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FRONT END ENGINEERING DESIGN FOR LARGE INDUSTRIAL PROJECTS: INDUSTRY PERCEPTIONS AND STATE OF PRACTICE

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ABSTRACT

Front end planning (FEP) is the process of developing sufficient strategic information with which owners can address risk and decide to commit resources to maximize the likelihood of a successful project. Recently, the Construction Industry Institute (CII) identified a critical industry need to better characterize the maturity and accuracy of front end engineering design (FEED) deliverables as part of FEP activities. The primary objective of this paper focuses on ascertaining the construction industry's perception of FEED by administering a detailed survey to stakeholders of large industrial projects. A key result is that there is no consistent definition of FEED, which led the researchers to develop a comprehensive FEED definition based on 80 survey responses. Results also identify external factors that can potentially affect the accuracy of FEED, such as the time and funding granted to the execution team to perform FEED, the existence of standard FEED processes in the organization, and so on. Ultimately, the results from this survey will help establish a baseline for the development of an evaluation tool that quantifies the maturity and accuracy of FEED for large industrial projects.

KEYWORDS: Front End Planning, Front End Engineering Design, Maturity, Accuracy.

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INTRODUCTION

The Construction Industry Institute (CII) is a consortium of more than 130 leading owner, engineering-contractor, and supplier firms from both the public and private arenas. These organizations have joined together to enhance the business effectiveness and sustainability of the capital facility life cycle through practice based research, related initiatives, and industry alliances. CII defines front end planning (FEP) as the process of developing sufficient strategic information with which owners can address risk and decide to commit resources to maximize the chance for a successful project (CII 2014a). FEP is a critical process for uncovering project unknowns, while developing adequate scope definition following a structured approach for the project execution process (CII 2011). Arguably, FEP is the single most important process in a project's lifecycle (CII 2006). While addressing the FEP of projects, in general, past CII research efforts have not specifically focused on assessing the maturity and accuracy of the engineering design component of front end engineering design (FEED) activities. Both the owner and the engineer/designer have to be aligned as the project design process moves forward (CII 2005). The owner's expectation is to be able to make informed and reliable decisions including cost and schedule predictions. These decisions also include the contingency level needed for the project and the predicted impact on the success of subsequent phases which include detailed design and construction, project execution, and start-up. Moreover, it is well documented that schedule compression during FEP may lead to challenges with design maturity and accuracy (CII 2006). Due to these identified needs, Construction Industry Institute (CII) Research Team (RT) 331 was formed to assess the maturity and accuracy of FEED to support phase-gate approvals during FEP.

This research effort documents the current state or perception of the industrial project sector regarding FEED, maturity, and accuracy and provides the results of a 15 question survey that gathered this information from industry practitioners. First, a systematic review of various engineering and construction literature was completed to recognize previous efforts that focused on the maturity and accuracy of engineering design, in addition to studies that looked explicitly at FEED. Second, based on the outcomes of the literature review, gaps in knowledge about FEED were identified and research objectives and methodology were developed. This is followed by survey data characteristics, results, discussion, and conclusions.

RESEARCH METHODOLOGY

The overarching research effort to develop standard definitions of FEED, maturity, and accuracy and to test the industry state of practice, occurred through a three-step process as shown in Figure 1. The research steps included: (1) conducting a literature review, (2) holding sub-team focus groups, (3) administering an industry survey. A comprehensive literature review was conducted to analyze the state of knowledge, inform the hypotheses development, and compile performance metrics that served as a solid basis for the survey development process. Through RT 331 sub-teams, the survey was developed by the academic team and industry practitioners, who provided feedback and industry input throughout the development process. After the survey was completed and thoroughly reviewed, an online version was created and pilot tested with RT 331 industry members. Further refinement of the survey took place as a result of the pilot study. To begin the data collection stage the CII data liaison shared the survey with CII member organizations and targeted owners and contractors involved in large industrial projects.

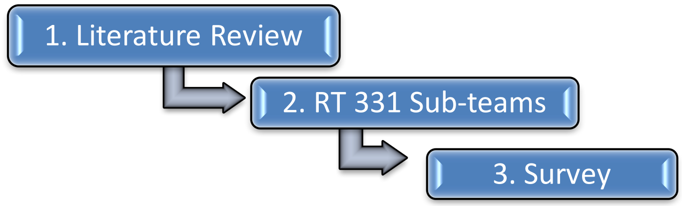

Figure 1: Research Methodology

BACKGROUND & LITERATURE REVIEW

The first step of this research consisted of a thorough review of the engineering and construction literature to summarize the state of knowledge of FEED and to develop standardized definitions of FEED, maturity, and accuracy. FEED was mentioned seldom in the literature due to the relative originality of the subject. The literature review is structured into several subsections. First, the literature regarding FEP and FEED are discussed within the context of engineering design and other past research on the subject. Second, the maturity of FEED and the Project Definition Rating Index (PDRI) for Industrial Projects (CII 2014b) are discussed. Finally, a third subsection of papers is discussed that focuses on accuracy in the industrial engineering and construction sectors and other industry sectors.

Front End Planning

CII defines FEP as the process of developing sufficient strategic information with which owners can address risk and decide to commit resources to maximize the chance for a successful project (Gibson et al. 1993). FEP has been considered by CII to be a best practice in the development of a project's scope for over 15 years (Collins 2015). FEP begins after the project concept is considered desirable by the business leadership of an organization, and continues until the beginning of detailed design and construction of a project (Gibson and Dumont 1995). Gibson et al. (1994) outlined there are 14 specific activities and products of a good FEP. Some of these activities include options analysis, scope definition and boundaries, life-cycle cost analysis, cost and schedule estimates. Moreover, FEP has many other associated terms, including pre-project planning, front end loading (FEL), programming, and schematic design among others. Figure 2 illustrates the concept that decisions made during the early stages of a project's life cycle have a much greater influence on a project's outcome than those made in later stages (CII 1994).

