Responsible Design and Delivery of the Constructed Project
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THE COST IMPACT OF FRONT END ENGINEERING DESIGN (FEED) ACCURACY FOR LARGE INDUSTRIAL PROJECTS

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Assessing the accuracy of front end engineering design (FEED) for large industrial projects is a critical task with the potential to considerably impact overall project success. At this early phase of the project, the owner's expectation is to be able to make informed decisions including cost predictions to determine whether the project should proceed to the next phase. The primary objective of this paper is to evaluate FEED accuracy and measure its impact on project cost performance. The authors collected and analyzed data from 33 completed large industrial projects representing over $8.83 billions of total installed cost. A primary finding is that projects with high FEED accuracy significantly outperformed projects with low FEED accuracy in terms of cost growth in relation to the approved budget at Phase Gate 3. This finding assists owners and contractors focusing on the front end planning phases of their large industrial projects to considerably improve cost performance.

Keywords: Front end planning, Construction industry institute, Project definition, Rating index, Cost growth, Performance.

1 BACKGROUND AND OBJECTIVE

For many projects, front end planning (FEP) is considered to be the most important process within the project lifecycle (Construction Industry Institute (CII) 2012). Planning efforts conducted during FEP can have significantly more influence on project success than efforts undertaken after detailed design and construction have begun (Gibson *et al.* 1993). While addressing FEP of projects in general, past research efforts have not focused specifically on assessing the accuracy of the engineering component of front end engineering design (FEED) for large industrial projects. A consistent understanding of FEED will allow the owner, engineer, and contractor to be better aligned as the project design process moves forward.

This paper quantifies the accuracy of FEED deliverables at the end of the detailed scope phase. It provides details about the research background and methodology, data collection efforts, project data analysis, and conclusions of the work performed by the research team. The research team set forth the following objectives: (1) identifying the enabling factors that drive effective engineering design during FEED (e.g. capability of the engineers, turnover of key design team members, time allowed for FEED, etc.); and (2) testing the impact on project performance by comparing the level of accuracy definition at the end of FEED versus corresponding cost performance factors for a sample of completed large industrial projects.

1.1 FEP Definition

FEP is defined as the 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. FEP is also known as front end loading, pre-project planning, feasibility analysis, conceptual planning, programming/schematic design, and early project planning (Construction Industry Institute (CII) 2012). FEP Phase 1 is known as "feasibility," Phase 2 is known as "concept," and Phase 3 is known as "detailed scope" as seen in Figure 1. Each of these phases is followed by a Phase-Gate (diamonds in the figure) that marks a decision to move forward to the next stage of the project. The focus of this research effort is the detailed scope phase or Phase 3, the gateway to detailed design and construction.

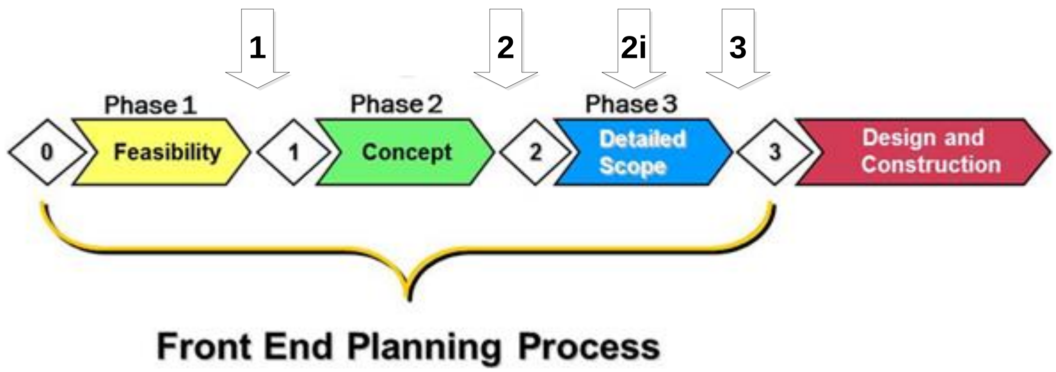

Figure 1. Typical front end planning process.

1.2 Research Scope

Within the FEP body of knowledge, the scope of this research specifically deals with the accuracy of FEED engineering deliverables. For maximum impact, the study also concentrates on large industrial projects, namely ones with the following characteristics:

- Projects completed within industrial facilities such as (or similar to): Oil/gas production facilities; refineries; chemical plants; pharmaceutical plants; paper mills; steel/aluminum mills; power plants; manufacturing facilities; food-processing plants; textiles mills.
- Total installed cost greater than USD 10 million (in some cases, respondents felt that their projects were complex and met the remaining criteria, despite being slightly below $10 million) and construction duration greater than nine months.
- More than ten core team members (e.g., project managers, project engineers, owner representatives) and a combination of part-time and full-time to complete full-time availability of core team members.

