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A Framework for Enhancing Engineering Deliverables to Improve Construction Performance in Oil and Gas Projects

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by

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Abstract

Alberta's oil industry is one of the largest constituents of Canada's economy, and will remain a key determinant of the nation's economic growth for the foreseeable future. Existing research conducted on the performance of Alberta's oil industry capital projects reveals that construction cost overruns and schedule delays are among the leading contributors to capital expenditure in oil and gas projects. The significance of project cost and schedule growth has motivated industry and academia to initiate a great amount of research identifying the factors affecting construction performance in oil and gas construction projects. Problems in the project engineering phase, along with many other factors, have been identified as a root cause leading to cost and schedule slippage in construction within oil and gas projects.

The current study aims at bridging the existing knowledge gap of: (a) what factors in engineering deliverables are actually contributing to poor cost and schedule performance, and (b) how those factors can be mitigated during the process of projects. This research has been conducted in two phases to address those objectives. A quantitative research approach was adopted in the first phase to detect the issues in engineering deliverables, and a qualitative method was used in the second phase to identify the root causes that contribute to those issues, and the measures to mitigate them. In the first phase, the research data were collected through a questionnaire survey, and were quantitatively analysed to rank the identified issues by their impact on construction performance. In the second phase, interviewing was the main instrument for collection of data, which were then analysed using qualitative research techniques. Three major groups of issues were identified as the top-rank contributors to poor construction performance: engineering design issues, engineering schedule issues, and design changes after IFC (Issued for Construction) revision. The qualitative study in the second phase of the research revealed *communications* as the root of what needs to be

improved to enhance engineering deliverables. Built on the foundations of the findings in the two phases of the research, a framework was developed for enhancing engineering deliverables to improve construction performance.

The outcomes of this study can be used by oil industry project officials at different levels, to prevent construction cost and schedule growth, through implementing the findings of the research in project process, procedures, and other activities.

Acknowledgements

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Dedication

To Gitty, for her love and devotion,

… and to Kian and Nickan

… I love you all, and forever.

To Parvaneh and Ali,

Mom, Dad,

Thank you for all your prayers, and all the love you devoted from far away.

… *I am sure Dariush is smiling at me now.*

And to myself:

You did it!

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List of Symbols, Abbreviations and Nomenclature

Abbreviation	Definition
3D	Three Dimensional
C	Construction
CAD	Computer-Aided Drawing
CI	Confidence Interval
CIC	Construction Industry Council
CII	Construction Industry Institute
COAA	Construction Owners Association of Alberta
CWP	Construction Work Package
DBM	Design Basis Memorandum
DQ	Data Quality
E	Engineering
E&I	Electrical and Instrumentation
EDS	Engineering Design Specification
EHT	Electrical Heat Tracing
EP	Engineering and Procurement
EPC	Engineering, Procurement, and Construction
EWP	Engineering Work Package
FEED	Front-End Engineering Design
FEL	Front-End Loading
FID	Final Investing Decision
HAZOP	Hazard and Operability
HSE	Health Safety and Environment
ICT	Information Communication Technology
IFC	Issued for Construction
IFD	Issued for Design
IFP	French Institute of Petroleum
IFQ	Issued for Quotation
IFR	Issued for Review
IEA	International Energy Agency
IPA	Independent Project Analysis
IQ	Information Quality
IQS	Information Quality System
ISO	Isometric drawings
KOM	Kick-Off Meeting
KPI	Key Performance Indicator
LCC	Life Cycle Cost
LDT	Line Designation Table
LNG	Liquefied Natural Gas
LRDC	Late Deliverable Risk Catalogue

mb/d	Million barrels per day
MOC	Management of Change
MOM	Minutes of Meeting
NPV	Net Present Value
OTD	On-Time Delivery
P	Procurement
P&ID	Piping and Instrumentation Diagram
PE	Project Engineer
PFD	Process Flow Diagram
PM	Project Manager
PMBOK	Project Management Body of Knowledge
PMI	Project Management Institute
PO	Purchase Order
QA	Quality Assurance
QMS	Quality Management System
RFI	Request for Information
RII	Relative Importance Index
SRS	Simple Random Sampling
TBE	Technical Bid Evaluation
UFD	Utility Flow Diagram
VE	Value Engineering

Chapter One: **Introduction**

1.1 Overview

The oil and gas industry constitutes one of the largest sectors in world economy. Earlier world energy market forecasts indicated an average annual global oil and gas capital project investment of about USD 1 trillion per year between 2011 and 2035 (IEA, 2018; Rui et al., 2017). Although such a market outlook may be debatable given the oil price turmoil of the past few years, the current global economic growth, at 3.9% in 2018, suggests demand for oil grows at an average annual rate of 1.2 mb/d (million barrels per day), reaching a global oil demand of 104.7 mb/d in 2023 (IEA, 2018).

Oil industry construction projects are generally large, complex, and challenging to manage, and are characterized by their complexity, extreme size, fast-tracking execution strategy, and multi-disciplinary engineering teams. Cost overruns and schedule delays have been common phenomena in oil industry construction projects. A study by Merrow (2012) shows that about 78% of mega-projects (i.e. USD 1 billion and greater) in the oil and gas industry have experienced severe cost overrun and schedule delays.

Therefore, many scholars have conducted significant research to investigate construction performance, and to determine major contributors to cost overrun and schedule slips in oil and gas construction projects. There is no single cause for poor construction performance in oil and gas projects, as would be expected. The research findings encompass a wide range of causes and factors that vary based on the level of detail, categories, geographical and geopolitical applications, type of organization, size of projects, and other factors.

Among many factors that can affect construction cost and schedule performance in the oil industry, engineering and design deliverables (being the primary input for construction to realize the project) can be taken into account in improving or impairing construction performance. A number of research works about construction issues, such as rework and productivity, indicate that the causes of these issues can partially be traced back to some factors related to engineering performance (Ahmed, Ruwanpura, & Clark, 2005; Dai, Goodrum, Maloney, & Srinivasan, 2009; A. Hanna & Heale, 1994).

1.2 Research Significance and Problem Statement

As discussed in the previous section, cost overruns and schedule delays are common problems in the oil and gas industry. Construction projects in the Alberta oil industry have also been facing cost and schedule issues. A comparison between projects in Alberta versus the United States shows that projects in Alberta generally experienced poorer cost and schedule performance than projects in the United States. Between 2010 and 2014, Alberta project cost growth was 15.9% on average, while the average cost growth for the United State projects was 0.5% (COAA, 2014). For project schedule growth the numbers are 16.2% for Alberta versus 5.4% for the United States (COAA, 2014). Similar comparison of construction costs and schedule performance reveals that construction cost growth performance for Alberta projects was 24.8%, and for United States projects was 1.7%. Construction schedule growth was 17.5% for Alberta projects and 7% for projects in the United States. (COAA, 2014).

One other area that makes Alberta construction projects more vulnerable to poor performance is the amount of engineering design completed prior to the start of construction. Engineering and construction phases often overlap in EPC projects to reduce the project schedule. Starting construction activities without complete design information typically results in subsequent problems in construction, leading to poor cost and schedule performance. The average percentage of engineering design completion prior to the start of construction was 55% for Alberta projects and 75% for the United States projects, between the years 2010 to 2014 (COAA, 2014).

Canada's oil industry has faced a lot of strain from the low price of oil, which fell from at least USD 105 per barrel in mid-2014 to as low as the vicinity of USD 25 per barrel in early 2016. This oil price crash caused oil and gas construction project performance to get even more attention.

Previous research indicates that construction problems such as rework, productivity, and constructability, considered to be among the major contributors to poor construction performance, are in part the result of design problems (Cheng, Li, Love, & Irani, 2001; Dozzi & AbouRizk, 1993; Love, Edwards, & Irani, 2008; Ruwanpura et al., 2003). Design errors, for example, have accounted for the total amount of rework (Love et al., 2008). The findings of Jarkas and Bitar (2014) show that, out of the top ten ranked factors affecting construction productivity, six are directly related to engineering deliverables. Fayek, Dissanayake, and Campero (2004), who investigated the root causes of construction field rework through a case study on a mega-project in Alberta, found that design errors and omissions, and late design changes, were among the causes of rework in construction.

The impact of design change on construction productivity has been studied by a number of researchers. Georgy, Chang, and Zhang (2005) showed that 48% of scope changes and 56% of development changes in industrial projects take place during the detailed design phase. Jergeas (2009) identified the top ten areas for construction productivity improvement in oil industry projects, four of which pertained to preconstruction and engineering related activities.

A comprehensive literature review (presented in Chapter 2) reveals that, while a large quantity of research is dedicated to identifying factors affecting construction performance, very little research is conducted with a focus on the engineering phase, at the deliverable level, to identify potential causes of poor construction performance. As discussed earlier in this section, existing research (regarding causes of construction performance issues) primarily considered construction cost and schedule problems in the form of rework in construction, construction productivity, and labour productivity, and sought root causes for those problems in various aspects of project. Their findings, however, consisted of factors related to different phases of projects, which included only some high-level aspects of engineering, without consideration of the project engineering activities at the engineering deliverable level. Furthermore, little research addressed the direct impact of engineering on construction cost and schedule performances. The researchers were mostly aiming at mitigating certain aspects of construction such as rework and productivity.

Additionally, very little research addresses mitigating the engineering problems once they have been identified as contributors to poor construction cost and schedule performance.

1.3 Research Goals and Objectives

In order to address the shortcomings mentioned in the problem statement above, the factors in the engineering that directly impact construction cost and schedule need to be identified at the level of project engineering activities and deliverables, and once identified, proper actions should be taken to enhance the engineering deliverables by mitigating those factors or their consequences and, as a result, improving construction performance.

The purpose of this research will therefore be to develop a framework to enhance engineering deliverables in order to improve construction performance in oil and gas projects.

In order to reach the goal of the project, it should first be understood what factors in the engineering deliverables may cause poor cost and schedule performances in construction. Therefore, the first objective to tackle would be to identify the problems or issues in the engineering deliverables that can have a negative impact on construction performance. Once the problems in engineering deliverables that account for poor construction performance are identified, the second objective would be to develop a framework in oil and gas projects to mitigate those issues and enhance the engineering deliverables so that the construction performance is improved.

Hence, the primary research questions are as follows:

> ***Research Question One:*** What are the major factors in engineering deliverables that have a negative impact on construction performance?
>
> ***Research Question Two:*** How can engineering deliverables be enhanced to improve construction performance?

Based on the two main research questions, the secondary research questions can be listed as:

- What are the top ranked problems in engineering deliverables that impact construction cost?
- What are the top ranked problems in engineering deliverables that impact the construction schedule?
- How common are these problems in oil and gas construction projects?
- How can these problems be eliminated or reduced?

1.4 Research Scope

The scope of this research is limited to engineering construction projects in the oil and gas industry, which are defined in the Field Development Stage (See Section 2.1.1) and include production facility design and implementation. The following points may provide a better understanding of this research scope:

- This research investigates construction projects in oil and gas industry; therefore, the data collected through interview or questionnaire surveys were obtained from individuals experienced in oil industry projects.
- The engineering activities and processes, which are investigated to enhance the engineering deliverables through the outcome of this research, range from project early stages (FEL, as discussed in Chapter 2) to the end of the detailed engineering phase, including engineering services needed for construction after the detailed engineering phase is completed.
- The main focus of this study, in improving construction performance, is limited to the engineering impact on construction cost and schedule performances. Other aspects of construction performance (which are further discussed in Chapter 2, such as health, safety, and environmental (HSE) performance, quality of work, etc.,) are not considered in this research.

1.5 Research Methodology

In order to address the two research questions introduced in section 1.3, the research was conducted in two major phases, each addressing one of the research questions. The two research phases and corresponding research methodologies adopted for each phase are discussed below.

Phase I:

Phase I of this research aims at answering the first research question mentioned earlier, and identifying major factors related to the engineering deliverables, which may have a negative impact on construction performance. This phase also involves the ranking of these factors by impact and commonality. The outcome of this phase is understanding and prioritising the issues within engineering deliverables that need to be mitigated or eliminated to improve construction performance. As will be discussed in Chapter 3, this phase of the research complies with the characteristics of descriptive research; therefore, a quantitative research methodology is used for this phase of the research.