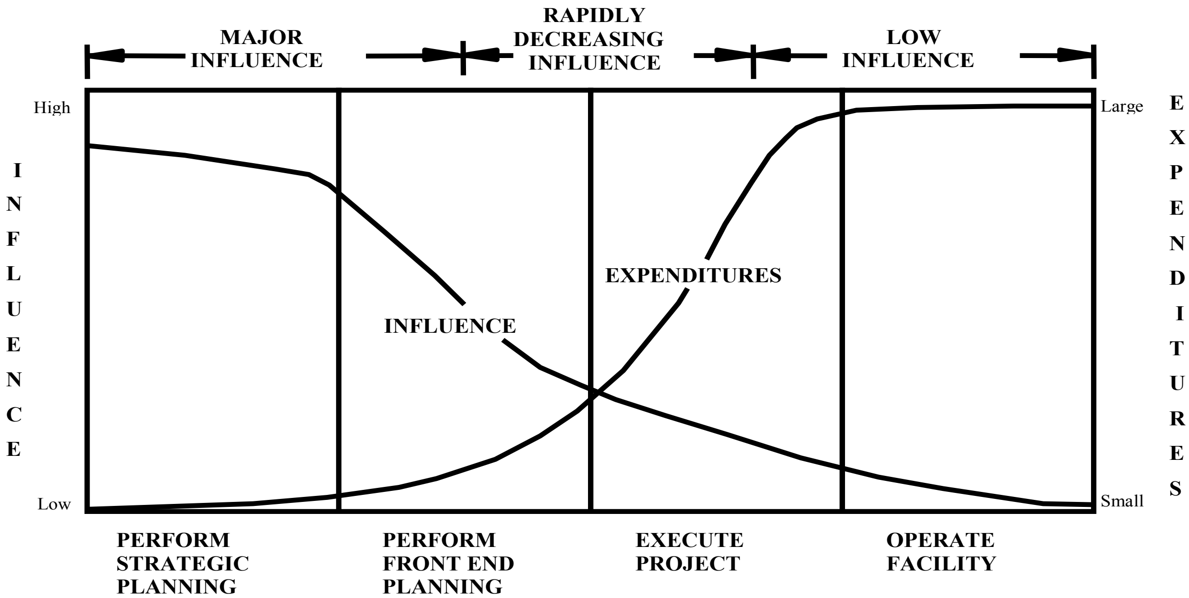

Figure 2: Influence and Expenditures Curve for Project Life Cycle (CII 1994)

Figure 3 shows the typical steps involved in the FEP process and are adapted from the CII FEP Toolkit (CII 2014a). The key takeaway point from Figure 3 is that FEED activities are usually completed during detailed scope, but before detailed design are initiated.

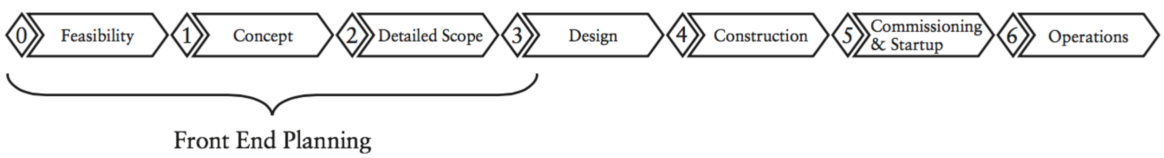

Figure 3: Front End Planning Process (CII 2014a)

Front End Engineering Design (FEED)

A general theme noticed in the literature is there has been little research conducted to define FEED and its processes. FEED is rarely mentioned as a stand-alone term, and frequently linked to the different processes associated with FEP. Merrow (2011) characterized FEED of the oil and chemical industries specifically in the third phase of FEP, which consists of business case development, scope development, project definition and planning, and the work processes needed to prepare a project for execution. A report from CII (2013) referred to FEED as "basic design." O'Connor et al. (2013) defined FEED as a phase that involves the optimization of the design basis for the concept, execution plan, and completion of any work needed to initiate detailed engineering design. By the end of this phase, the project has received funding, the project team has been formed, a preliminary construction plan has been put into place, and the long-lead equipment has been identified. The project schedule has been refined, and costs are estimated to an accuracy of ±10 percent. Schaschke (2014) defined FEED as a conceptual study used for the development and analysis of process engineering projects. FEED defines the processing of objectives and examines the various technical options associated with the design components of process engineering. The key takeaway point from the research presented here is that FEED has many different definitions depending on who is evaluating the project and what FEP phase they are evaluating the project in.

FEED Maturity and the Project Delivery Rating Index-Industrial Projects (PDRI-Industrial)

FEED maturity is not explicitly mentioned in the literature. Some members of the research team indicated that their organizations actively use the PDRI to evaluate the maturity of engineering design. Therefore, previous research regarding the PDRI for industrial projects served as the baseline for determining which engineering design components most appropriately represent the maturity of design during FEED activities.

The PDRI-Industrial is a tool developed by the Front End Planning Research Team (CII 1994b) and has two major components: first, a description list includes elements that should be addressed during FEP and second, a weighted score sheet corresponding to the element descriptions. The outcome of this work recognized 70 elements related to industrial project planning and divided these elements into three separate sections: (I) Basis of Project Decision, (II) Basis of Design, and (III) Execution Approach which is explained briefly below.

First, The Basis of Project Decision consists of information necessary for understanding the project objectives. The completeness of this section indicates whether the project team is aligned enough to fulfill the project's business objectives and drivers during FEED (CII 1994b). The categories in this section include manufacturing objectives, business objectives, basic data & research development, project scope and value engineering.

Second, The Basis of Design addresses processes and technical information elements that should be evaluated for a full understanding of the engineering/design requirements necessary for the project (CII 1994b). The categories in this section include site information, process/mechanical, equipment scope, civil/structural/architectural, infrastructure, and instrument & electrical.

Last, The Execution Approach consists of elements that should be evaluated for a full understanding of the owner's strategy and required approach for executing the project construction and closeout (CII 1994b). Categories within this section include procurement strategy, deliverables, project control, and project execution plan.

Overall, the authors used the PDRI industrial to form an initial baseline of how FEED maturity was being evaluated in the industry and gathered specific deliverables associated with the engineering elements from the PDRI to help in the survey development process.

Factors Affecting FEED Accuracy

FEED accuracy is not explicitly mentioned in literature, therefore the authors started by studying the accuracy of cost and schedule estimates in-order to begin developing the factors that could potentially affect the accuracy of FEED. This section of the literature review reports on several articles focusing on the accuracy of the (1) construction cost, (2) construction schedule estimates, and accuracy factors related to (3) the project leadership and (4) project resources.

