These results indicate that offshore-facility concepts are not major drivers of weight growth. This provides a foundation for investigating offshore-facility weight growth overall, instead of for an individual concept.

The extent of the weight growth may be a surprise for those in the industry. In terms of average weight growth and variance, project teams systematically fail to understand uncertainty.

Industry Contingency-Setting Performance

As discussed in the preceding section, weight growth is a concern for offshore facilities. To mitigate the effects of weight growth resulting from uncertainty, Independent Project Analysis collected client data showing that the industry assigns a certain amount of weight as a contingency for offshore facilities. **Fig. 5** shows the industry-average estimated weight contingency. On average, for the topsides, 16% of dry weight is used as a contingency at the end of front-end loading (FEL) 2, and 7% is used at authorization; similar amounts are assigned for substructures. Variances also significantly decrease from the FEL 2 gate to the authorization gate—with more engineering performed during front-end engineering design, there is less uncertainty at authorization, therefore less contingency is needed.

Fig. 6 shows a comparison between the estimated and required contingency for topsides. For the topsides, in terms of the average contingency, the estimated contingency is just short of 5% at the end of FEL 2 and 3% lower at authorization. Although the contingency levels being set by project teams are only slightly below what the industry experiences on average, in terms of variances, the estimated contingency is much narrower than the actual, required contingency. It shows clearly that contingency estimates line up with the average very closely, but fail to account for uncertainty.

The trend for substructure weight contingency is very similar **(Fig. 7).** This tells us that the project teams expected weight growth, and they assigned an average amount of contingency on the basis of general rules, but did not consider each project-specific situation, such as completeness of engineering definition and if the project was schedule driven. Consequently, although industry average contingency setting is fine, the estimates generally fail to incorporate the appropriate level of uncertainty. This means that project teams fail to estimate the uncertainty of offshore-facilities weight because they do not understand what drives weight growth in the estimates. Thus, understanding the drivers of weight growth is important for improving weight estimation.

Next, we explore the reasons for these outcomes so that we can determine best practices for improving performance and help project teams allocate the appropriate amount of weight contingency to avoid systematically underpredicting contingency.

Understanding Poor Weight Predictability

Many factors affect the industry's weight-predictability performance. With our analysis, we concluded that offshore-facility growth is driven by two major factors: *engineering status* and *schedule-driven projects.*

Engineering status looks at aspects related to the process design (or conceptual design) progress. Independent Project Analysis (IPA) classifies design status in four levels: full-design specification, advanced study, limited study, and screening study. IPA defines advanced study as best practical at authorization and limited study

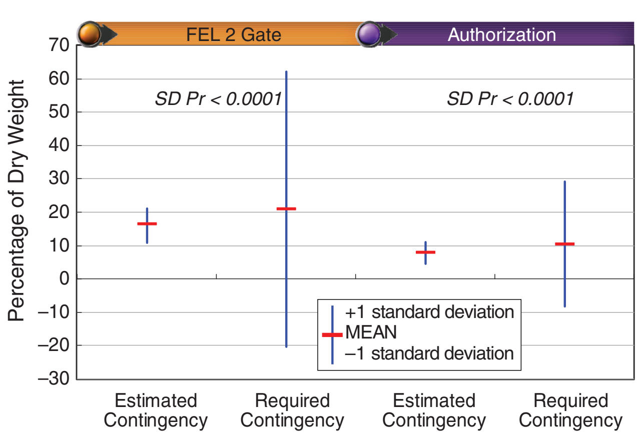

Fig. 6—Comparison of estimated contingency and required contingency for topsides.

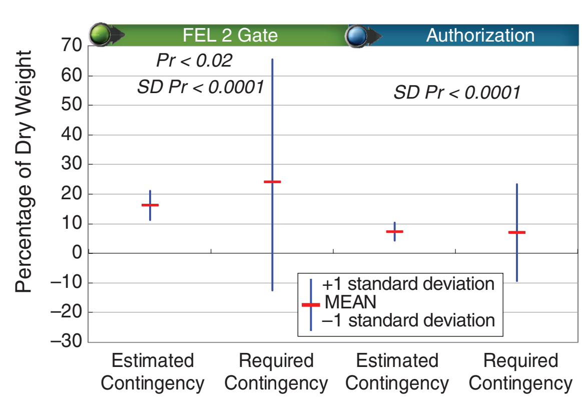

Fig. 7—Comparison of estimated contingency and required contingency for substructure.