- **Data Collection for Phase I:** A questionnaire was the major data collection instrument employed for this phase. A preliminary list, consisting of 12 factors related to engineering deliverables with negative impact on construction cost and schedule performance, was prepared based on a comprehensive literature review, as well as discussions in focus groups consisting of experts in oil and gas EPC projects. A questionnaire was designed using the 5-point Likert measuring scale to validate the above-mentioned list, prioritize and rank the factors by their impact on construction cost or schedule performance, and their commonality (i.e. how common each factor is in oil and gas construction projects).
- **Sample size for Phase I:** Decisions regarding the sample size were made based on the adequate margin of error and confidence level. The sample size selection process is discussed in detail in Chapter 3.
- **Data Analysis for Phase I:** The quantitative analysis of data included the factor ranking method, which quantifies the significance of each factor through calculating and comparing the relative importance index (RII) in order to rank the factors of engineering deliverables in terms of their level of impact on construction cost and schedule, and their commonality.

The output of Phase I would define which engineering deliverables issues need to be enhanced in Phase II.

Phase II:

Phase II of this research is designed to answer the second research question, and is aimed at developing a framework to enhance engineering deliverables by eliminating or mitigating the issues in engineering deliverables identified in Phase I. Unlike Phase I, the nature of the research question in Phase II does not involve identifying existing phenomena or measuring attributes. Instead, this phase is about developing a better understanding of why the issues identified in Phase I are happening. Therefore, this part of the research complies with qualitative research characteristics, and a qualitative research method was implemented. This research was conducted by borrowing and using the major concepts of Grounded Theory, which is a form of qualitative research methodology seeking to construct theory grounded in data. This methodology is distinct from other qualitative research methods in that the concepts out of which the theory is constructed are derived from the very data collected during the research process (Leedy & Ormrod, 2013).

- **Data Collection for Phase II:** The main instrument for data gathering for this phase of the research is interview. The sample population from which the interviewees were selected were basically the project professionals who had participated in the Phase I questionnaire survey, as well as other project specialists who had not been approached in Phase I. In total, 26 interviews were conducted in this phase. A semi-structured interview approach was chosen for the interviews. This is because, first, the topic and the subject around which the interview questions revolved were already known to both the researcher and the interviewee, and second because the questions had to be open-ended, and yet the interviewee needed to be given enough space to add new but relevant ideas and feedback (a fundamental concept in Grounded Theory method).

- **Sample Size for Phase II:** Data collection in Grounded Theory is based on the *theoretical sampling* philosophy. Theoretical sampling refers to a method of data collection which is based on concepts derived from data during analysis, where further questions about these concepts drive the next round of data collection. The size of the sample is based on arriving at the point of saturation, where further data gathering does not add to what the researcher has already found. Decisions for the sample size in Phase II are discussed in detail in Chapter 3.
- **Data Analysis for Phase II:** Data analysis in Grounded Theory involves what is commonly referred to as *coding*, which is basically using mental strategies and analytical tools to interpret data. *Open coding* is generally referred to as breaking data down into more manageable pieces (known as *concepts*), examining them closely, and comparing them for possible relations, similarities, and dissimilarities. *Axial coding* is relating the concepts developed in open coding, and identifying major categories and their subcategories. *Selective coding* is the final stage of data analysis in Grounded Theory. Once the coded data categories and subcategories are identified through open coding and axial coding, the core category, which represents the main theme of the research, would be identified through selective coding.
- **Developing the Framework:** Once the core category was identified and the theme of the research was known, a framework was constructed through tailoring the core category and analysing data from the interviews, with the engineering deliverables issues the research sought to enhance.

1.6 Research Findings

Phase I of this research was aimed at identifying major engineering deliverables issues that have a negative impact on construction performance. The results showed three groups of issues in engineering deliverables that have a major impact on construction performance:

- **Engineering Design Issues:** refers to different dimensions of design problems including design errors, lack of constructability, and inadequacy of design.
- **Engineering Schedule Issues:** refers to schedule delays as well as the untimeliness of engineering deliverables.
- **Changes after IFC:** refers to changes in the engineering deliverables after the issuance of the IFC drawings. The changes after IFC can also be considered scope change for construction.

Following the findings of the first phase of the research, Phase II was seeking solutions to mitigate these issues, and thus enhance the engineering deliverables to improve construction performance. The result of the qualitative research adopted for this phase included identifying seven major categories, which were related by the category of *Communication*. Eventually the core category was conceptualized as *Communication: The One Thing to Enhance*. The wording used in the core category indicates not only that communication needs to be improved, but also that it is the most crucial of all the categories to be addressed.

The framework was then developed, comprising three modules as follows:

- **Module 1:** Communication and Enhancing Engineering Design Issues
- **Module 2:** Communication and Enhancing Engineering Schedule Issues
- **Module 3:** Communication and Enhancing Engineering Scope Issues

1.7 Research Contributions

The research has valuable contributions to both theory in academia, and project management practice in oil and gas construction industry projects. The research has employed pure scientific methods to identify one of the root causes of poor construction performance in the engineering phase of projects, and introduced a framework to mitigate the issues. This was achieved by bringing in first-hand project knowledge of oil and gas project experts, and by using academic instruments to obtain valid findings that can be used to further both theory and practice.

- **Contribution to Theory:** The current research provided an academic theoretical basis for identifying communication problems as one of the fundamental concerns in oil and gas projects, which was previously only acknowledged through the individual perceptions of project experts based on their personal experiences. The research helped fill the identified gap, through comprehensive review of the literature and studies pertaining to engineering-related contributors to poor construction performance. This research introduced unique features in the adopted research method as complementary to the standard research methodology. These unique and creative techniques can be used by other researchers to conduct similar qualitative research in the future. It was scientifically concluded that communication problems are actually the basis for a number of other engineering-related issues, such as coordination, alignment, stakeholder involvement, scope definition, constructability issues, and even lack of adequate knowledge in teams.
- **Contribution to Industry:** The current research provides tangible, practical, straightforward, and yet academically-supported solutions to improve communication as a major industry challenge, in the form of more than 200 recommendations and guidelines (Chapter 6). These can be practically implemented in the day-to-day activities of project

teams including lead engineers, project engineers, engineering managers, project managers, etc., in oil and gas projects. A further contribution to industry includes proposing practical mechanisms that can facilitate communication among different project stakeholders.

The research contribution to the industry and the academia are discussed in further detail in Chapter 7.

1.8 Thesis Structure

This thesis is presented in seven chapters and three appendices. The chapters and their content are as follows:

- **Chapter 1 - Introduction:** This chapter provides an overview of the entire research, and discusses the research problem statement, goals and objectives, scope and methodology, and findings and major contributions.
- **Chapter 2 - Literature Review:** This chapter presents a comprehensive review of the previous literature pertaining to topics relevant to the current research, including construction performance and the factors influencing it, engineering deliverables and their impact on construction, etc. The knowledge gap that exists in the area of the current research is also presented.
- **Chapter 3 - Research Methodology:** This chapter discusses, in detail, the methodology adopted for Phases I and II of the research. A brief introduction of the quantitative and qualitative research philosophies is presented. The quantitative approach for Phase I is elaborated upon, and the qualitative method adopted for Phase II is also discussed in detail. Extensive discussions about sampling and sample size for both Phases I and II are also presented.

- **Chapter 4 - Data Collection and Analysis for Phase I:** The whole process of quantitative data gathering and analysis performed for Phase I is discussed in detail, including questionnaire design, measuring scales, selected sample size, and the factor ranking method. The findings of this phase, in terms of identifying and ranking the factor in engineering deliverables and corresponding discussions, are also presented.
- **Chapter 5 - Data Collection and Analysis for Phase II:** This chapter elaborates upon Phase II of the research, as well as the qualitative research methodology employed to find solutions to mitigate the issues identified in Phase I, and developing the framework to enhance engineering deliverables. The process of open coding and axial coding for this research is explained, and a sample work for a selected interview is presented (note that the comprehensive analysis of data for all 26 interviews are presented in Appendix A). The core category and overall research theme are identified.
- **Chapter 6 - Developing the Framework:** This chapter presents the framework for enhancing engineering deliverables to improve construction performance, which encompasses the findings pursuant to the two research questions in Phases I and II of the research.
- **Chapter 7 - Conclusion:** This chapter presents a summary of research processes and findings, followed by a detailed discussion of research contributions. Finally, the general recommendations and future possible research areas are presented.
- **Appendix A:** The actual work of open coding, axial coding, and writing analytical memos for all of the 26 interviews conducted for this research are presented in Appendix A. This appendix is intended to be studied alongside Chapter 5 as a reference for the descriptions of concepts and code numbers, and how they are grouped and categorized.

- **Appendix B:** Research participant recruitment documents.

Chapter Two: **Literature Review**

This chapter investigates the existing literature in the areas relevant to the key research questions. The literature search included textbooks, journal articles, dissertations, and the Internet. Among the major library databases used for the current literature review were *Compendex* and *Google Scholar,* two of the most comprehensive bibliographic database of engineering and management research available.

2.1 Engineering Process in Oil and Gas Industry

As discussed in Chapter 1, the main purpose of this study is to enhance engineering deliverables in terms of addressing construction performance requirements. To achieve this, one would need to develop an understanding of the current framework of engineering practices in oil and gas projects.

2.1.1 Project Life Cycle

The focus of this research is projects defined for production facility design and implementation. However, it is also useful to have a broader picture of a typical hydrocarbon field life cycle, where the production facility design and implementation is only one phase.

The French Institute of Petroleum (IFP) views a typical hydrocarbon field life cycle as having five major stages as listed below and shown in Figure 2.1:

1. Field Discovery
2. Field Evaluation
3. Field Development
4. Field Production
5. Field Abandonment

This concept is used extensively in the oil and gas industry, with minor differences depending on the focus of the organization and any activities driven by a business need related to that particular stage or phase. For example Jahn, Cook, and Graham (2008) defined an oil field life cycle with five stages: 1) gaining access, 2) exploration, 3) appraisal, 4) development, 5) production, and 6) decommissioning. This definition is very similar in concept to the IFP definition.

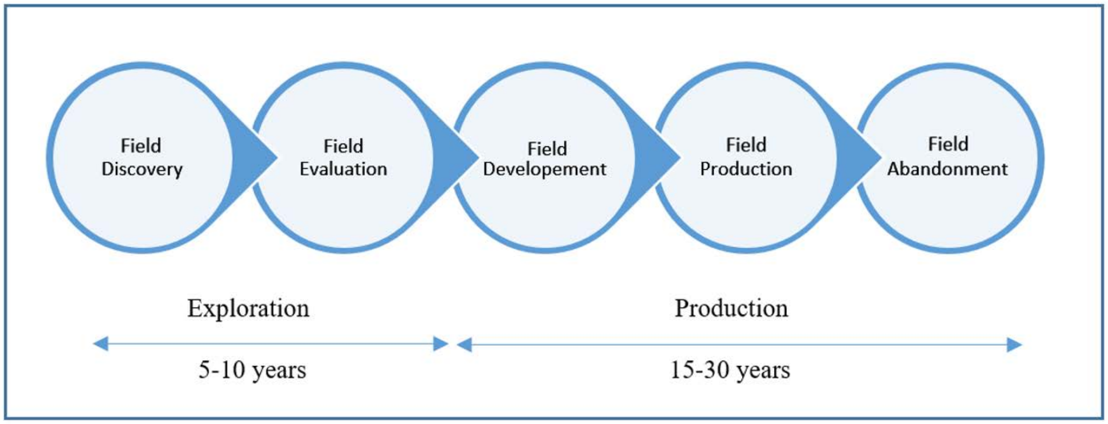


Figure 2.1: Typical hydrocarbon field life cycle

As shown in Figure 2.1, the first two stages (field discovery and field evaluation) constitute a major phase called *Exploration*, which normally takes five to ten years to complete. The three stages of field development, production, and abandonment form the *Production* phase, which will last 15 to 30 years depending on the size and capacity of the field, or the economical rate of production. (IFP School)

The field development stage in the *Production* phase includes the production facility design and implementation (IFP School), which is the main scope of knowledge for this research. The following activities take place in the field development stage (Jahn et al., 2008):

- Project selection and conceptual design
- Detailed design of the facilities
- Procurement of the resources for construction

- Fabrication and installation of facilities
- Commissioning of all plants and equipment

For the purpose of this study, and hereafter, *Project Life Cycle* refers to a sequence of phases of activities that take place during the facility design and implementation stage.