Accuracy of Cost Estimates

Researching the accuracy of cost estimates was critical for developing several FEED accuracy factors. Cost estimation accuracy is a function of the quality and level of detail of data available as input (Chen et al. 2005). In addition, the experience level of the cost estimator will have an influence on the cost estimate accuracy (Skitmore et al. 1990). Improving Early Estimates RT 131 relayed the accuracy of early cost estimates based on the four determinants of who, what, how and other factors that were considered when preparing the estimate (CII 1998). Trost and Oberlender (2003) found that the lack of necessary information is the most important factor influencing estimate accuracy during the planning stage of projects. Moreover, Flyvbjerg et al. (2002) found that the accuracy of cost estimation is also influenced by the over or underestimation of costs. According to Flyvbjerg et al., the error of underestimating costs is much more common than the error of overestimating costs. Furthermore, the accuracy of the construction cost estimate increases as the design advances and the project scope becomes more defined (Lim et al. 2015). Lim et al. also indicated that accuracy also increases as the level of detail of project information increases. Lim et al. relates the choice of estimating method to estimating accuracy and the application of these estimating methods also entails adequate historical data, sufficient knowledge, and expertise.

Accuracy of Schedule Estimates

Researching the accuracy of construction scheduling was also important for developing several FEED accuracy factors. The studies summarized in this subsection provide insights on the accuracy of schedules as well as several factors that could potentially influence the accuracy of FEED.

Schedule accuracy is defined as "the number of days that the contractor worked on a controlling (critical) activities divided by the total number of days worked" (Mattila and Bowman 2004). For example, most roadway projects suffer a gap between the planning stage and actual construction/implementation stage, which is magnified by delays encountered during actual roadway construction (Parthasarathi and Levinson 2010). Parthasarathi and Levinson stated that the differences between the assumed highway network and the actual in-place network may also be a source of inaccuracy. Their study concluded that the accuracy of progress schedules increased with the allowance of controlling concurrent activities. In addition, inaccurate estimation of activity duration, usually overestimation, by contractors affects the accuracy of the entire project schedule.

Ostrowski (2006) examined construction schedule accuracy through the comparison of as-planned schedules to as-built schedules in the course of schedule delay analysis. Ostrowski states that the construction activities can change in their duration and in their relationships to other activities on a fairly consistent basis. Thus, duration of construction activities have a direct effect on schedule accuracy. Ostrowski concluded that it is not fair to judge a schedule's accuracy by simply determining the percent of schedule completed as planned. However, the original schedule should be used as comparison to an as-built schedule because it is unlikely that an accurate analysis can be based on a flawed baseline.

Recently, Moosavi and Moselhi (2012) investigated complex projects scheduling assessment. They looked at the owner, contractor, and subcontractors obligations at providing scheduling input. The authors concluded the most significant criteria that each schedule should satisfy are contractual provisions. Subcontractors should be required to sign-off on the schedule as verification of their commitment to the scheduled dates. While conducting the scheduling review process, owners should verify if the schedule is technically correct and ensure that the job logic and activities duration are reasonable for the stated purpose of the work. Finally, for accurate schedule assessment, complex projects should be reviewed using project scheduling software as opposed to manual schedule assessment.

Accuracy Factors Related to Project Leadership and Stakeholders

Several factors that affect accuracy outside of the construction cost and schedule estimate were also found in the literature; more specifically, these factors dealt with project leadership and the project stakeholders themselves. A report from CII (1999) indicated that project leadership is a latent construct that cannot be measured directly; however, experiential evidence suggests that leadership plays a significant role in the success of the project. Leadership is a complex concept involving the leader, the people the leader is attempting to lead, and the situation (in this case the engineering design of industrial projects). Project leadership roles vary from company to company and may include a venture manager, project manager, project director, construction manager, and other key stakeholders. These individuals ultimately will be held accountable for project success (CII 2012). FEED accuracy is influenced by the leadership team's previous experience and whether they have executed a project of similar size, scope, and location, including having gone through the FEED process itself (CII 1999). Previous experience increases the familiarity of the leadership team with the project planning, design, and execution processes. Repetition plays a major role in both organizational learning and in the creation of routines and capabilities in general (Nelson and Winter 1982). Another factor that can affect FEED accuracy is personnel turnover, which is a measure of how long individuals stay with the leadership team and how often they are replaced (Woods 2016). Excessive turnover will lead to loss of knowledge and perspective (CII 1994) and could ultimately affect FEED accuracy outcomes.

The accuracy of FEED can also be influenced by the project stakeholders and whether they are appropriately represented on the project leadership team (e.g., the sponsor, marketing, project management, operations and maintenance). Proper stakeholder input provides the leadership team with diverse expertise that covers both the technical and management areas of the project and helps to facilitate better solutions to the problems faced by the team (CII 2005). Organizational values and beliefs should align with the development and outcomes of a successful process (McLaughlin 2016). Moreover, key personnel at different levels on the owner side should show their commitment throughout the FEED process by always communicating its objectives and its required deliverables (Graetz 2000).

A final research critical to the development of the accuracy factors included work from the CII Alignment Thermometer (CII 1994) which is used to assess the state of alignment of a project team. The authors of this research concluded that alignment is a state not a process, and ten alignment issues were identified as shown in Table 1. These ten alignment issues may not be directly related to the accuracy of FEED, but will certainly play a role in making sure that FEED is performed in a well-aligned environment and through an openly-communicated process. One could argue that this would lay the groundwork for an accurate FEED development process.