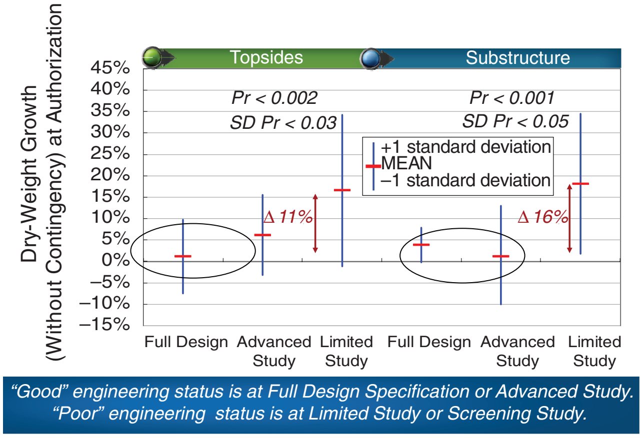

Fig. 8—Engineering status and weight growth of projects.

as best practical at the end of front-end loading (FEL) 2. At the authorization gate, approximately 58% of projects have reached the advanced-study level, with 11% at full-design specification. There are no projects at the screening-study level, but a large number of projects are at limited study. We group the four levels into two categories for this study. At the authorization gate, good engineering status is assigned if the project has achieved advanced study or full-design specification. Otherwise, we assign a poor status.

As shown in **Fig. 8,** weight growth is not significantly different between full-design specification and advanced study. There was a slight improvement in weight performance from advanced study to full-design specification, but the difference and variance are not significant. However, there is a significant difference between the good-engineering-status group and the poor-engineering-status group, in terms of both average and variance. The *average weight-growth difference* between good and poor engineering status is 11% for topsides and 16% for substructure. In addition, the good-engineering-status group has consistently better weight predictability than the poor-engineering-status group. Therefore, engineering status is a key factor in determining weight outcomes. Suboptimal engineering status leads to large weight growth and high uncertainty. Case A clearly illustrates the weight-growth problem resulting from suboptimal engineering status and helps us to understand the underlying issue **(Table 3).**

If a project is schedule-driven, it means that businesses are willing to trade capital cost for schedule, and the schedule targets are typically achieved through overtime, extra shifts, and a longer overlapping of phases. A major difference between upstream and other industries is that the upstream business tends to prioritize the schedule for exploration-and-production (E&P) projects. Therefore, E&P project teams are regularly told to minimize the duration to first oil production or accelerate the schedule—more than 50% of upstream projects are explicitly schedule-driven. Quality starts to erode when projects intend to achieve unobtainable or very aggressive schedules. IPA research shows that schedule-driven upstream projects tend to have multiple failed outcomes—cost, schedule, and production attainment (Nandurdikar and Kirkham 2012).

Fig. 9 shows that schedule-driven projects also have worse weight performance than nonschedule-driven projects. The weight growth for schedule-driven topsides projects is 7% higher than that of nonschedule-driven projects; schedule-driven projects also have a slightly larger variance. Substructures have even worse weight outcomes. Schedule-driven substructures have more than 11% weight growth and a significantly larger variance than nonschedule-driven substructures. Schedule-driven projects tend to have overlapping phases that prevent teams from optimizing the weight design, leading to weight growth. For example, a project with an aggressive schedule required engineering to be completed without enough hard data that were supported from available reservoir analyses, causing an error in determining the net payload. In addition, to reach the schedule targets, the project team was willing to take any available alternative during execution instead of what had been planned [e.g., choose available material grade and