The Construction Industry Institute (CII) considers five phases for projects: *Front-end Planning*, *Detailed Engineering*, *Procurement*, *Construction*, and *Commissioning* (Robu, Sadeghpour, & Jergeas, 2018). Typically, however, the oil industry project life cycle has three major sections, which are defined based on different business needs, the involvement of stakeholders, risk allocation, level of scope definition, etc. The three major sections in oil and gas projects life cycle are (Merrow, 2012):

- Front-End Loading or FEL
- Project Execution (Engineering, Procurement, and Construction or EPC)
- Commissioning and Operation

2.1.1.1 Front-End Loading

Front-End Loading, also known as FEL, is a series of activities typically directly managed by the owner to bring the project from an initial idea all the way to the point where a Final Investing Decision (FID) can be made. In other words, FEL is the owner work process that prepares the project for FID (Merrow, 2012). FEL is formatted into three separate phases, which are mainly focused on value identification. Each phase has its own specific goal and deliverables, and ends with a stage gate where a decision is made to move the project to the next phase, redo the current or previous phase, or even shot down the project altogether (Walkup & Ligon, 2006). The front-end loading phases are discussed below (Merrow, 2012; Moazzami Goudarzi, 2016; Walkup & Ligon, 2006):

FEL 1- Feasibility: The Feasibility phase is basically the business case development and appraisal phase, where it is decided whether the project is feasible and matches the corporate strategic goals, and broadly identifies other key stakeholders of the project. This phase ends with the decision to continue to the next phase and, in the case of a go-ahead decision, an execution plan for the next phase.

FEL 2- Selection: different development plan alternatives for the projects are studied and the best plan is selected during the selection phase. Technical and commercial aspects of alternative development plans are reviewed by an experienced team. Concept design on a very broad range is performed in this phase for the selected alternatives. An important deliverable of this phase is the Design Basis Memorandum (DBM), which serves as the basic design information used in the next phase.

FEL 3- Front-End Engineering Design (FEED): In this phase, the concept design from the selection phase is completed with details that make the design sufficient for FID. Project scope and specifications are prepared to greater details and project cost is estimated, with an accuracy ranging from -20% to +30% (Moazzami Goudarzi, 2016). The main deliverable of this stage is the Engineering Design Specification (EDS), which is a fundamental document used in the EPC stage to develop a detailed engineering design, and start procurement and construction. Value engineering processes are sometimes implemented at this phase to ensure that the final plan effectively and efficiently meets project needs, as well as organizational business requirements.

FEL section finishes at the end of FEL 3 (FEED), where adequate information is there for the owner organization to approve (or reject) the FID. With FID in place, the project moves to the Project Execution or EPC phase.

2.1.1.2 Project Execution

The Project Execution phase starts once the FID is approved, and encompasses three major activities: engineering (E), procurement (P), and construction (C). Despite the fact that this stage, compared to FEL, accounts for a greater portion of project Capital Expenditure (CAPEX), generates the majority of project deliverables, involves sometimes even hundreds of subcontractors and thousands of people (Walkup & Ligon, 2006), demands tremendous project management skills and experience, and can have a huge impact on the success or failure of the project, it is still considered one phase in the project life cycle. This is mainly because of the fact that the ownership and the risks of all of these activities are to a great extent allocated to an entity outside the owner's organization, normally referred to as the General Contractor, or EPC Contractor. The EPC Contractor is completely in charge of the execution of the plan during this phase, and of delivering the facility to the owner.

Possessed of the biggest portion of project CAPEX, the Project Execution phase plays an important role in achieving project cost and schedule objectives. However, research shows that causes of project performance issues, such as cost overruns and schedule delays, can be traced back to poor performance and inadequacy of design and scope definition during the Front-End Loading (FEL) stage of the projects (Jergeas, 2008; Jergeas & Ruwanpura, 2009; McTague & Jergeas, 2002). The Execution phase ends with the completion of construction and pre-commissioning activities to prepare for plant turnover to the owner.

2.1.1.3 Commissioning and Operation

The Commissioning and Operation phase in the project lifecycle involves turnover activities to verify construction completion and mechanical completion of the project and that the plant is ready to commence operation. The turnover scope of work provides the list of activities that must occur to meet contract obligations for mechanical completion. The EPC contractor is also responsible for providing high-quality information deliverables to the owner/operator to enable effective operation and maintenance of the designed and constructed facility, and capture historical project information in a way that it can be retrieved for future reference.

At the end of this stage, the Field Development stage of the hydrocarbon field five major stages mentioned earlier (Figure 2.1) is completed, and Field Production is commenced.

The project life cycle for a typical oil sand project in Northern Alberta is shown in Figure 2.2 (Jergeas, 2008). The five distinct phases of an oil and gas project life cycle discussed above, and high-level concept of activities and deliverables, can be seen in Figure 2.2.

Phase 1 Identify and Assess Opportunities	Phase 2 Generate and Select Alternatives	Phase 3 Develop Preferred Alternative	Phase 4 Execute	Phase 5 Operate and Evaluate
Determine project feasibility and alignment with business strategy	Select the preferred project development option	Finalize project scope, cost and schedule and get the project funded	Produce an operating asset consistent with scope cost and schedule	Evaluate asset to ensure performance to specification and maximum return to the shareholders
PFD	P&ID	AFE	Detailed design Procurement Fabrication Construction	

Note. AFE appropriation for expenditure, PFD =process flow diagram, P&ID piping and instrumentation diagram.

Figure 2.2: Life cycle of an oil sand project (adapted from Jergeas, 2008)

2.1.2 Design Process and Deliverables

The majority of engineering activities occur in the Project Execution phase of the project life cycle discussed in section 2.1.1, which involves detail engineering, procurement, and construction of the project. The project execution phase is where all engineering deliverables are used in procurement and construction are generated.

A project milestone list prepared by the Construction Owners Association of Alberta (COAA) for oil and gas EPC projects identifies in detail the milestone for each engineering discipline, as well as corresponding engineering deliverables for each phase of a typical EPC oil and gas project (COAA, 2016). Derived from that list, Figure 2.3 shows a high-level list of engineering deliverables per discipline. It should be noted that not all of the engineering deliverables listed in Figure 2.3 are directly used in the construction phase. However, such deliverables are equally important in that they serve as prerequisites for other deliverables used in construction, and therefore can impact other documents dramatically. Additionally, there are other interdisciplinary documents that are issued among the engineering disciplines to provide input data necessary for design. Those documents are not officially referred to as deliverables, and there is no contractual obligation for the engineering body to deliver such documents to the owner. Structural load lists, equipment general arrangement, different types of layouts, and clash lists are among such documents.

Process

- Process Flow Diagram - IFR
- Process Flow Diagram - IFD
- P&IDs and UFDs - IFR
- P&IDs and UFDs and LTDs - IFD
- PI&Ds - IFC

Mechanical

- Preliminary Equipment List - Issue for DBM
- Equipment Datasheets - IFQ
- Equipment List - IFD

Piping

- Plot plan - IFD
- Plot plan - IFC
- Tie-in list - IFC
- Final client model/layout reviews
- First ISO issue

Civil/Structural

- Rough grading plan-IFC
- Deep underground-IFC
- Piling-IFC
- Foundations / Sitewide concrete-IFC
- Structural steel-IFC
- Final grading and Paving-IFC

Instrumentation

- I&C Inputs for DBM - IFR
- Instrument tagging procedure-IFD
- Inline devices data sheets-IFR
- Bidder's specifications/vendor data IFD
- I/O count/loop drawings-IFD
- Shutdown keys -IFC
- Control room layout IFD
- Instrument index - IFC

Electrical

- Area classification-IFR
- Load list-IFD
- Single Line Diagrams IFD
- Electrical equipment data sheets-IFD
- Area classification-IFD
- Cable and Tray Schedule-IFC
- Electrical equipment layout -IFC
- Single line diagrams IFC
- Electrical heat tracing ISO's IFC

Glossary:

DBM - Design Basis Memorandum
IFC - Issued for Construction
IFD - Issued for Design
IFQ - Issued for Quotation
IFR - Issued for Review
ISO - Isometric Drawings
LDT - Line Designation Table
P&ID - Piping and Instrumentation Diagram
PFD - Process Flow Diagram
UFD - Utility Flow Diagram

Figure 2.3: High-level list of engineering deliverables per discipline

2.2 Construction Performance in Oil Industry Projects

The most fit-to-purpose criteria for any project success are its objectives, and the degree to which the objectives have been met determines the success of the project (De Wit, 1988). Derived from this conceptual definition of project success, construction project performance can be translated as the extent to which the project has achieved its planned goals.

Oil industry projects have shown decreasing success rates in the first decade of the 21st century (Merrow, 2012). Research by Independent Project Analysis (IPA) reveals that while non-oil and gas development projects increased in size and difficulty, they maintained a success rate of approximately 50%, whereas only 22% of oil and gas mega-projects could reasonably be called successful (Merrow, 2012).

When evaluating construction performance, different aspects of performance may be studied and measured. Five common aspects of construction project performance, which can well define overall project performance, are as follows (Chanmeka, Thomas, Caldas, & Mulva, 2012; COAA, 2014; Ikpe, Kumar, & Jergeas, 2014):

- Cost
- Schedule
- Construction Safety
- Changes
- Rework

Project cost and schedule performance indicate the amount of variation from planned cost and schedule goals at project sanction (COAA, 2014). For safety, changes, and rework, there is normally no initial pre-defined target or goal at project sanction. However, these aspects may be measured in terms of overall performance at project completion.

Over the last two decades, oil and gas capital construction projects have constituted a large portion of the construction industry in Canada (Jergeas, 2009). Recently, many large capital construction projects in the oil industry have experienced significant cost and schedule overruns (Jergeas & Ruwanpura, 2009). The poor performance of construction projects meeting cost and schedule projections cannot be traced to a single cause. However, cost and schedule performances in construction projects can clearly be associated with productivity in the construction sector.

The construction industry in North America has suffered from declining productivity over the past three decades (Jergeas, 2009) and productivity is one of the major concerns of the construction industry (McTague & Jergeas, 2002). Industrial facility construction—including oil and gas construction projects, which represents a major portion of the construction industry—is therefore impacted by problems associated with the loss of productivity.

2.2.1 Construction Cost Performance

Cost performance is evaluated based on the variation from the original planned cost estimate at project sanction. Cost performance issues in construction projects have been a major concern for both owners and contractors. It seems that cost performance problems are faced in many industries other than oil and gas. Construction projects ranging from the simplest to more complex projects such as nuclear plants, environmental restoration, transport systems and oil and gas facilities have increasingly faced cost overruns (Baloi & Price, 2003). A study by Morris and Hough on a total of 1778 projects funded by the World Bank between 1974 to 1988 shows that 63% of the projects under study had resulted in significant cost overruns (Morris & Hough, 1987).

When project actual cost represents a significant positive difference from its FID estimates, it can be considered a failure in cost performance. This, however, does not necessarily mean that the project is not profitable. The amount of cost overrun only reduces the Net Present Value (NVP) of the project. Based on this criteria, 78% of 318 mega-projects studied by Merrow (2012) suffered from an average 33% cost overrun. This finding is consistent with a 2006 survey by Booz Allen Hamilton that studied 20 companies including major EPC firms and heavy industrial companies across the United States, Europe, and Asia, with more than $100 billion capital spending combined. The survey showed 40% of the projects in these companies suffered from costly budget and schedule overruns (McKenna, Wilczynski, & VanderSchee, 2006).

2.2.2 Construction Schedule Performance

Like cost overruns, construction delays are one of the most common problems in oil and gas construction projects. Construction cost and schedule performance problems can have common root causes in projects; one obvious consequence of schedule slip in a project is cost overrun in the same project. In other words, issues that lead to poor schedule performance will likely eventually result in significant impacts on actual construction cost. For this reason, a number of researchers addressed both cost and schedule issues in oil and gas construction projects, and their corresponding causes within projects in their research works (Ahmed et al., 2005; Alias et al., 2015; Ikpe et al., 2014; Jergeas & Ruwanpura, 2009; McKenna et al., 2006; Merrow, 2012).

As a result, one can conclude that the overall perspective of schedule performance in oil and gas construction projects is no better than cost performance. As discussed earlier, McKenna et al. (2006) showed that 40% of the overall projects of 12 major EPC companies from the United States, Europe, and Asia underwent considerable schedule delays. Independent research across the globe shows similar results for schedule performance in oil industry projects in different countries. For example, in Saudi Arabia 70% of capital construction projects had 10–30% delays in schedule. This number is 50% in the United Arab Emirates, and just above 17% in Malaysia (Ruqaishi & Bashir, 2013).

2.3 Factors Affecting Construction Performance

As might be anticipated, there is no single cause for poor construction performance in oil and gas projects. A great deal of research has been conducted to find causes of performance issues in the construction industry. As mentioned earlier, there are similarities between oil and gas projects and other major construction projects in terms of the factors affecting construction performance.

The research findings encompass a wide range of causes and factors that vary based on the level of details, categories, geographical and geopolitical applications, type of organization, size of projects, etc.