Table 1: Ten Alignment Issues (CII 1994)

1. Stakeholders are appropriately represented on the project team	2. Our team culture fosters trust, honesty, and shared values
3. Project leadership is defined, effective, and accountable	4. The Pre-Project Planning process includes sufficient funding, schedule and scope to meet our objectives
5. The priority between cost, schedule, and required project quality features is clear	6. Reward and recognition systems promote meeting project objectives
7. Communication within the team and with stakeholders is open and effective	8. Teamwork and team building programs are effective
9. Team meetings are timely and productive	10. Planning tools (e.g., checklists, simulations, and work flow diagrams) are effectively used

Accuracy Factors Related to Project Resources

This subsection of the literature review reports on several articles focusing on project resources and how they could potentially affect the accuracy of FEED. The availability of key team stakeholders who contribute to the preparation of FEED in a substantive and measurable way is one of the key aspects to a successful process (CII 2005). The amount of time allocated per work cycle that key personnel are available to spend on FEED preparation is also important (Lan and DeMets 1989, Saudargas and Zanolli 1990). In addition, the quality and level of detail of engineering data available (e.g., as-builts, geotechnical, renovation history, site information, etc.) will impact FEED accuracy (CII 2005). Furthermore, sufficient funding is required to support the FEED process from the initiation of FEED until the final FEED deliverables are documented and approved (CII 2005). It is also important to have an excellent understanding of standards and procedures such as design standards, standard operating procedures, and guidelines (CII 2003, 2005). Moreover, the knowledge that the project team has developed over time in a given area ensures that the FEED is based on experience and adapted to the local culture and environment (CII 2003). It is also advantageous to have frequent project team meetings (Vafeas 1999). The availability of technology/software such as AutoCAD, Primavera, STAAD Pro, ETABS, SAP 2000, CSI SAFE, MXRoads, Pipe 2012, and others will impact the FEED process (CII 2005). The involvement of key vendors/subcontractors in FEED preparation is critical and their availability is important to acquire subject matter expert review that enriches the technical and practical content of FEED (CII 2005).

Overall, the literature review helped the research team to identify several gaps in knowledge about FEED, establish definitions of FEED, maturity and accuracy, gather maturity elements (which are from the PDRI-industrial) and factors that could potentially affect the accuracy of FEED.

PROBLEM STATEMENT & RESEARCH OBJECTIVES

Lately, the Construction Industry Institute (CII) identified a critical industry need to better characterize the maturity and accuracy of front end engineering design (FEED) deliverables as part of FEP activities. The primary objective of this paper focuses on ascertaining the construction industry's perception of FEED by administering a detailed survey to stakeholders of large industrial projects. Based on the outcome of the literature review, several gaps in knowledge were identified. These gaps included the following: First, FEED is rarely mentioned as a stand-alone term and is influenced by many project related factors, such as timing of the engineering design effort, construction cost and schedule estimate and alignment of key project stakeholders during detailed scope. Moreover, the authors noted that maturity of engineering design is not explicitly mentioned and had to rely on existing literature related to the PDRI for industrial projects in order to understand how FEED maturity is currently evaluated. Finally, while many project related factors can affect the accuracy of FEED, testing these factors on real world projects and how they affect performance outcomes is essentially non-existent. Therefore, the objective of this research investigation is to gauge the industry's perception of FEED and how industrial firms currently assess FEED, maturity and accuracy in order to create a more objective, scalable, and efficient tool to evaluate FEED at the end of detailed scope.

Definitions of FEED, Maturity, and Accuracy

First, as indicated in the previous section, an extensive literature review was conducted in order to document the state of knowledge of FEP, FEED, maturity, and accuracy and helped the research team develop definitions of FEED, maturity, and accuracy. These definitions, the maturity elements and accuracy factors were refined through research sub-team focus groups that included industry practitioners and research scientists. Based on this collective knowledge the research team developed standardized definitions of FEED, maturity and accuracy as follows.

FEED is defined as:

A component of the FEP process performed during detailed scope (Phase 3), consisting of the engineering documents, outputs, and deliverables for the chosen scope of work.

FEED *maturity* is defined as:

The degree of completeness of the deliverables to serve as the basis for detailed design at the end of detailed scope (Phase Gate 3).

FEED *accuracy* is defined as:

The degree of confidence in the measured level of maturity of FEED deliverables to serve as a basis of decision at the end of detailed scope (Phase Gate 3).

In addition to FEED, the project definition package (also known as the FEED package) typically includes non-engineering deliverables such as a cost estimate, a schedule, a procurement strategy, a project execution plan, and a risk management plan. Figure 4 illustrates the FEED definition and its relationship to the various other deliverables that are associated with the project definition package. The list of deliverables in Figure 4 is not meant to be an exhaustive list.

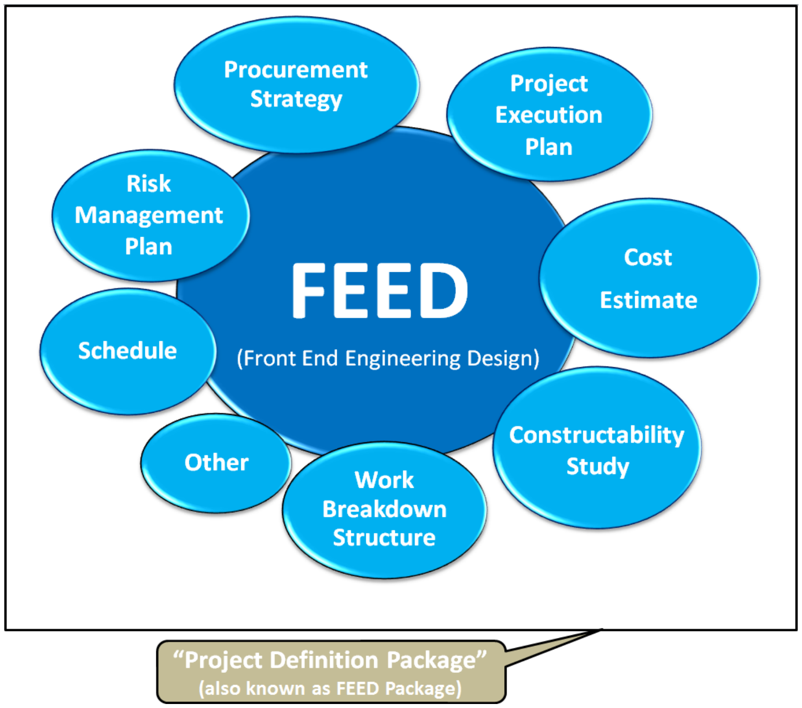

Figure 4: Project Definition PackageTo collect data for this research investigation the authors developed a multi-part 15 question survey to gauge the industrial construction sector's perceptions of FEED, maturity, and accuracy. The survey collected detailed information about FEED and various engineering aspects that are associated with a typical FEED process. The survey was developed with the Qualtrics Survey Software and distributed electronically to CII member organizations during fall 2015. The results of the survey were analyzed and discussed with the research team to finalize the definitions of FEED, maturity, and accuracy. Subsequent steps that were not part of this initial research effort included the tool development, workshops, and testing of in-progress projects. The next sections of the paper will illustrate the survey data characteristics and results.