Characteristic	Case A: Poor Engineering	Case B: Schedule-Driven	Case C: Poor Engineering and Schedule-Driven
Facility concept	Floater	Floater	SPJ
Topsides weight (1,000 t)	Approximately 26 000	Approximately 7000	Approximately 7000
Substructure weight (1,000 t)	N/A	Approximately 12 000	Approximately 12 000
Engineering status	Poor	Good	Poor
Schedule-driven	No	Yes	Yes
Weight growth from authorization to completion	Topsides: 30%	Topsides: 13% Substructure: 8%	Topsides: 24% Substructure: 8%
Causes for weight growth	1. Planned equipment was not available in market; equipment and deck plans had to be changed. 2. Factored turret design drove major modification to support substructure. 3. P&IDs that did not include HAZOP study results caused many design errors. 4. Living quarters increased by 100 beds because of lack of communication with operations.	Schedule pressure resulted in a design change to heavier deck material that was available.	1. Used 9-slot platform drawings for 15-slot platforms, and drawings were not approved at authorization. 2. HAZOP study not completed at authorization, leading to P&IDs changes. 3. After authorization, project team was still considering design alterations.

P&IDs = piping and instrumentation diagrams. HAZOP = hazard and operability analysis.

Table 3—Case studies for the weight growth of three offshore facilities.

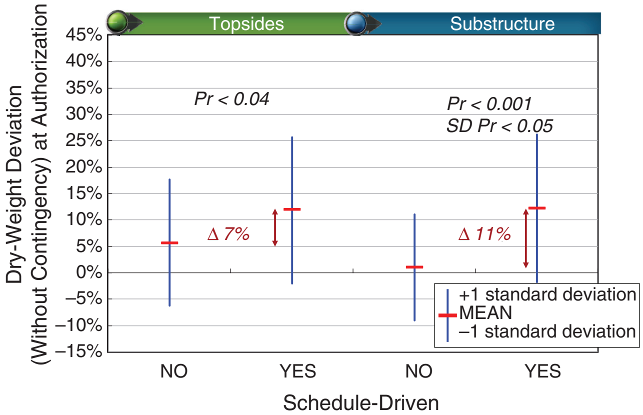

Fig. 9—Effect of schedule driver on the weight growth of a project.

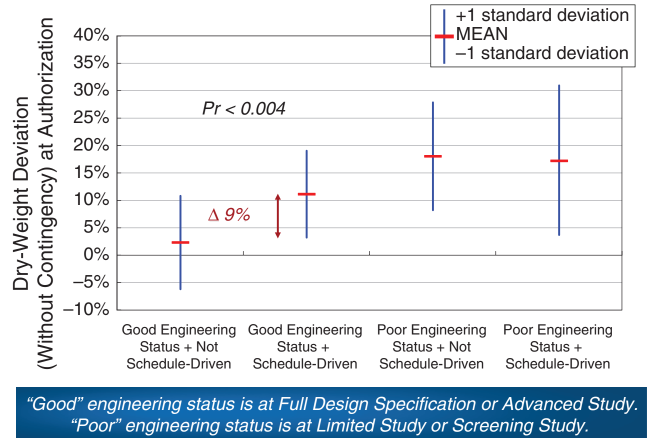

Fig. 10—Topsides weight-predictability performance in four different scenarios.

select modular construction, which increase the weight (Ellis and Shirley 2005)]. All of these actions or activities induced by aggressive schedules highly erode the engineering quality and increase weight growth. In general, there is a trade-off between schedule and weight predictability, which should be recognized by the industry. Case B in Table 3 shows the effect of schedule-driven pressure on weight growth.

Poor engineering status and schedule-driven projects both have profound adverse effects on weight outcomes, but these two factors are not mutually exclusive—they are interactive. **Fig. 10** shows the effect on weight predictability for four different combinations of these two factors. Topsides have only 2% weight growth when they are nonschedule-driven and have good engineering status, which shows that the industry can attain strong weight performance if project teams have good engineering definition and a reasonable schedule. However, when we compared the first two good-engineering-status groups, it is observed that projects with good engineering status had 9% higher weight growth if they were driven by schedule. Thus, projects with good engineering that were not schedule-driven will underrun 6% on the basis of the 9% average industry estimate contingency in weight estimation, while projects with good engineering that were schedule-driven will use all of the weight contingency. In other words, speed can destroy the benefits of good engineering. Schedule-driven projects can cause many issues in engineering and execution—tasks out of order, errors, excessive overlap of schedule phases, late changes—that can contribute to weight growth.