Among earlier attempts to define and improve project success, Hayfield (1979) identified two very basic and high-level sets of factors that impact the outcome of a project, referred to as *macro factors* and *micro factors*. Macro factors are those factors mainly under the control of owners, such as the realistic definition of projects ("what"), efficient manner of project execution ("how"), comprehension of project environment ("context"), and selection of the organization to fulfill the project ("by whom"). Micro factors, on the other hand, are those that are mainly managed by the engineer/constructors' organization, such as sound project policies, clear and simple project organization, selection of key personnel, efficient management controls, and a reliable management information system. Although Hayfield's categorization of factors addressed a very high-level and general project concept, the nature and ownership of the above-mentioned categories imply that only the execution (engineering and construction) section of project life cycle is being considered.

Almost a decade later, a pilot study conducted by Ashley, Lurie, and Jaselskis (1987) at the University of Texas, which was carried out on successful construction projects, addressed similar but more specific success factors be emphasized in order for a construction project to achieve its goals. Those factors included planning effort (both in construction and design), project manager goal commitment, project team motivation, project manager technical capabilities, scope and work definition, and control systems. The factors suggested by the study were shown to be related to certain success criteria, including *budget performance, schedule performance, client satisfaction, functionality, contractor satisfaction*, and *project team satisfaction*. Interestingly, only one factor related to the design phase, namely *planning effort in design*, was identified as being among the factors affecting construction success.

Baloi and Price (2003) categorized the factors affecting the cost performance into two major categories: one was the factors intrinsically related to construction organizations and are solely the responsibility of those organizations to manage; and the other was the factors closely related to the socio-cultural, economic, technological and political environments within which such organizations operate (*global risk factors*), which normally cannot be managed by the construction organization.

Jergeas and Ruwanpura (2009) studied reasons for cost and schedule overruns in oil sand mega-projects in northern Alberta. The study revealed root-cause factors such as *lack of understanding the complexity of project, inadequate front-end loading and definition of project scope, misaligned strategies for project management, contract, design, procurement, construction*, and *commissioning*, which do not consider factors such as *level of scope definition, fast-tracking requirements, market conditions etc*., and *poorly directed execution of projects*. Although the authors do not directly refer to any engineering-related case for poor construction performance, some aspects of engineering deliverables (such as proper timing, and considering the fast-track nature of the projects) are indirectly implied.

2.3.1 Rework in Construction

Rework (which is essentially a non-value-adding repetition of a task during construction) has been identified as one of the major factors affecting construction cost and schedule performance. Research by the Construction Industry Institute (CII) reveals that direct costs caused by rework average 5% of total construction costs (Smith & Jirik, 2006), which can be even higher because they do not include other costs such as litigation costs, costs incurred due to the schedule delays, and other costs incurred due to poor quality (Love, Li, & Mandal, 1999). This is in alignment with the facts presented by Hegazy, Said, and Kassab (2011) based on the review of existing literature on rework cost reported in various studies, as shown in Figure 2.4.

There is a common understanding in recent times that a major factor contributing to the occurrence of cost and time overruns is rework, which typically demonstrates itself in the form of changes and errors (Love, Edwards, & Irani, 2008). Much research has been dedicated to identifying the causes of rework in construction and its impact on construction performance. Many others have focused on finding a way to mitigate rework.

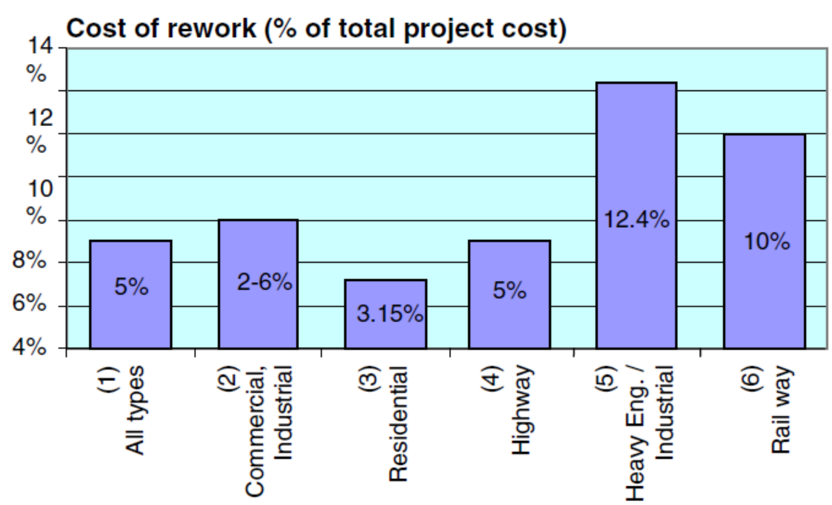


Figure 2.4: Cost impact of rework reported in various studies (adapted from Hegazy et al., 2011)

According to Love, Irani, and Edwards (2004), analysis of rework costs clearly indicate that rework is a main source of cost growth in projects, and emphasizes that the amount of rework needs to be reduced if construction performance is to be improved. The researchers also identified the significant variables that contributed to rework in 161 building construction projects, and used those variables to develop an alternative procurement model that could be used to reduce rework in construction projects. The research finds that four major contributors (out of 87 variables) to the total rework cost are: *client changes*, *value management in design*, *ineffective use of information technology by design team*, and *not freezing design scope*. The findings of this research clearly emphasized the role of the design process in reducing rework and thus improving construction performance. This study showed that value management can be used to re-evaluate the functionality and the requirements of clients, and can thus be used to minimize client-initiated changes. Value management can also be used to minimize design changes and errors. According to this research, the ineffective use of information technology may lead to inadequate and non-timely transfer of information between design team members, and cause significant restrictions on decision-making as a result. The study also suggested that when information technology is used effectively by design team members it can improve information flow and communication, and facilitate decision-making and design coordination.

(Hwang, Thomas, Haas, & Caldas, 2009) conducted a study on the impact of rework on construction performance using data from 359 selected projects out of the CII Benchmarking and Metrics program database which, at the time of research, was composed of data from 1,057 projects completed by 41 owner and 35 contractor companies. The data from the selected projects were analysed separately for owner and contractor organizations. The categories of construction projects included light and heavy industrial, buildings, and infrastructures. The sources of rework were classified as *owner change, design error/omission, design change, vendor error/omission, vendor change*, *constructor error/omission*, *constructor change*, *transportation error,* and *other*.

The research findings showed that, on both owner and contractor reported projects, owner change and design error/omission appeared to be the root causes of rework having a relatively greater cost impact than other sources. Constructor error/omission was indicated as one of the greatest cost impact sources on owner reported projects, whereas design change was reported more on the contractor reported projects (Hwang et al., 2009).

Compared to the topic of cost performance, little research has addressed the impact of rework on construction schedule performance. A study by Hegazy et al. (2011) highlighted how rework can be treated in construction project scheduling, and suggested incorporating the delay due to rework for each activity as a negative percentage complete, assigned to the activity on a specific date.

Icmeli-Tukel and Rom (1997) introduced a model and a solution procedure for project scheduling problems with the objective of maximizing quality implicitly by minimizing rework time and rework costs. The author defined *project quality* by the proportion of work which does not require rework, and suggested a mixed integer programming procedure for solving the resource-constrained project scheduling problem to minimize rework. Similarly, Maghsoudlou, Afshar-Nadjafi, and Akhavan Niaki (2017) attempted to consider the risk of rework for multi-skill project and resource-constrained project scheduling (where a multi-skilled workforce may be able to perform different tasks with different quality levels) by considering the effect of the assigned resource's skill level on the probability of reworking the same task, thus minimizing the rework risk of the activity.

2.3.2 Construction Productivity

Construction productivity factors in oil and gas industry are, to a remarkable extent, common with those in the overall construction industry. Jergeas (2009) reveals that the productivity decline on Alberta oil and gas construction projects is consistent with the decline of construction productivity in North America over the past three decades. This suggests that research findings regarding factors affecting construction productivity in the construction industry can be generalized for oil and gas construction projects as well.

A large number of researchers have studied construction productivity barriers on various construction projects. These studies identify a wide range of factors that impact construction productivity. Earlier studies, like the works of Borcherding and Oglesby (1974) and Maloney (1981), examined factors such as craft motivation in construction labour productivity. Project delivery methods, material management practices, and fabricators are other factors whose impact on construction productivity has been studied extensively by others (Horman & Thomas, 2005; Thomas & Sanvido, 2000; Thomas, Sanvido, & Sanders, 1989). Post-secondary institutions in Canada, such as the University of Alberta and the University of Calgary, are presently conducting research on construction productivity improvement in partnership with major Canadian construction companies. Research performed by the University of Alberta has indicated productivity is a complex issue, as many factors such as labour, capital, material and equipment influence productivity. Technical problems, such as inadequate design or incomplete engineering work, can also lead to reductions in productivity. Similarly, restrictive and redundant procedures impact the effectiveness of a project (Dozzi & AbouRizk, 1993; Jergeas, 2009).

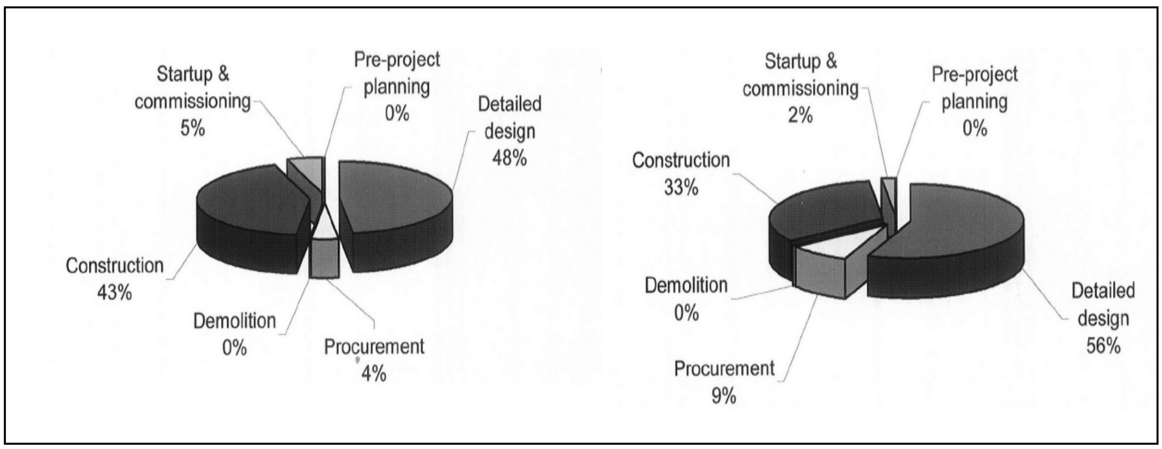
Contractors' perspective on the factors affecting labour productivity was studied by Jarkas and Bitar (2014). Although the study focused on Kuwait industrial projects, it is consistent with the findings of other research presented in this chapter. The 45 factors under study were classified under four major groups: management, technological, human/labour, and external. The factors under each group were ranked separately based on a calculated relative importance index. For example, clarity of technical specification, with a relative importance index of 84.33%, ranks first not only in the technological group, but also amongst the 45 factors explored.

As shown in this study, the top ten ranked factors affecting the labour productivity in Kuwait are: (1) clarity of technical specifications; (2) the extent of change orders during the execution stage of projects; (3) coordination level among design disciplines; (4) lack of labour supervision; (5) proportion of work subcontracted; (6) design complexity level; (7) lack of incentive scheme; (8) lack of construction manager's leadership; (9) stringent inspection by the engineer; and (10) delay in responding to requests for information (RFI). An interesting finding of Jarkas and Bitar's research is that, of the top ten ranked factors affecting productivity, six were directly related to engineering deliverables (Jarkas & Bitar, 2014).

The impact of change orders on construction productivity was studied by Moselhi, Leonard, and Fazio (1991). Through statistical analysis of data gathered from 90 construction projects in Canada and the United States, Moselhi et al. showed that the percentage of change orders (change order hours divided by actual contract hours) correlated directly with the percentage loss of productivity on contract work, with a linear relationship and strong correlation. The research also revealed a noteworthy finding: productivity losses from change orders were not affected by construction type, namely building versus industrial construction. Furthermore, the study showed that if the impact of change orders were concurrent with one or two other productivity-related major causes, such as lack of coordination or poor scheduling, the productivity loss increased another 11% to 24%—

dependent on the number of additional causes, as well as area of construction such as electrical, mechanical, or civil works (Moselhi et al., 1991).

Project changes are classified as either *scope changes*, which depict changes in the scope of projects, or *development changes*, which represent changes required to achieve the original scope of work with different strategies. Both types of changes can have negative impact on construction productivity because they generate field rework. The research findings of Georgy et al. (2005) showed that 48% of scope changes and 56% of development changes in industrial projects occur during the detailed design phase (Figure 2.5).