SURVEY DATA CHARACTERISTICS AND RESPONDENTS

This section of the paper showcases the survey data characteristics indicating who responded to the survey, i.e., owner organizations versus contractor organizations. The next section elaborates on each of the survey questions and responses are discussed within the context of FEED. This is followed by conclusions and steps for future work.

The research team administered the survey through the CII data liaisons to 211 individual industry contacts. The survey was aimed at industry practitioners with minimum FEED experience of ten years with large industrial projects. The authors sent an email to each of the industry contacts with a brief description of the research and a request to complete the survey through a provided website link. Each industry member of RT 331 was asked to pass along the survey to any other practitioner that they felt might be interested in providing insight regarding FEED. The survey was open for a three-month period between December 2015 and February

2016. In total, 80 responses were received from individuals representing 33 organizations (19 owners and 14 contractors).

All data provided to CII in support of this research activity is considered confidential information. Individual company data will not be communicated in any form to any party other than the CII authorized academic researchers. Any data or analyses based on these data that are shared in this paper represent summaries of data from multiple participating organizations that have been aggregated in a way that will preclude identification of proprietary data and the specific performance of individual organizations.

SURVEY RESULTS

This section presents the survey results categorized into four subsections: (1) results on terminology, (2) results on FEED maturity, and (3) results on FEED accuracy. These three main subsections are followed by a discussion of the results.

Results on Terminology

First, one of the major objectives of the survey was to explore whether organizations have standard definitions of FEED. Thus, the first question asked, “Does your organization have a standardized definition of Front End Engineering Design (FEED)?” Forty-eight (60 percent) of respondents stated their organization has a standardized definition of FEED. These respondents were asked to provide their organization’s definition of FEED and 48 different FEED definitions were received. The remaining 32 respondents indicated that their organizations did not have standardized definition of FEED. The key takeaway point from this question is that 40 percent of respondents’ organizations did not have a standardized definition for FEED, and those that did all have different definitions. This question added value to the motivation of this research by showing that a standardized definition of FEED is warranted in the industrial project sector.

The next question tested whether respondents agreed with the research team’s FEED definition previously defined in the research methodology. Eighty-one percent (59 of 73) of respondents agreed with the research team’s definition of FEED. The survey also asked for feedback from respondents in order to help the research team refine its definition of FEED. Some of the feedback is shown here.

- I have not ever seen a "market analysis" as part of FEED.
- Need to have the estimate accuracy included.
- I have seen better end results when FEEDs are implemented during the FEL-2 phase of the project. This helps much better lock-in the scope during the FEL-3 phase and provides additional gains toward project alignment prior to FEL-3 initiation.
- Accuracy of the cost estimate or order of probable cost estimate (+/-10%) should be included in the FEED definition.

The subsequent question asked, “Does your organization have other terms that are used in place of the term FEED?” Fifty-five percent (40 of 73) of respondents indicated that their organizations use other terms instead of FEED. The respondents who answered that their organizations have other terms used instead of FEED were directed to question seven and asked to provide those terms. The most common terms that organizations use instead of FEED included: basic engineering design, basic design, preliminary engineering, project definition, concept design, and feasibility study. The key takeaway point from question six indicated that of the organizations that implement FEED, they have varying terms that are used in place of FEED which may hold different meaning to other organizations. This question provided further motivation that a standardized definition of FEED is warranted in the industrial project sector. Also, the diverse terminologies that organizations use, sometimes incorrectly, show that FEED is often mistaken for other project process.

The survey included a question regarding the percentage of all engineering design at the completion of FEED. This question asked, "In your opinion, at completion of FEED for a typical grassroots process facility of known technology, approximately what percentage of all engineering design (including process and non-process design) should have been performed (in terms of total engineering work-hours)?" Figure 5 provides a summary of the responses to this question. The maximum value was 80 percent and the minimum was five percent with the average value being 31.4 percent. The most frequent answer was 26-30 percent and it was chosen 25 times. This question tested the state of practice in organizations regarding the engineering design completion at the end of FEED.

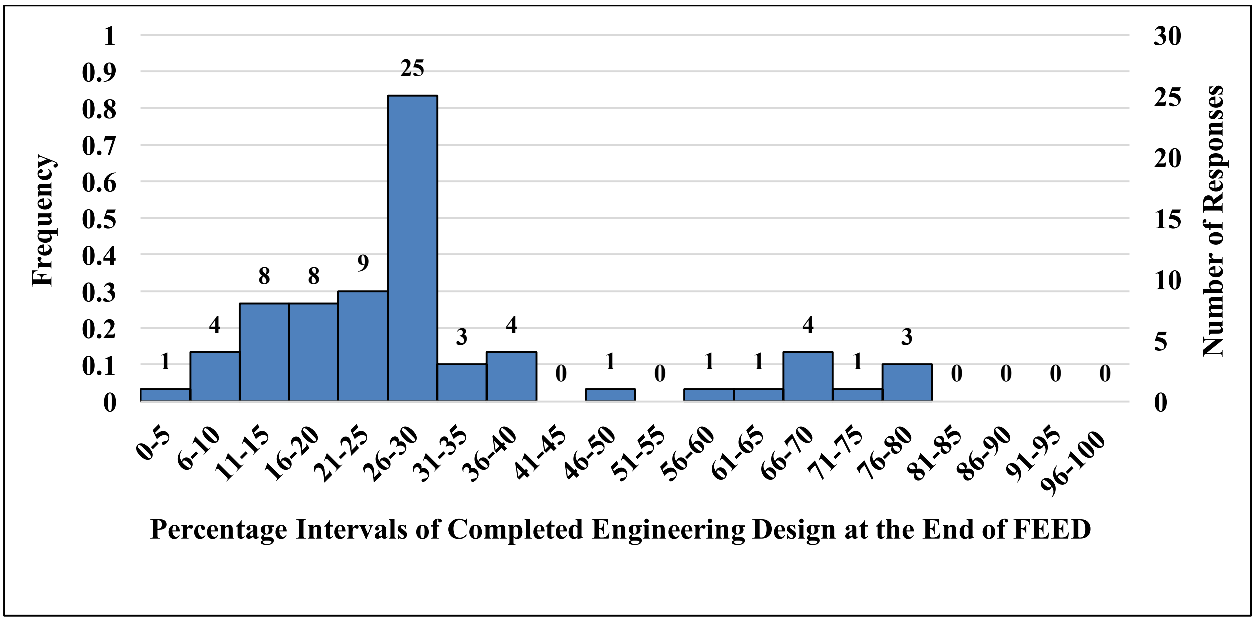

Figure 5: Percentage of Engineering Design Complete at the end of FEED (N=73)

The main take away point from Figure 5 is that the consensus average of engineering design completed at the end of FEED is 30 percent.