Fig. 10 also shows that when engineering status is poor, we do not see much difference between the weight growth for non-schedule-driven and schedule-driven projects. The conclusion is that engineering work quality is the foundation of successful weight predictability, but more than 30% of projects fail to achieve the best practical engineering definition. There are many cases in which poor engineering will cause late changes in execution, leading to overlap between engineering and construction that, in turn, results in onshore work with fabrication issues and weight changes for many offshore facilities. The weight outcomes for projects with poor engineering status are likely to be poor, whether the project is schedule-driven or not. Case C in Table 3 illustrates the consequences of poor engineering on a schedule-driven project.

Conclusions and Recommendations

Offshore-facility projects that experience large weight growth tend to slip schedule and overrun cost, ultimately eroding net present value. On the basis of the comprehensive analysis conducted by Independent Project Analysis, it was found that exploration-and-production (E&P) offshore facilities experience a 21% weight growth from the end of front-end loading (FEL) 2 to completion and 10% weight growth as they progress from authorization through execution to completion. The study results show that the average contingency levels are actually reasonable; the primary issue is that the project teams do not recognize the uncertainty of the weight estimates at poor levels of project definition. However, there are ways to improve estimating with best practices in engineering to eliminate uncertainty. Weight predictability will improve with use of best practices; in particular, projects with advanced engineering status are strongly positioned for good weight predictability. Good engineering status is the foundation for successful weight outcomes, but schedule pressure can destroy the advantages from good engineering. However, schedule pressure has no effect on the weight outcomes for projects with poor engineering. E&P projects tend to be schedule-driven, but this trade-off between weight growth and schedule for good-engineering-status projects should be recognized by the industry. In some extreme cases in which it is impossible to achieve good engineering definition, it is best to acknowledge the limitations faced by the project and set enough contingency to account for the large uncertainty.

Nomenclature

Pr = the *p*-value for t-tests
SD Pr = the *p*-value for sd-tests

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Ray (Zhenhua) Rui is an exploration-and-production project researcher at Independent Project Analysis. Previously, he was a petroleum-engineering researcher at the Institute of Northern Engineering, Alaska, from 2006 to 2011. Rui was a research geophysicist at the Beijing key laboratory of petroleum-exploration geophysics from 2004 to 2006. His research interests include oil and gas asset/project evaluation and economic analysis, petroleum/reservoir engineering, oil and gas infrastructure analysis, oil and gas model and tool development, project development, benchmarking and

appraisal, opportunities assessment, risk analysis, and statistical analysis. Rui has authored or coauthored more than 25 peer-reviewed-journal papers on the oil and gas field, and has given numerous presentations at international conferences, including the SPE Annual Technical Conference and Exhibition. He holds a PhD degree in energy engineering management, an MS degree in petroleum engineering, and an MBA degree in capital market from the University of Alaska, Fairbanks; an MS degree in petroleum geophysics from China University of Petroleum; and a BS degree in applied mathematics from Nanjing Normal University, China. Rui currently serves as a member of the SPE Projects, Facilities, and Construction Advisory Committee, a Young Professionals Chair for the SPE National Capital Section, a member of the SPE Annual Technical Conference and Exhibition and International Petroleum Technology Conference Project, Facilities, and Construction subcommittees, and a technical editor for SPE peer-reviewed journals. He is also an associate editor of the *Journal of Natural Gas Science and Engineering* and an editorial board member for the *International Journal of Oil, Gas and Coal Technology.*

Jason Walker is the Research Team Leader for Exploration and Production with Independent Project Analysis (IPA). He has led or supported more than 20 research studies related to the exploration-and-production industry and has spoken at numerous industry conferences. Walker is a subject-matter expert in subsurface benchmarking, appraisal effectiveness, and statistical analysis. Before his current position with IPA, he was a senior research analyst, also for IPA, where he has worked for more than 10 years. Walker holds a BS degree in integrated science and technology from James Madison University and an MDiv degree from Southwestern Baptist Theological Seminary.