Scope changes Development changes

Figure 2.5: Frequency of changes during project phases (adapted from Georgy et al., 2005)

The impact of changes on productivity was studied by Hanna, Russell, Gotzion, and Nordheim (1999). Combined with the findings of the research by Georgy et al. (2005) and Moselhi et al., (1991), one can conclude that design changes, as a considerable portion of change orders, can thus be considered a major cause for productivity loss in industrial projects.

2.4 Impact of Engineering on Construction

Some researchers have taken into account the role of engineering performance and deliverables in improving or impairing construction performance. In investigating construction productivity barriers, some researchers identified factors related to engineering performance that can be traced to some attributes of engineering deliverables. The availability of work drawings, for example, which pertains to the timelines of the engineering deliverables, is repeatedly referred to by researchers as a major construction productivity barrier (Dai, Goodrum, & Maloney, 2009; Hanna & Heale, 1994; Ruwanpura et al., 2003).

All of the root causes mentioned above are obviously related to the performance of preconstruction activities and the quality level of engineering deliverables.

The impact of engineering deliverables on construction craft productivity can also be found in previous literature. A study conducted by Dai et al. (2009) investigated factors affecting construction labour productivity. They identified 83 factors affecting construction labour productivity through 18 focus groups with craft workers and their immediate supervisors on nine jobsites throughout the United States. Among those factors are *drawing errors*, *availability of drawings, slow response to question with drawings,* and *errors in prefabricated material*, all of which can be correlated, again, to some engineering deliverable attribute and/or engineering performance.

Research specific to the oil and gas industry has also highlighted the impact of pre-construction activities, including engineering, as a major potential source of productivity problems in oil and gas construction projects. In a survey conducted by Ahmed et al. (2005), as part of research on EPC projects in Alberta, 92.45% of the respondents identified the design (engineering) phase of a generic EPC project as the factor which, if delayed or poorly defined, would have the greatest impact on the final project cost. The second to fourth ranks are *pre-project planning* (91.7%), *material management* (90.38%), and *construction* (86.86%) respectively. Jergeas (2009), in a report submitted to Alberta Finance and Enterprise, identified the top ten areas for improving construction productivity in Alberta oil and gas projects, based on 309 specific recommendations from the industry. Table 2.1 below shows the top ten areas for construction productivity improvement, and their corresponding ranks, based on the number of recommendations received by each area and the percentage of the overall observations shown in the table.

Table 2.1: Top Ten Areas of Construction Productivity Improvement in Oil and Gas Industry (adapted from Jergeas, 2009)

Rank	Target Areas	Number of Recommendations	%
1	Labour Management, Conditions and Relations	86	27%
2	Project front-end Planning (Loading) and Work Face planning	40	13%
3	Management of Construction and Support	31	10%
4	Engineering Management	30	10%
5	Effective Supervision and Leadership	29	9%
6	Communication	25	8%
7	Contractual Strategy and Contractor Selection	24	8%
8	Constructability in Engineering Design	23	8%
9	Government Influence	11	3.5%
10	Modularization, Prefabrication, Pre-build in Shops	10	3.5%
		309	100%

It can be seen that the items ranked 2, 4, 8, and 10 pertain to preconstruction and engineering-related activities. Furthermore, it can be inferred that improving these four areas correlates to enhancing the engineering deliverables.

2.4.1 Format of Deliverables

The format of engineering deliverables and the resulting impact on craft performance in industrial projects was studied by Sweany, Goodrum, and Miller (2016), based on the cognitive workload demand and mental loading of engineering information delivered in three different formats: 2D drawings, CAD 3D, and 3D printed models. The study relied on empirical data collection to determine whether the different formats of engineering deliverables have any impact on craft performance in the execution of a given task. The metrics used in the study included *time to completion, direct work, indirect work, rework*, and *number of final errors*. The findings supported the hypothesis that the format of engineering deliverables influenced craft performance in the aforementioned criteria. Engineering information delivered in the richer 3D design format improved task performance, by comparison with the conventional 2D format (Sweany et al., 2016).

2.4.2 Late Deliverables

Research has been conducted in the field of work packaging, supply chain management, material management and stakeholder relationship (Barry & Leite, 2015) in an attempt to enhance the reliability of construction material delivery and coordination on site.

The Construction Industry Institute Research Team 300 (RT 300) initiated a series of studies to identify and document a full spectrum of the potential impacts that late deliverables to construction can have on five pillars of construction projects: *cost, schedule, quality, safety,* and *organizational capacity*. The late deliverables ranged from complex engineered equipment to design decisions, and different types of human resources (Barry & Leite, 2015). The same studies also acknowledged late deliverable to construction as one source of construction dispute.

RT 300 studies also contributed to categorizing and cataloguing known late deliverables and impacts, as well as creating a database of common types of deliverables, and consequently developing a tool as a user interface to navigate the late deliverable risk catalogue (LRDC). The main goal of this tool is to help project teams recognize related risks and improve alignment and understanding between project stakeholders (Barry et al., 2015).

Based on more than 240 surveys, RT 300 rated both the *commonality* and *severity* of each category of late deliverables, and found that the severity vs. commonality graph showed a positive trend line, indicating that the most severe impact on construction results from the most common category of late deliverables. The ranking of commonality of the *late deliverables* category is shown in Table 2.2 (Barry, Leite, & O'Brien, 2014).

Table 2.2: Ranking of Commonality of Late Deliverables Categories (Barry et al. 2015)

Rank	Late Deliverable Categories
1	*Engineering documents and responses*
2	*Engineered equipment*
3	*Fabricated material*
4	*External permit*
5	*Fabricated assemblies*
6	*Project execution planning*
7	*Human resources*
8	*Utilities and infrastructure*
9	*Bulk material*
10	*Construction equipment*

As shown in Table 2.2, *Engineering Document and Response* is the highest rated in terms of commonality. The findings of the same research indicates that this category also has the highest severity rating. In other words, the timeliness of engineering deliverables, according to the RT 300 study, has the highest impact among other deliverables on construction performance.

2.4.3 Quality of Engineering Deliverables

The quality of engineering deliverable, and quality-oriented engineering processes, can have a significant impact on construction performance. A case study conducted by Love et al. (1999), with a focus on understanding why and how reworks occurred along the supply chain in the project under study, identified the lack of quality-oriented design as the main cause of supply chain dysfunction in projects. The findings from the case study addressed the interfaces that existed between functional disciplines as a potential barrier for effective communication, leading to the flow of inaccurate information causing ineffective decision making. The study concluded that the cause of rework was primarily attributable to the sequential nature of the supply chain, which resulted in inadequate communication and poor decision-making; this was further intensified by the absence of a quality focus during the design process, resulting in the supply chain becoming dysfunctional, thereby leading to rework during the construction of the project (Love et al., 1999). The Construction Industry Institute formed Research Team 320 to address the definition and measurement of the quality of engineering deliverables. As part of these RT 320 studies, O'Connor and Woo (2017) identified a list of 53 quality problematic engineering deliverables and tasks, and prioritized the top 11 deliverables with higher frequency and significant impact on construction project performance. The 53 engineering deliverables considered in the study, and the top 11 deliverables, are shown in Table 2.3 and Table 2.4 respectively.

Table 2.3: Quality Problematic Engineering Deliverables (O'Connor and Woo, 2017)

	Deliverable / Task		Deliverable/Task
1	*Front End Engineering Design (FEED) validation*	*28*	*Electrical equipment/building envelopes*
2	*Piping material classes*	*29*	*Control equipment building envelopes*
3	*Process data sheets*	*30*	*Nozzles, ladders, platforms for tower/vessels/tanks*
4	*Mechanical data sheets*	*31*	*3D model reviews*
5	*Instrument data sheets*	*32*	*Structural stress loads*
6	*Piping and Instrumentation Diagram (P&ID)*	*33*	*Structural design*
7	*Stress critical line list*	*34*	*Fire protection study*
8	*Line list requiring hydraulic check*	*35*	*Earthwork*
9	*Plot Plan*	*36*	*Roads*
10	*Safety review*	*37*	*Piling*
11	*Constructability input*	*38*	*Foundations*
12	*Maintainability input*	*39*	*Fencing*
13	*Level 3 baseline schedule*	*40*	*Underground services*
14	*3D models*	*41*	*Piping routing and isometrics*
15	*Standard piping details*	*42*	*Stress analysis*
16	*Standard civil details*	*43*	*Hydraulic checks*
17	*Standard site details*	*44*	*Model updates*
18	*Standard architectural details*	*45*	*Bulk material take-off*
19	*Standard electrical details*	*46*	*Equipment specifications*
20	*Vendor data*	*47*	*Inline instrument data*
21	*Equipment list*	*48*	*Miscellaneous pipe support drawings*
22	*Mechanical equipment model volumes*	*49*	*Electrical design*
23	*Duct model volumes*	*50*	*Junction box location*
24	*Single line routing*	*51*	*Instrumentation design*
25	*Cable and cable tray routing*	*52*	*Lighting*
26	*Cathodic protection*	*53*	*Clash detection*
27	*Structural modeling*		

Table 2.4: The Top 11 Priority Problematic Deliverables (O'Connor and Woo, 2017)

Rank	Deliverable
1	*Piping and Instrumentation Diagrams (P&ID)*
2	*Constructability input*
3	*Vendor data*
4	*Maintainability input*
5	*Level 3 baseline schedule*
6	*Equipment specifications*
7	*Piping routing and isometrics*
8	*3D models*
9	*FEED validation*
10	*Nozzles, ladders and platforms for towers/vessels/tanks*
11	*Miscellaneous pipe support drawings*

2.4.4 Rework Due to Engineering Deliverables

Design errors are said to have accounted for as much as 70% of the total amount of rework that is incurred in projects (Burati, Farrington, & Ledbetter, 1992; Love et al., 2008). In fact, the project may continue without major problems until close to the final stages, when errors made in earlier stages (such as the engineering design phase) are discovered, causing a significant amount of costly rework (Cooper, 1993). The causes of design errors leading to rework have been categorized by Love et al. (2008) as follows:

- Skill base and experience
- Miscommunicated client / end-user requirements
- Schedule pressure, design fees, and planning during design
- Design checks, audits, and reviews

The study suggests undertaking design reviews and verifications as the first step to minimizing the potential impact of errors. However, the study notes these practices will not prevent design errors from occurring, and more emphasis needs to be given to properly planning the design process and ensuring that qualified resources (such as an appropriate firm with skilled and experienced staff) are available to undertake the required work.

The Construction Owner's Association of Alberta (COAA) Field Rework Committee identified the most significant causes for field rework as originating from engineering deliverables. Based on COAA studies, Ruwanpura et al. (2003) performed the prioritization of the most critical construction rework issues due to engineering deliverables. *Engineering and Reviews*, with a 30% impact, was rated the most significant cause for rework (Ruwanpura et al., 2003). The Engineering and Reviews category was further divided into subcategories of rework causes:

a. Errors and omissions in engineering work packages
b. Scope changes
c. Document control
d. Late design changes

Subcategories were further divided into intermediate level root causes. These intermediate level root causes were then prioritized and the top ten intermediate rework causes were identified, as shown in Table 2.5 (Ruwanpura et al., 2003).

Table 2.5: Top Ten Intermediate-Level Rework Causes (Ruwanpura et al., 2003)

Rank	Intermediate Rework Cause
1	*Insufficient time between engineering and construction*
2	*Poor scope definition*
3	*Inadequate constructability reviews*
4	*Changes in client requirements*
5	*Inadequately defined design scope*
6	*Inadequate scope input*
7	*Inadequate engineering hours*
8	*Inadequate cooperation and coordination*
9	*Wrong or late vendor info*
10	*Owner does not communicate complete requirements*

2.5 Engineering Design Enhancement

2.5.1 Design Flexibility

One aspect of enhancing engineering design practices tackles system engineering, with the goal of delivering enhanced final products—in terms of non-technical attributes, such as economic value)—to build acceptance among decision makers. For example, Cardin, Ranjbar Bourani, and Neufville (2015) studied flexible engineering strategies to improve the life cycle performance of engineering on an on-shore LNG production design. According to the authors, flexibility in engineering design means that a system is designed in such way that it is able to capture any potential value associated with different scenarios. It aims at maximizing the value of a project in the context of uncertainty in order to increase its resilience against uncertainty in the market. A flexible design enables desirable changes in configuration (e.g., by increasing capacity as needed) over time and thus increases the cumulative density function of the value of the design. With this definition in the background, the authors worked on factors such as economies of scale, time value of money, and learning rate; they used a Monte Carlo simulation to deal with the uncertainty in parameters such as discount rate (which impacts the Net Present Value, NPV), a stochastic version of demand, etc., to perform a flexibility analysis to improve the expected value of large scale capital-intensive project (in this case, an LNG project).