Results on FEED Maturity

This subsection presents the results received on FEED Maturity. The following question asked respondents to rank the top five engineering deliverables/documents (in accordance with the PDRI-Industrial) that are critical to conducting the FEED process. The question asked, "We realize that engineering deliverables/documents are important during the FEED process. The following three deliverables are usually defined by this time; Products produced by the facility, capacity of the facility in terms of products, and technology employed in the production process. In addition to the above, which deliverables in the list below do you feel are most critical for front-end engineering design?" Fifteen possible FEED deliverables/documents were posed based on information obtained from the PDRI-Industrial. The responses to these questions along with which engineering deliverables were chosen the most can be seen in Figure 6. These engineering documents/deliverables are reviewed throughout the FEED process. Overall, the top five deliverables included piping and instrumentation diagrams, project design criteria including applicable codes and standards, plot plans showing the location of new work in relation to as-builts, site location investigation, and process flow sheets.

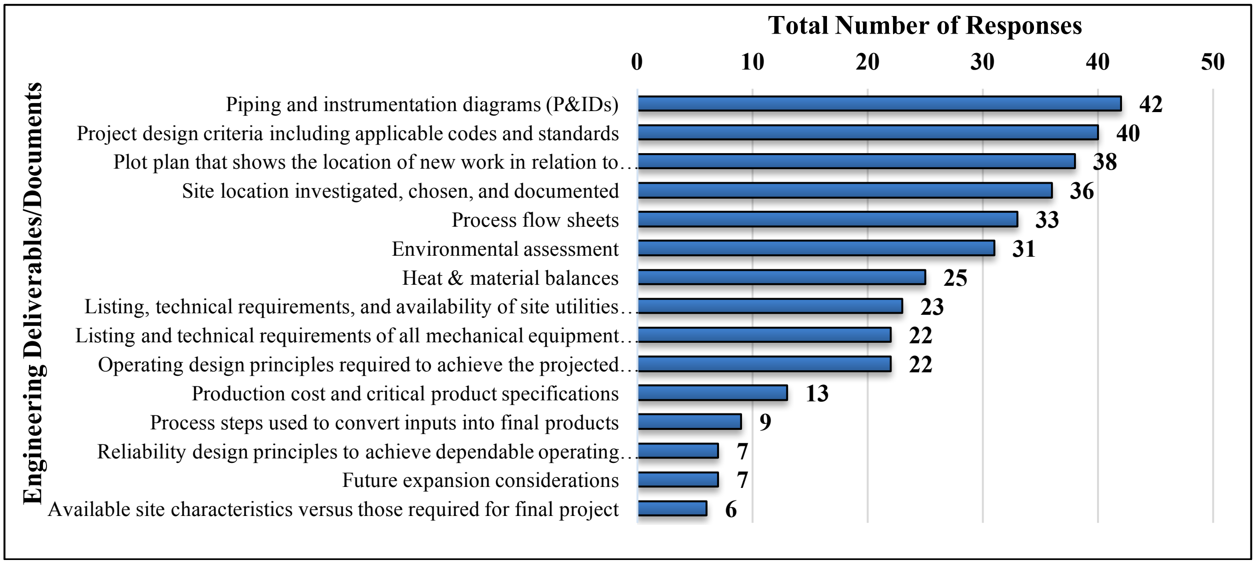

Figure 6: Engineering Deliverables/Documents Critical to the FEED Process (N=71)

Central to the main objective of this research effort, the survey included a question regarding the methods used by organizations to evaluate the maturity of the FEED documents at the end of detailed scope. The next question asked, "Maturity of the engineering deliverables is reached when the team is ready to move into detailed design. In your experience, how is the maturity of the FEED documents evaluated at Phase Gate 3?" Eleven possible evaluation methods were posed and the respondents were to check all that applied. Responses to this question can be seen in Figure 7.

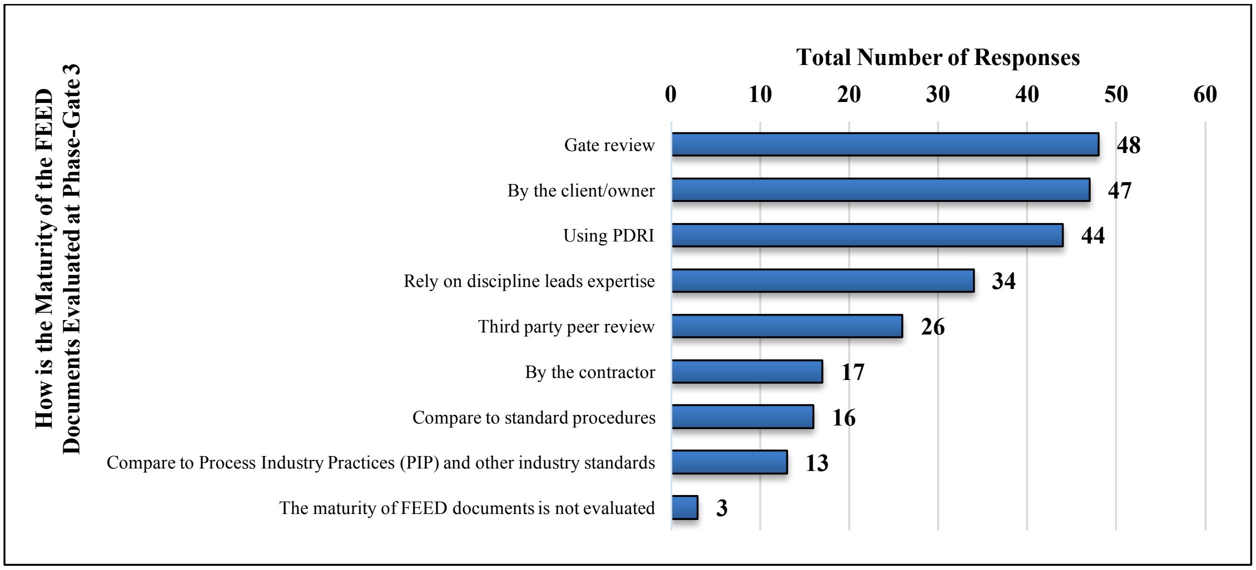

Figure 7: How is the Maturity of FEED Documents Evaluated at Phase-Gate 3? (N=71)