2 RESEARCH METHOD

The specific research hypothesis is as follows: FEED accuracy impacts project cost growth. To test this hypothesis, a comprehensive literature review was completed to identify all the relevant accuracy factors. These factors were provided and prioritized through a series of four industry-sponsored workshops with engineering and construction professionals experienced in the front end planning of large industrial projects. Specific project data regarding (1) the FEED development effort, (2) measures for accuracy factors, (3) cost budgets at the beginning of detailed design, and (4) project cost at the completion of the projects, were collected and analyzed. FEED accuracy scores were calculated for each project and compared to project performance data through statistical analysis.

The authors identified a total of 37 accuracy factors from the literature review and the survey and completed focus group exercises to identify any missing factors that needed to be added or any similar factors that needed to be combined. The authors and their industry research team of 20 FEED experts also developed detailed definitions for each of the accuracy factors based on the literature, and verified them based on industry experience. Through the workshops with 48 industry experts, the number of factors was narrowed down to a final list of 27, and the research team developed weights for each of these factors through a modified Delphi ranking approach. Four geographically dispersed workshops were hosted at various locations across the United States and Canada, as shown in Table 3-2. Overall, 48 industry professionals representing 31 organizations (14 owners and 17 contractors) attended the workshops as shown in Table 1.

Table 1. Workshop locations and number of participants.

Location	No. of Participants
Houston, Texas	14
Seal Beach, California	6
Cherry Hill, New Jersey	9
Calgary, Alberta, Canada	19
Total: 4 Workshops	**Total: 48 Participants**

The authors used several statistical methods to analyze the data collected at the workshops. Statistical analysis allowed the authors to interpret the data and provided a basis to offer recommendations regarding the efficacy of measuring FEED accuracy and predicting project outcomes. The methods employed by the authors include boxplots, histograms, normality tests, variance tests, regression analyses, t-tests, Mann-Whitney-Wilcoxon ranked sum tests and step-wise sensitivity analyses. Microsoft Excel™, Minitab™, and the statistical R package were the primary software platforms used to analyze data.

3 INITIAL FINDINGS: FEED ACCURACY FACTORS

The accuracy of FEED is not studied in literature. Therefore, the authors started by studying the accuracy of other project requirements, such as cost and schedule estimates, as there are established criteria for evaluating accuracy for these types of estimates in construction projects (e.g.; Skitmore *et al.* 1990, Construction Industry Institute (CII) 1998, Oberlender and Trost 2001, Heinemann and Zeiss 2002, Chen *et al.* 2005, Construction Industry Institute (CII) 2006, Rigby and Bilodeau 2015, Lim *et al.* 2016). Next, literature and past CII research efforts regarding factors that impact accuracy are evaluated, including those related to the project team (leadership and execution team) and project resources. The studies reviewed were conducted over four decades, span various industries, and were mined by the authors for accuracy factors that may apply to FEED. The discovered FEED accuracy factors are organized in four distinct types as shown in Figure 2.

In summary, no research was found in the literature that focused on FEED accuracy for large industrial projects. Thus, accuracy factors from previous research were studied and adapted in developing the FEED accuracy factors. The final list of 27 accuracy factors was developed with input from 23 literature references, the survey, 20 research team members, and 48 industry experts that participated in the workshops.

	1. PROJECT LEADERSHIP TEAM
1.a	Leadership team's previous **experience executing** a project of similar size, scope, and/or location, including FEED
1.b	**Stakeholders** are appropriately represented on the project leadership team
1.c	Project **leadership** is defined effective and accountable
1.d	**Leadership team and organizational culture** fosters trust, honesty, and shared values
1.e	Project leadership team's attitude toward **change**
1.f	Key personnel **turnover** (e.g., how long key personnel stay with the leadership team)
	2. PROJECT EXECUTION TEAM
2.a	**Technical capability and relevant training/certification** of the execution team
2.b	**Contractor/Engineer's team experience** with the location, with similar projects, and with the FEED process
2.c	**Stakeholders** are appropriately represented on the project execution team
2.d	Level of **involvement** of design leads or managers in the engineering process
2.e	Key personnel **turnover** including the **stability/commitment** of key personnel on the owner side through the FEED process
2.f	**Co-location** of execution team members to one another
2.g	Team culture or history of the execution team **working together**
	3. PROJECT MANAGEMENT PROCESS
3.a	**Communication** within the team is open and effective; a communication plan with stakeholders is identified
3.b	**Priority** between cost, schedule, and required project features is clear
3.c	Organization implements and follows a **front end planning** process (e.g., phase gates, clear requirements) and a **formal structure** or process to prepare FEED
3.d	Significant **input of construction knowledge**
3.e	Adequate process for **coordination** between key disciplines
3.f	**Alignment** of FEED process with **available project information,** including the existence of peer reviews and a standard procedure for updating FEED
3.g	**Documentation** of information used in preparing FEED
3.h	**Review and acceptance** of FEED by appropriate parties
	4. PROJECT RESOURCES
4.a	**Commitment** of key personnel on the project execution team
4.b	**Calendar time** allowed for preparing FEED
4.c	**Quality** and level of detailed of engineering data available
4.d	**Amount of funding** allocated to perform FEED
4.e	**Local knowledge** (e.g., institutional memory, understanding of laws and regulations, understanding of site history)
4.f	**Availability of standards and procedures** (e.g., design standards, standard operating procedures, and guidelines)

Figure 2. Accuracy TYPES and factors.