However, flexibility of design, as explained in the context above, does not target construction performance of any kind. Therefore, this concept of flexibility is out of the scope of this dissertation.

2.5.2 Design Data

Westin and Sein (2013) studied enhancing engineering drawings in large construction engineering projects to improve the quality of data they convey, arguing that since the drawings are based on data, errors in these documents can be traced back to poor data and information quality (DQ/IQ) within the construction engineering data sources and systems. They suggested a tool called Information Quality System (IQS) be used to improved quality assessment frameworks. The background target of their study (the problem the researchers were trying to solve by improving DQ/IQ) were the delays and cost overruns in construction projects.

The authors mentioned a number of quality dimensions or metrics as DQ/IQ problems from the previous literature. A sample of these dimensions are shown in Table 2.6.

Table 2.6: A Sample of Quality Dimensions (adapted from Westin & Sein, 2013)

Dimension	Description
Accessibility	Available
Security	Secure, protected, authorized access
Relevancy	Relevant
Completeness	Include all necessary (required) values
Consistency	Consistent meaning
Timeliness	Current, delivered on time, timely
Logical coherence	Two or more values do not conflict with each other

However, a Delphi study was conducted for the research to identify those problems that have highest negative impact on the profit margins in the projects under the study in the corresponding company. The top five DQ/IQ problems were identified as follows:

1. Accuracy
2. Completeness
3. Consistency
4. Timeliness
5. Logical coherence

The study then validates that the developed IQS improves the DQ/IQ through comparison between a test project and two other previously competed projects.

There are two aspects in the study conducted by Westin and Sein that makes it notable for this dissertation: a) final engineering deliverables, namely design drawings and specifications, have been considered to foster enhancement in the engineering process; and b) the improvement in the engineering deliverables are targeted for the purpose of improving project performance. However, the research relies solely on previous literature to relate poor construction performance to lack of some attributes in the engineering deliverables. Additionally, the research provides no more than a systematic quality control procedure, which checks the existence of some criteria defined by the project within the generated document. It does not address engineering process factors such as discipline interrelation, engineering management concerns, construction requirements, or constructability reviews. Furthermore, while the research provides a tool to detect quality problems, it lacks any provisions to improve the quality of engineering deliverables, and leaves it to the expert project team to deal with the detected problems.

2.5.3 Design Quality

The quality of a service or product is generally assessed in terms of how well its features or attributes meet the customer's needs (Thomson, Austin, Devine-Wright, & Mills, 2003). ISO 9000 and BS 4778 (British Standards Institution, 1991) have similar views of quality, the latter defining it as an inherent characteristic of a process, product, or system which is related to a requirement.

However, the term *quality* encompasses a wide range of characteristics associated with the subject under consideration. This is the case in most of the research works conducted to investigate the quality of design or design documents. Generally, the term *quality of design documents* in literature means being free of any type of faults or deficiencies. Andi and Minato (2003), who acknowledged defective design as the most important risk for the success of a project, considered 12 attributes for design quality, which include a variety of factors such as *life cycle cost issues, material efficiency, economy, relevancy, constructability, innovation*, and *aesthetics*. Such an approach towards design quality yields only a general concept of the level of excellence of design documents, without targeting specific areas such as the objective or motivation to improve the quality. Nor does it suggest a specific focus area to address to improve quality.

In an attempt to measure design quality, the UK's Construction Industry Council (CIC) developed the Design Quality Indicator (DQI) as a tool for evaluating the quality of building design. The DQI, which was developed for targeting, mapping, measuring and managing performance improvement in construction, has been piloted across the UK construction sector. It was developed explicitly to measure quality of design embodied in the product (buildings themselves). It was not intended to assess the design process (Gann, Salter, & Whyte, 2003). The DQI considers quality as factors that add value to the final product (buildings) in terms of fulfilling the end users' needs. These factors address physical parameters (such as the level of light in a room, measured in lux) as well as perceptual and subjective parameters (such as the feeling of warmth emanating from a particular heat source) (Gann et al., 2003). Note that the DQI approach does not involve the quality of the design documents themselves. Instead, it assesses the design quality by the level at which it satisfies the end-product users' needs. The DQI fails to identify areas that require correction to improve the quality of design procedure, and only focuses on satisfying customer needs in the final product.

Given such a perspective of quality, some researchers tried to explore opportunities for incorporating the DQI into a project management system that ensures the delivery of stakeholder value during the design stage, which included customization of the DQI content and the context of application at this stage of a project (Thomson et al., 2003). Similar attempts have been made to incorporate quality improvement practices in earlier stages of the project. Gibson and Gebken (2003) recommended the use of the PDRI (Project Definition Rating System, a tool for analyzing the level of scope definition developed by the Construction Industry Institute in 1999) during pre-project planning by integrating the perspectives of the various project participants, in order to enhance the quality of design. Similarly, Gransberg and Molenaar (2004) identified six owner approaches to articulating quality requirements in their RFPs for design build projects. Awareness of the project stakeholders' requirements is cited as a significant factor to improving the quality of design in these research works.

As discussed earlier, existing approaches mainly consider the final users' level of satisfaction as a significant criterion of design quality. With this concept in mind, attempts to improve design quality, in most of the cases, are limited to developing a better understanding of clients' requirements and trying to incorporate them into design so that the final product can satisfy the client. However, focusing solely on the end-users' satisfaction does not necessarily yield a design that addresses productivity issues. Customer satisfaction may be achieved by employing a rigorous quality management system (QMS) which can detect design nonconformities during the design and construction phases, and take necessary corrective actions, as many times as needed, to ensure quality of design and excellence of the final product, without addressing any productivity issues.

Although the quality of engineering deliverables ultimately affects the owner's perception of the constructed facility, project clients are not necessarily the direct users of the engineering deliverables. Engineering deliverables are the end products of the engineering phase of an EPC project, which are directly used by the procurement and construction phases. Hence, focusing on the owner's satisfaction as the only indicator of quality of engineering products, may neglect the requirements of procurement and construction phases in many aspects including productivity.

2.5.4 Design Reliability

Previous literature mainly referred to reliability (of design, product, etc.) based on different approaches. IEEE (1990) defined reliability as the ability of a system to execute its required functions under specified conditions for a certain period of time. This understanding of reliability is also noticeable even in some earlier related literature. Kalashnikov (1987), for example, in an attempt to calculate design reliability of compressors before fabrication and mock-up testing, considered reliability as the probability of trouble-free operation. Similarly, Myers and Howat (2005) defined design reliability as the likelihood of a process to meet constraint under normal operation despite uncertainty in the underlying parameters. This concept was used as the basis for reliability estimation by process designers.

With this concept of reliability, most of the research on design reliability revolved around reducing the operation and/or maintenance cost of any given product (building, equipment, etc.) by taking such into consideration during the design stage. For instance, Phaller and Brach (1981) identified *unreliability*, illustrated by the phrase "hardware that won't stay working" as being very costly to the American public. They then identified two types of failure that result in unreliability: one type that can be removed from the system by increasing tests and inspection, and the other type that is inherent in the design and in the manufacturing process, and is removed only when the design or manufacturing processes are corrected. Similar approaches to design reliability have remained among researchers' interests over the years. Wu et al. (2006) investigated the impact of reliability analysis in the life cycle cost (LCC) of building system. They discussed such ideas as reliability design, maintainability design, and maintenance policy to realize the prediction of lifecycle cost savings.

Safety of the final product is another aspect of design reliability found in some research. In one article (Lee, Han, Na, & Yoo, 1997), a design reliability assurance program for a nuclear reactor facility was investigated in which the main goal was to ensure that safety considerations in the early stages of the design are maintained during the detailed design stage. Similarly, Deng and Qiu (2004) defined reliability (of construction activities) as a hierarchy of multi-objective systems with time, safety, and quality being the first layer, and cost being the second layer.

A different perspective of reliability, found in some previous research works, considers reliability as opposed to *variability*. Variability during the production process and construction phase is seen as the combined effect of complexity and uncertainty in projects resulting from such factors as urgent requirements, non-consistent construction sequences, lack of supply chain co-ordination, project scope changes and poor quality (González, Alarcón, & Mundaca, 2008). From a scheduling perspective, for example, reducing the variability of construction activity schedules was attempted by developing a “reliability buffering” system that considers time contingencies without sacrificing project schedule performance through determining an optimal contingency buffer size for activities (Park & Pena-Mora, 2004). With such a perspective on reliability, research works regarding design reliability mainly focused on provisions undertaken in the design stage (or earlier stages such as planning stage) to minimize variability in the construction phase. For instance, the Last Planner System (LPS™), a production planning and control system based on lean production principles, has been increasingly applied in the construction industry during the last decade to improve planning reliability and reduce the negative impact of variability. However, the hypothesis that reduction in variability, measured as an increase in planning reliability, will improve project performance was later investigated by Gonzalez et al. (2008), where a planning reliability index (a ratio of actual to planned weekly progress of an activity) was used to determine the relationship between planning reliability and project performance.

2.5.5 Design Predictability

Predictability, in some previous literature, is generally related to the level of accuracy. Srivastava and Sarrafzadeh (2002) referred to *predictability* as the quantified measure of accuracy of an estimate. Attempts to improve design predictability lead to methods and procedures to produce designs that are more robust at handling inaccuracies. In this understanding of design predictability, predictable design means more accurate design. However, in literature pertaining to other scientific fields, *predictability* is also described as the awareness of a system's behaviour or reaction in advance, by knowing its behaviour in previous situations. This concept of predictability is considered in medical research conducted by Barbáchano, Coad, and Robinson (2008), where predictability, described as knowing the features and treatment provisions of previous patients tells you which treatment will be allocated next, was considered to be a problem in the success of treatments.

Rather than predictability as a whole, some researchers studied certain aspects of predictability in design systems. Karmakar, Chakravarty, Venkatraman, and Rao (2006) discussed improving schedule predictability by focusing on handoff deliverables between different design discipline (sub-teams) in terms of adequacy and validation of information. In this approach, *schedule predictability* is merely the probability of the task being finished on time, and enhancement of predictability can be envisaged as one of many results of implementing a sort of quality control system. Thiele and Wilhelm (2004) also followed a similar approach in discussing threats to timing predictability of safety-critical embedded systems in application domains such as automotive, avionics, and multimedia processing. *Timing predictability* in their research involved increasing the possibility for systems to operate under hard real-time constraints by employing sound methods and tools to drive run-time guarantees that are not only reliable, but also precise.

As can be seen from the above, both holistic and partial approaches towards the concept of predictability have been used in previous literature and in researchers' attempts to improve design predictability. However, irrespective of the researchers' conceptual definition of predictability, the suggested courses of action are similar to efforts to improve other aspects of the design process such as accuracy and quality, and improvement in predictability is only one of several secondary results of such actions.

2.5.6 Design Timeliness

Timeliness of design and construction has been widely investigated by researchers. Timeliness, in most research works, is mainly considered as finishing activities or taking actions on time, and, with this perspective, it has been shown by many researchers that timeliness is crucial for project performance improvement. A. Hanna and Heale (1994) identified timeliness as one factor of great importance to construction productivity, among other factors such as quality of labour skill, project communication, and equipping of crews. Issues encountered in their research regarding timeliness included *timely inspections, timely action on change orders, timely decisions by management and engineering staff on important matters, timely delivery of materials,* and *timely expediting of monthly billings*.

Timeliness of design is also studied by some research. Andi and Minato (2003) investigated the quality of design documents in Japanese construction by categorizing document attributes into two categories, namely *design attributes* (such as economy, life cycle cost, and constructability), and *documentation attributes* (such as timeliness, completeness, accuracy, coordination, and conformity). Timeliness, as they discussed, was that design documents are provided when required, to avoid delays.

Another approach towards design timeliness not only considers the on-time delivery of design documents and services, but also emphasizes the timeliness of when documents or services are delivered. This perspective of timeliness involves recognizing construction needs and incorporating them into the design schedule. Few research works, however, were conducted regarding this approach. Armentrout (1986), in an attempt to improve engineering productivity in design firms, briefly mentioned the need for appropriate timing of design activities in order for commitments to be fully met, by concluding that "the *right* things must be done on time."

Timeliness of engineering deliverables is also of great importance on fast-tracked projects, where engineering and construction have considerable schedule overlaps.

2.5.7 Engineering Process Enhancement

Unlike researchers such as Westin and Sein (2013), introduced in section 2.5.2 of this chapter, who studied final engineering deliverables without considering engineering process, some research works such as that of Park and Ryoo (2008) tried to highlight the role of engineering process, rather than output, in responding to construction needs. The researchers raised the concern that most construction solutions are mainly developed based on data integrity rather than process integrity, and emphasized the necessity of identifying order of engineering deliverables according to order of construction procedure in engineering construction projects. The authors conducted a case study on a then-ongoing capital infrastructure project in Korea, where design and construction work schedule integration was achieved through a well-defined framework of interfaces, which was capable of adjusting the schedule, based on real-time progress of construction.