The responses here provide further motivation to the research as follows: First, this question shows that standardized practices to evaluate the maturity of FEED are warranted, citing the low response rate of "compare to standard procedures" and "compare to process industry practices and other industry standards." Second, the overall purpose of the research is to provide a standardized method/tool to conduct phase-gate reviews from the client/owner perspective to objectively measure maturity. From Figure 7 one can observe that gate reviews, client/owner evaluations, and using a PDRI are, by far, the top three methods used to evaluate the maturity of FEED documents/deliverables and shows that the development of standardized tools to measure maturity is warranted in the industrial project sector.

Further advocating the main objective of this research effort, the subsequent question asked, "Do you have a process/method/tool to objectively measure the maturity of FEED engineering deliverables? (For example, do you have a document that provides criteria for giving a 1, 2, 3, 4, or 5 score to deliverables in the PDRI?)" Respondents were asked to choose "yes" or "no" and if they chose "yes," they were directed to question twelve and asked to describe this process/method/tool. Fifty-two percent (37 of 71) of respondents indicated that they do not have a process/method/tool to objectively measure maturity of FEED, which gave even further motivation to the research team that a standardized method for evaluating maturity is warranted.

Figure 8 shows the total number of responses received for each process/method/tool. The most frequent process/method/tool was the PDRI appearing in 20 of the 38 responses. The second highest was third party reviews which appeared in 6 of the 38 responses. The main takeaway point from this question indicated that a majority of respondents were using the PDRI to evaluate maturity of FEED.

Overall, the key learning from the responses to the FEED maturity questions is that organizations are primarily using the PDRI to conduct their maturity evaluations. With this knowledge the research team can now posit, with validated certainty, that development of a standardized method to evaluate FEED maturity is warranted in the industrial project sector.

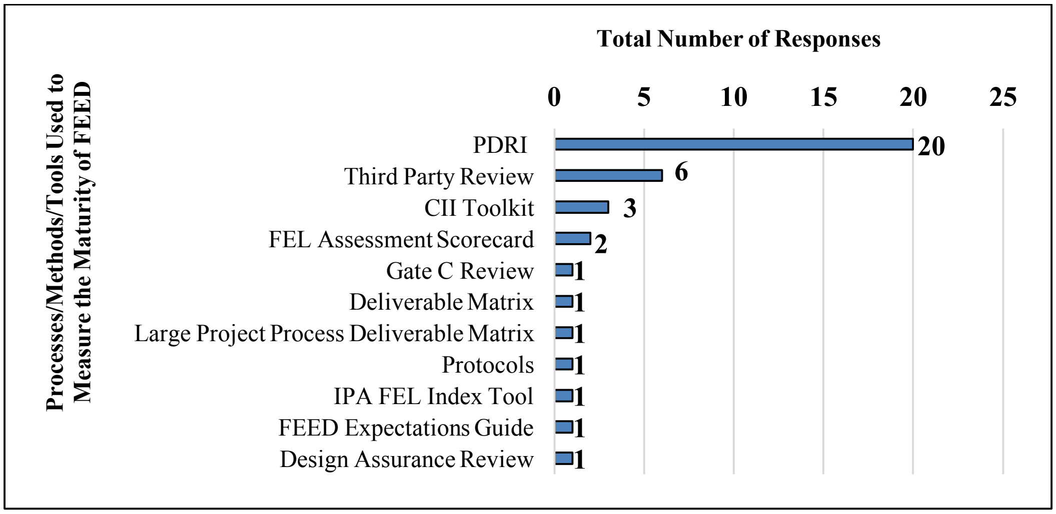

Figure 8: Processes/Methods/Tools Used by Organizations to Measure the Maturity of FEED Engineering Deliverables (N=38)

Results on FEED Accuracy

The survey included a question regarding the contextual factors that can influence the accuracy of FEED; the subsequent question asked, "The following contextual factors can influence the accuracy of FEED during front end planning. Based on your experience, please rank the top five factors in order of importance." Figure 9 summarizes the total number of responses for each contextual factor received for this question.

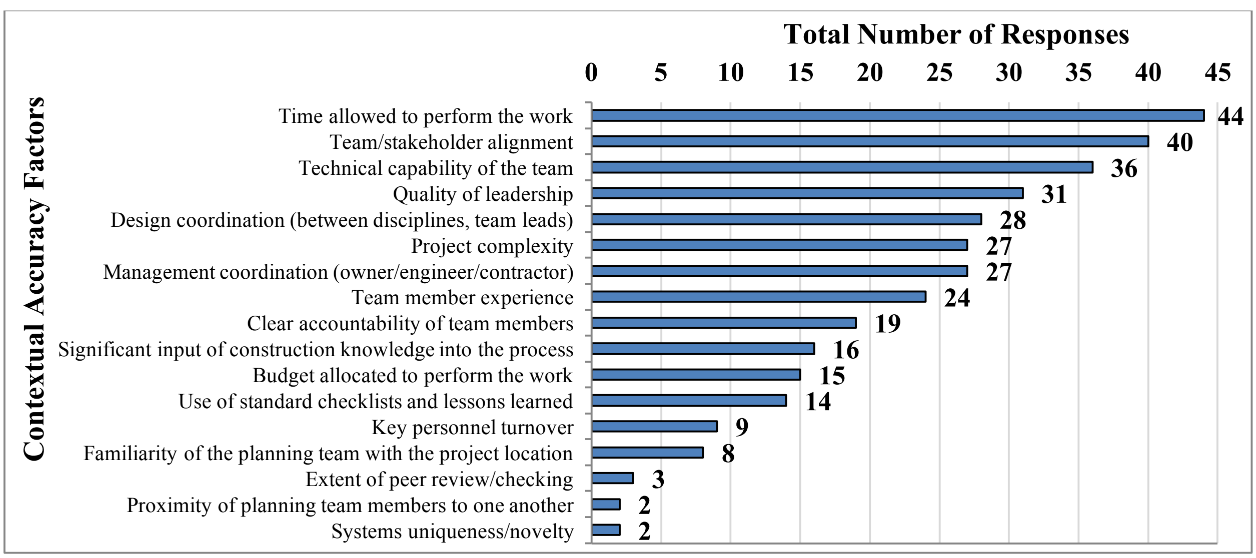

Figure 9: Contextual Factors that can Influence the Accuracy of FEED during Front end Planning (N=70)

From Figure 9 the top five contextual accuracy factors included the following: time allowed to perform the work (FEED work), team/stakeholder alignment, technical capability of the team, quality of leadership, and design coordination between disciplines and team leads. Based on these responses, the research team formed the baseline of accuracy factors to use in the tool development process. Figure 10 shows the frequency of the key strategies that organizations use to identify and mitigate feed deficiencies during FEP.