Workshop participants were also asked to rank order the top five accuracy factors in each accuracy type and to prioritize each accuracy type by allocating percentage values that represented the relative importance of each accuracy type to the accuracy of FEED. The final factor numbers and weights are based on the rank ordering of factors per accuracy type, and distributed among the following five possible ratings for each factor:

- High Performing = 100%
- Meets Most = 75%
- Meets Some = 50%
- Needs Improvement = 25%
- Not Acceptable = 0%

4 THE IMPACT OF FEED ACCURACY ON PROJECT COST PERFORMANCE

A total of 48 industry professionals from 31 different organizations provided project data, professional comments, and suggestions, during the 4 workshops. These participants have a combined engineering/project management experience of 962 years with an average of 23 years of experience per participant. Complete project data were collected for 33 projects with sizes ranging from US $8 million to US $14 billion, and an average project cost of approximately US $276 million. These 33 completed projects represent over US $8.83 billion in total installed cost and are geographically dispersed across six countries and nine states of the US. Table 2 provides some descriptive statistics for the completed project sample.

Table 2. Descriptive statistics (N=33).

Metrics	Avg.	Median	Std. Dev.	Min	Max
Total Installed Cost ($M)	276.01	114.20	455.80	7.78	1,939.00
Total Project Duration (Days)	924.39	750.00	472.02	240.00	2,340.00
Cost Change (%)	9.47	7.16	18.67	-27.27	53.44

The authors calculated accuracy scores for each completed project. Scores ranged from 24 to 97. A regression analysis was conducted to investigate any correlations between accuracy and cost growth. For the linear regression of cost change vs. accuracy, the resulting p-value was 0.015 indicates that there is a statistically significant relationship, e.g.; the slope of the regression equation is non-zero. This suggests that changes in the predictor variable (accuracy score) are significantly correlated with changes in the response variable (cost change). However, the R-squared value of 0.181 indicates that only 18.1% of the variance is explained by the predictor (accuracy score), so more variables are also impacting cost growth as expected. These other variables can be related to design, construction, scope, and other factors throughout the project. The data points and regression line are shown in the fitted line plot in Figure 3. Looking at the trend, one can see how accuracy scores starting around 75 and higher are associated with smaller cost change compared to projects with low FEED accuracy scores. In fact, several of these high accuracy projects have negative cost growth which implies savings in cost.

On projects that average millions of dollars, even small percentage savings are considerable. These quantitative results were also tested qualitatively on a dozen in-progress large industrial projects that used this method to gauge their FEED accuracy and confirmed the significant value added to their projects and FEP process.

5 CONCLUSION

This paper evaluated FEED accuracy and measured its impact on project cost performance. A primary finding is that projects with high FEED accuracy significantly outperformed projects with low FEED accuracy in terms of cost growth. Ongoing work is also measuring the effect of

FEED maturity on project performance, in an effort to understand the combined impacts of FEED accuracy and maturity on a number of key performance metrics.

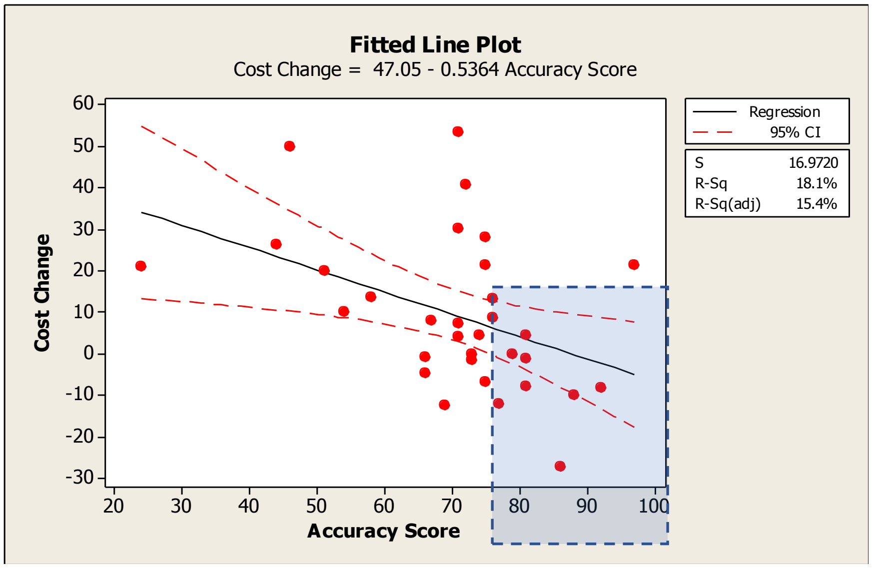

Figure 3. Regression results for cost change vs. FEED accuracy score.

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