The study highlights the vital nature of interface management integration and communication between design and construction and concludes that the approach of assessing the progress in design packages and drawings based on different status of achievement at control points (e.g. first issue, client approval, etc.) has been found to be an appropriate way of evaluating the earned value for design activities. In addition, the consistency between the information systems/information technology (IS/IT) used by different parties such as the owner, engineering, and constructors, was also emphasized (Park & Ryoo, 2008).

As can be observed, the study does not address any measures within the engineering process to improve the final deliverables in terms of responding to construction needs; the study is concerned solely with providing design deliverables when construction needs them. To some extent, the two studies by Park and Ryoo (2008) and Westin and Sein (2013) may be viewed as complementary to each other, as one is tackling the engineering final output and the other is targeting the engineering process, and both are aiming at improving construction performance. However, neither of the studies acknowledge the necessity of adopting both approaches concurrently to achieve their common goal. Additionally, each has viewed only a small portion of related engineering issues, in the context of single projects of different natures through case study.

Gries and Restrepo (2011) looked at engineering design as a separate project, and tried to apply standard project management key performance indicators (KPI) for measuring and monitoring engineering processes. In order to determine which KPI can be used, and how each KPI should be modified to suit the purpose to fit the specific engineering design project, the authors performed a case study in the context of a business transformation project at a global power generation equipment manufacturer during a period of 15 months in three locations. The proposed KPI for the engineering design process is shown in Table 2.7.

Table 2.7: Selected Engineering KPIs

KPI	Definition
Outsourcing Rate	*No. of external partners / No. of own engineering staff)*
Engineering Utilization	*Allocated project demand (h) / Total available capacity (h)*
Engineering Productivity	*Total worktime booked (h)/ Total contractual worktime (h)*
Cost Performance Indicator (CPI)	*Budgeted cost of work performed /Actual cost of work performed*
Schedule Performance Indicator (SPI)	*Budgeted cost of work performed /Actual cost of work scheduled*
Engineering On-Time Delivery (OTD)	*No. of deliverables released on time /Total No. of deliverables*
Engineering First Pass Yield (FPY)	*No. of deliverables without rejection /Total No. of deliverables*

With the exception of *Engineering OTD* and *Engineering FPY* defined in Table 2.1, the KPIs proposed by the authors, despite providing a useful vehicle to evaluate engineering design performance, do not address any measurements improving construction performance or fulfilling construction needs. The authors acknowledge that these two KPIs are the only engineering-specific KPIs defined in that research. Additionally, the research does not address any methodology to improve those KPIs in the engineering design process.

Hartono and Muhamad (2014) investigated the current approach in applying project performance indicators for engineering design groups within the context of engineering, procurement, and construction (EPC) projects. They used a systems dynamics methodology and chose an EPC project of developing a geothermal power plant as an observed system. Hartono and Muhamad's work is among those that considered construction as the end user of engineering process output, and used this vantage point towards enhancement of engineering.

They also considered the multi-disciplinary (multi-design-group) nature of EPC projects in evaluating the schedule performance of each engineering department, acknowledging that the downstream departments are vulnerable to more rework due to the systematic effect that amplifies the number of rework from upstream to downstream engineering disciplines. The study aimed at providing a more accurate account on project performance at the discipline/department level by identifying the so-called "true performance" of departments, excluding errors originally generated and passed by others. One outcome of the study is that it emphasizes the fact that the current practices underestimate the work amount needed by respective departments, especially those in the downstream level. In particular, systemic effects such as hidden reworks were overlooked (Hartono & Muhamad, 2014).

2.6 Gap Analysis of the Existing Literature

A comprehensive review of the existing literature reveals the following major gaps and room for improvement:

- While a large amount of research is dedicated to identifying factors affecting construction performance, very little research is conducted with the focus on engineering phase, at the deliverable level, to identify potential causes of poor construction performance. The existing research regarding causes of construction performance issues primarily considered construction cost and schedule problems in the form of rework in construction, construction productivity, and labour productivity, and sought root causes for those problems in various aspects of project. Some researchers ranked the major contributors for construction problems, and their findings consisted of factors related to different phases of projects, which included some general aspects of engineering.
- Among the research works which did consider the role of engineering in improving construction performance, few addressed the impact of engineering directly on construction cost and construction schedule performances. The researchers mostly aimed at mitigating certain aspects of construction such as rework, and productivity issues.

- The studies regarding enhancing engineering performance either focused only on a single dimension of engineering problem—such as quality or flexibility—or considered the process of engineering itself as potential room for improvement. Little or no research was conducted to identify issues at deliverable level in engineering. Furthermore, very little research has been conducted to enhance engineering with the focus of fulfilling construction needs.
- Very few research works regarding engineering deliverables in oil and gas projects were conducted considering project engineering activities at the engineering deliverable level. One outstanding research work that can be mentioned here is that conducted by the Construction Industry Institute (CII) RT 320 (O'Connor & Woo, 2016; O'Connor & Woo, 2017), which identified a list of quality-problematic engineering deliverables and the top 11 priority problematic deliverables (Table 2.3 and Table 2.4). However, the research did not address any causes for these problems or methods for enhancing deliverables. Furthermore, the research did not study potential negative impact on construction due to these problems in the deliverables.

The current research seeks to bridge the gaps mentioned above, by identifying the major issues in engineering deliverables that directly impact construction cost and schedule performance, and improving construction performance through enhancing engineering deliverables by mitigating those issues.

Chapter Three: **Research Methodology**

This chapter presents the research methodologies adopted for different stages of the current research. As will be discussed, both qualitative and quantitative approaches are used to achieve the research objectives. Therefore, a brief review of quantitative and qualitative approaches are presented here. The major research questions are then introduced, which will define the two phases of this study. The corresponding research approaches adopted for each phase are also discussed in more detail.

3.1 Review of Qualitative and Quantitative Research Approaches

The set of tools and methods used to extract meaning from data is commonly called *research methodology*. The methodology to be used for a research problem must always consider the nature of the data which is to be collected in the resolution of the problem. In other words, the type of data collected, to some extent, determines the research method (Leedy & Ormrod, 2013). Numerous methodologies have been develop to interpret different forms that data could possibly take. However, these methods are normally categorised into two broad categories: *quantitative* research, and *qualitative* research.

In general, quantitative research is looking at quantities of variables or comparison phenomena in terms of the quantities of one or more variables in them. Quantitative research normally involves measuring variables in a numerical way, or by using designed measures of some characteristics such as questionnaires and rating scales.

Qualitative research, on the other hand, looks at qualities or characteristics that normally cannot be expressed by numerical values or measured by numbers. Qualitative research seeks a better and deeper understanding of a certain phenomenon in terms of, for example, behaviour, complexities, or other nuances. Table 3.1 demonstrates feature differences between qualitative and quantitative research approaches (Leedy & Ormrod, 2013).

Table 3.1: Comparison between Qualitative and Quantitative Research

	Qualitative Research	Quantitative Research
Purpose	• Builds theory • Seeks better understanding of phenomena	• Seeks prediction that will generalize to other cases/persons/etc. • Establishes relationship • Tests existing theories
Process	• Less-structured process • Variable research parameters that change during research • Holistic with specific focus • Information derived from data is context-bound	• Structured guideline and methods • Research parameters remain constant during the process • Allows objective measurements Detached from the context
Data Collection	• No district and measurable data • Smaller sample and fewer participants • Verbal and non-verbal data can be used	• Data specific to defined variables • Standardized methods of measurement • Validity and reliability of measurement attained through instruments • Data collected from large samples or population
Data Analysis	• Use of inductive reasoning • More subjective data analysis	• Rely more on deductive reasoning • Begins with theory ends with logical conclusion • Predetermined statistical procedures
Reporting	• Interpretive narratives • More personal literary style, needing skillful writers	• Summarized to means, medians, correlations, and other statistics • Formal scientific style, not personal language

3.1.1 Quantitative Research Method

Quantitative research, which falls under broader topic of descriptive quantitative study, seeks to understand and discover characteristics of an observed existing phenomenon (or situation) as it is, or explore other associations and relationships between two or more phenomena. Quantitative research is not looking toward finding a cause-and-effect relationship among the phenomena, or changing and modifying the status que of the situation under study.

In order to obtain quantitative information, different descriptive research designs can be used as follows (Leedy & Ormrod, 2013):

- Observation Studies
- Correlational Research
- Survey Research

The quantitative information yielded from each of the above mentioned descriptive research designs can then be summarised through performing statistical analysis techniques. Since the survey research approach is more frequently used (Leedy & Ormrod, 2013) and is also the quantitative approach adopted for part of the current research, it is briefly described later in this chapter.

3.1.2 Qualitative Research Method

Qualitative research focuses on phenomena that occurs in the real world, and in its natural setting, and tries to dig deeply for a complete understanding of the phenomenon, whereas quantitative research involves either identifying the characteristics of an observed phenomenon or exploring possible correlations among two or more phenomena (Leedy & Ormrod, 2013). Qualitative research is an approach to research design with main focus on human and targeting to delve deeply into people’s experiences, beliefs, and perceptions (Given, 2015). A qualitative approach is used to develop theories when partial or inadequate theories exist for certain populations and samples or existing theories do not adequately capture the complexity of the problem being examined (Creswell & Poth, 2017).

A qualitative method is chosen by researchers as their major avenue of research if the purpose of the research includes one or more of the following (Corbin & Strauss, 2014) (Leedy & Ormrod, 2013):

- To explore the inner experience of the participants
- To explore how meanings are formed and transformed
- To explore areas not yet thoroughly researched
- To take a holistic and comprehensive approach to the study of phenomena
- To describe the nature of settings, processes, relationships, people, or systems
- To interpret a particular phenomenon, and develop theoretical perspective about it
- To verify and test the validity of certain assumptions, claims, and theories
- To evaluate the effectiveness of particular innovations, policies, or practices

Qualitative researchers seek to connect to the research participants and see the phenomenon under study through their vantage point (Creswell & Poth, 2017).

3.1.2.1 Outcomes of Qualitative Research

There are three main outcomes of qualitative research: Description, Conceptual Ordering, and Theory discussed below (Corbin & Strauss, 2014).

- Description is an avenue to convey information about what is going on, how things are, ideas about things, people, places and the like. Descriptions may seem objective, but this objectivity is argued by many qualitative researchers (Leedy & Ormrod, 2013) indicating that it is mainly subjective, involving purpose, and selective audience. They are also meant to convey believability and judgement, and can be a basis for even more abstract interpretations.

- *Conceptual ordering* refers to the arrangement of data into distinct categories and ratings based on their properties and characteristics. It is an attempt to make sense out of the data through grouping them based on such schemes as *types* or *stages*. Conceptual ordering requires description as a basic fundamental. Rating (of anything), as an example of conceptual ordering resulted from qualitative research conducted on a selective population, requires researchers to include various amount of descriptive material to explain their rating.
- *Theory* means a set of well-developed concepts that are systematically developed in terms of their properties and dimensions, and are related through statements of relationship which together constitute an integrated framework that explains something about a phenomenon (Corbin & Strauss, 2014). Theory can be described as a foundation for explaining a specific phenomenon which also can provide hypothesis for subsequent research. The main function of theory is to condense raw data into levels of concept (similar to conceptual ordering), and show the relationship between the concepts (the main difference between theory and conceptual ordering) through the following:
    a) Defining the main problem area under study
    b) Explaining the possible action–interaction environment
    c) Relating the action and interaction to main problem and explaining how the action-interaction may change by changing their environment
    d) Relating the outcome to action and interaction

Essential for the theory is that the researcher develops concepts out of data, and integrates them around a core category through statements that denote the relationship between them.

3.1.2.2 Qualitative Research Designs

Over time, a considerable number of approaches have been developed by researchers and authors to conduct qualitative research. For example, Creswell (2012) has named 41 qualitative research approaches that have been classified and used by 13 authors between 1986 and 2011, for different disciplines and branches such as education, sociology, nursing, psychology, social science, and arts, with each discipline slightly emphasizing some approaches over others.

Out of all these approaches, however, some have consistently appeared over the years. Leedy and Ormrod (2013) as well as Creswell (2012) have indicated the following as common qualitative research designs, which can be applied in different disciplines (Creswell, 2012; Leedy & Ormrod, 2013).