The key strategies that organizations use to identify and mitigate feed deficiencies are reviews; which included design reviews, management reviews, quality reviews, project reviews, peer reviews, gate reviews, schedule reviews, cost reviews, PRDI reviews, interdisciplinary reviews, third party reviews, technical reviews, contractor reviews, etc. Regardless of the method, "reviews" appeared in 42 of the 69 responses to this question.

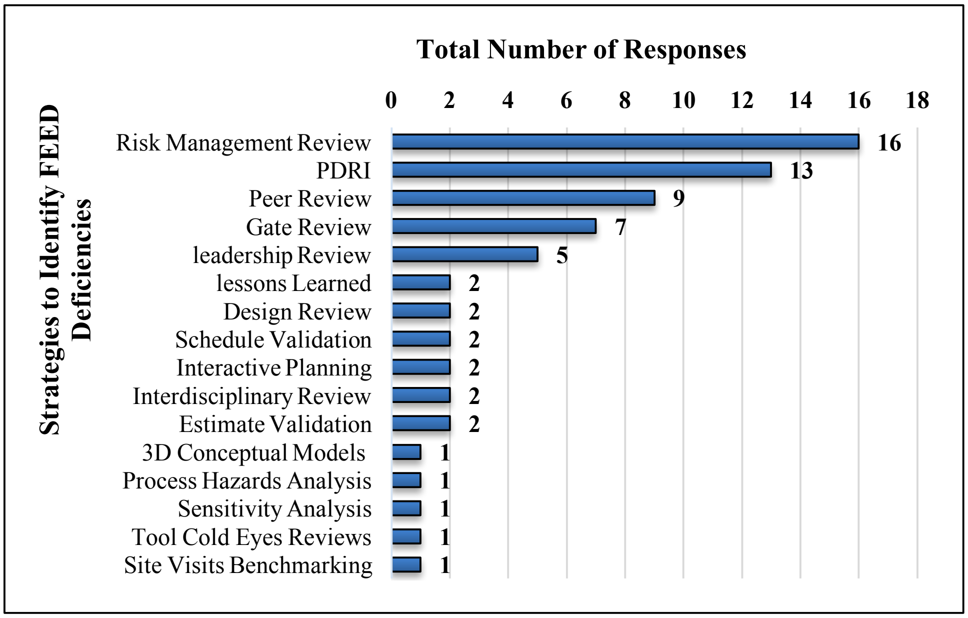

Figure 10: Strategies to Identify FEED Deficiencies

Finally, two open-ended questions were posed at the end of the survey, asking "Please provide key strategies that your organization uses to identify and mitigate FEED deficiencies during front end planning" and "Please feel free to share any other thoughts about FEED evaluation with the research team below."

Several key learnings were recognized from the results of the survey. First, a standardized definition of FEED is warranted in the industrial project sector. Second, the development of a project evaluation tool to objectively measure maturity and accuracy is warranted, citing that the PRDI or third party reviews are typically used. Third, 30 percent engineering design completed is the consensus average at the end of FEED and before moving to the design phase. Finally, several enabling factors that could potentially affect the accuracy of FEED were gathered and essentially "ranked" in the survey. Overall, the results from the survey will serve as a baseline for the development of the maturity and accuracy assessment tools to objectively measure maturity and accuracy of FEED for large industrial projects.

CONCLUSIONS

The authors and the research team received extensive input from survey respondents on FEED definitions, other terms used instead of FEED, FEED deliverables, process/tools/methods used to assess the maturity of FEED, strategies used to identify FEED deficiencies, and contextual factors that can potentially affect the accuracy of FEED. Several overarching conclusions from the survey are established.

RT 331 received several key results related to FEED, maturity, and accuracy definitions. The majority of respondents (60 percent) indicated that their organization has a standardized definition of FEED. However, the FEED definitions were diverse and inconsistent. Thus, a standardized definition of FEED is warranted in the industrial project sector. The majority of respondents (81 percent) agreed with the research team's definition of FEED. In addition, Fifty-five percent of respondents indicated that their organization has other terms used in place of FEED. Moreover, approximately 30 percent of engineering design complete seems to be the consensus for the end of FEED.

The survey also collected information on FEED maturity and organizations state of practice in assessing the FEED deliverables. In general, organizations do not have a standardized method for evaluating FEED maturity and have to rely on the PDRI or third party evaluation tools that may not have been verified with real world project data. The top five FEED deliverables (in accordance with the PDRI-Industrial) included piping and instrumentation diagrams, project design criteria including applicable codes and standards, plot plan showing the location of new work in relation to as-builts, site location investigation, and process flow sheets. Additionally, organizations consistently use "reviews" to identify and mitigate deficiencies associated with FEED.

Several key results were received on FEED accuracy. The top five contextual FEED accuracy factors included the following: time allowed to perform the work (FEED work), team/stakeholder alignment, technical capability of the team, quality of leadership, and design coordination between disciplines and team leads. Furthermore, the key strategies that organizations use to identify and mitigate feed deficiencies are reviews; which included design reviews, management reviews, quality reviews, project reviews, peer reviews, gate reviews, schedule reviews, cost reviews, PRDI reviews, interdisciplinary reviews, third party reviews, technical reviews, contractor reviews, etc. Regardless of the method, "reviews" appeared in 42 of the 69 responses to this question.

Overall, the development of a project evaluation tool to objectively measure FEED maturity and accuracy is warranted. The results of this paper add value to the motivation of this research and will help in developing assessment tools to aid in the evaluation of FEED maturity and accuracy for large industrial projects.

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