- Case Study
- Ethnography
- Phenomenological Study
- Content Analysis
- Grounded Theory Study

Case Study: Case study, which is also known as idiographic research, involves the in-depth study of a particular program or event for a defined period of time (Leedy & Ormrod, 2013). This design is used to narrow down a broad research field into one research topic, allowing further elaboration and building hypothesis on a subject. In case study, either a single case may be involved because of particular uniqueness or specific characteristics of that case, or multiple cases may be selected to provide a basis for comparison or to propose generalization.

Ethnography: In an ethnographic research approach, the broad cultural-sharing behaviors of individuals or groups are analyzed, and the researcher looks in depth at an entire group, specifically when a group shares a common culture (Leedy & Ormrod, 2013). The focus is on everyday behaviors to identify norms, beliefs, social structures and other factors to understand the changes in the group's culture over time (Williams, 2011).

Phenomenological Study: One definition of this approach by Creswell (2012) explains that it describes the common meaning of several entities regarding their experience of a concept or phenomenon. This study seeks to understand people's understanding and experience of a particular phenomenon or situation. The sample participants required for this approach need to be carefully selected to ensure they have direct experience with the phenomenon under study. This approach normally involves lengthy interviews of about one to two hours, which are often very unstructured, with both researcher and participants working together to get to the heart of the phenomenon (Leedy & Ormrod, 2013).

Content Analysis: This is a type of detailed scrutiny performed on particular material which may be in different formats of human communication (Leedy & Ormrod, 2013) such as books, newspapers, journals, and even films and music, for the purpose of finding relations, patterns, themes, and the presence of certain concepts. This approach can be used in broad range of studies including media, marketing, literature, gender, and culture studies.

Grounded Theory: This is one of the most popular approaches of qualitative research in the world (Birks & Mills, 2015). The defining characteristic of this approach is that it begins with the data and ends with developing a theory. It seeks to develop a theory around a process related to a certain topic, which normally includes action and interaction between individuals (Leedy & Ormrod, 2013). Since this approach is extensively used in the current research, further elaboration of the Grounded Theory research design is provided later in this chapter.

3.2 Research Questions

In all research, the research question establishes the boundaries of what will be studied. It also determines the research methodology that will be used in the study (Corbin & Strauss, 2014). The research question or questions can be assumed as the breakdown of the research main problem, which provides the researcher with a proper avenue to explore the research topic in some depth. It is necessary that the research question(s) be framed in a manner such that the investigator can easily identify the suitable research methodology to be used for answering them. This section is meant to introduce the questions of the current research as a basis for adopting proper methodologies throughout the entire study.

As discussed in Chapter 1, the purpose of this research is to develop a framework to enhance engineering deliverables in order to improve construction performance in oil and gas projects.

The first objective to tackle would be to identify the problems or issues in the engineering deliverables that can have a negative impact on construction performance. In other words, it should first be understood what factors in the engineering deliverables may cause poor cost and schedule performances in construction. Therefore the first research question is as follows:

Research Question One*:* What are the major factors in engineering deliverables that have a negative impact on construction performance?

Once the problems in engineering deliverables that account for poor construction performance are identified, the next step would be to develop a framework in oil and gas projects to mitigate these issues and enhance the engineering deliverables, so that the construction performance is improved. This leads to the second research question.

Research Question Two: How can engineering deliverables be enhanced to improve construction performance?

In the following sections, the appropriate methodology to address each of the research questions, depending on the nature of the questions, is introduced and discussed in detail.

3.3 Research Approach and Methodology

In order to address the two research questions introduced in section 3.2, the main body of the research work is divided into two major phases, each addressing one of the research questions.

Phase I:

The first phase of the research aims at identifying major factors related to the engineering deliverables that may have a negative impact on construction performance. Other than identification of the factors, this phase involves the ranking of factors by their level of impact and commonality. The outcome of this phase is understanding and prioritizing the issues within engineering deliverables, which need to be resolved should any improvement in construction performance be sought. Quantitative research tools are employed for data collections and analysis as discussed later in section 3.4.

Phase II:

Once the major issues in engineering deliverables are identified and ranked, the next phase will be started, aiming at developing a framework for enhancing engineering deliverables. The main purpose of this framework is to find methods, procedures, guidelines, etc., to mitigate/eliminate the issues found during Phase I. As the main objective of this phase suggests, and considering the discussion in section 3.2.2, the most appropriate research approach to address this phase would be Grounded Theory, which will further be explained in section 3.5.

Once the goals of Phase I and Phase II are accomplished, the developed framework is validated using standard methods described in the upcoming chapters. The overall research approach of this study is shown in Figure 3.1.

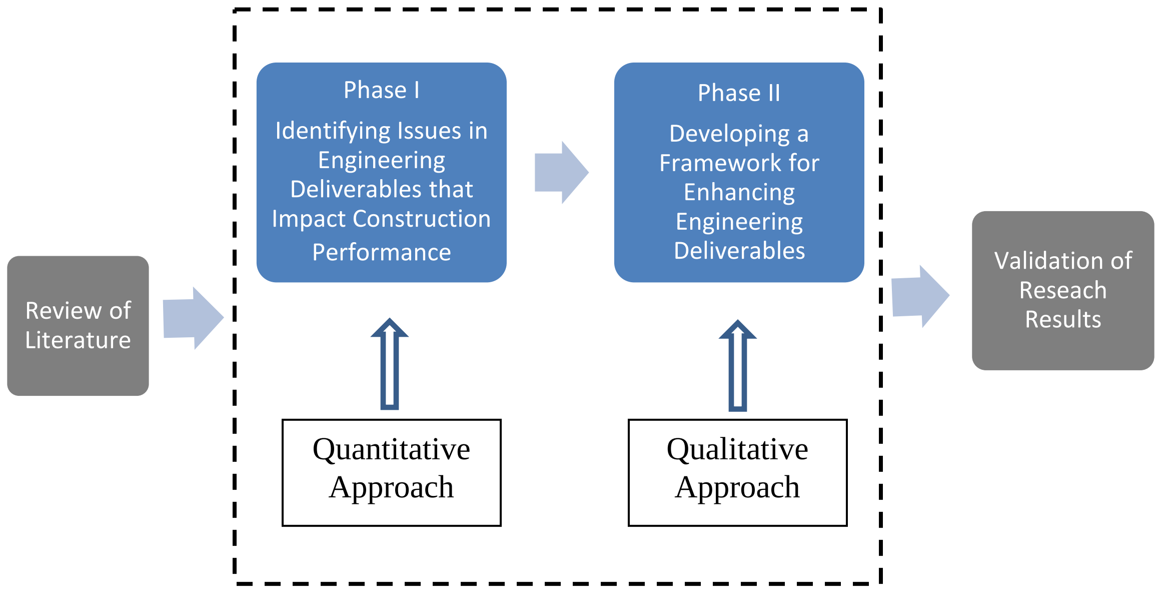


Figure 3.1: Overall research approach

3.4 Phase I: Factors Affecting Construction Performance

As mentioned in section 3.1, the research question in Phase I is "What are the major factors in engineering deliverables that have a negative impact on construction performance?" The nature of this question is to identify existing phenomena (problems in engineering deliverables) and measure some attributes of those phenomena (level of impact on construction performance). Based on what was covered in section 3.1 regarding qualitative and quantitative research approaches, one can deduce that this part of the research complies with descriptive research characteristics, and, hence, should be tackled using quantitative study tools and techniques which can be generalized in data collection and analysis techniques, sampling, and sample size decisions. A schematic of research methodology used in Phase I is shown in Figure 3.2.

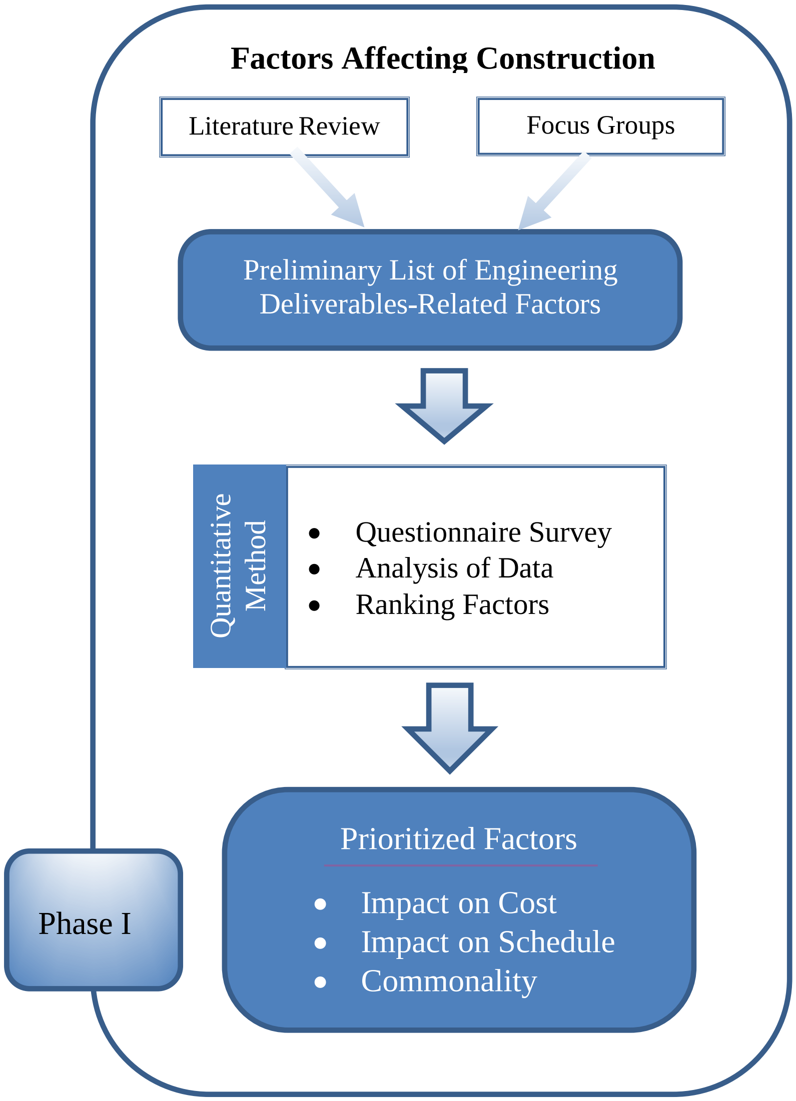


Figure 3.2: Methodology used in Phase I

3.4.1 Data Collection

Phase I of the study involves gathering the data that identify the major issues in engineering deliverables that have a negative impact on construction performance. For the first step, a list of those factors was prepared based on a comprehensive literature review (see Chapter 2), as well as discussions in focus groups consisting of experts in oil and gas EPC projects. According to Morgan (1996), the focus group method is a technique that is used for collecting data through group interaction on a topic determined by the research. Focus groups have many advantages, some of which are presented below (Morgan 1998):

- Yields (more likely) better results and information because of the interaction among the group
- Leads to a greater understanding when developing agreements and disagreements
- Provides better comparison of views and experiences among peer participants

The focus group held for developing a preliminary list of factors in engineering deliverables consisted of one project engineering manager, one project controls manager, one discipline lead engineer, and one field lead engineer.

The prepared list includes 12 major issues in engineering deliverables that are known to impact either construction cost performance or construction schedule performance (or both). The next step in collecting data for Phase I involves validating the above-mentioned list, and prioritizing or ranking the factors in terms of the significance of their impact on construction cost or schedule performance, as well as their commonality (meaning how common each factor is in oil and gas construction projects).

3.4.1.1 Survey Research

Survey research is so common a design that it may refer to any form of descriptive quantitative research. According to Leedy and Ormrod (2013), survey research involves obtaining information about the characteristics, opinions, attitudes, and previous experiences of one or more groups of people.

Gathering data in survey research can be done through questionnaires, face-to-face interviews, or telephone interviews. Irrespective of the means of data gathering, the questions posed in a survey should be carefully designed to ask only for the information that the researcher really needs. This is an important concern, considering that people are not always insightful about what they truly feel or think, and they normally express what they believe to be true, which may not be the truth itself. The design of the questionnaire is further elaborated in the following sections.

3.4.1.2 Questionnaire Design

As discussed in previous sections, survey research involves obtaining information about the opinions and previous experiences of one or more groups of people. In Phase I of this study, the main objective is to identify and rank engineering deliverables-related factors by relying on project professionals' experiences with real projects to determine how big the impact of the factor is on construction performance. To serve this purpose, a questionnaire survey was designed and an appropriate scaling method was employed. The questionnaire survey asked participants to provide, based on their experience, their opinion on how significant the impact of each of the 12 factors is, and how common each factor is in the projects with which they have been involved.

According to Saris and Gallhofer (2007), survey research is often used for descriptive research, which may provide merely the distribution of responses on specific questions.

An important aspect in designing questionnaires is to ensure that what is being measured is exactly what that is supposed to be measured. In other words, the process with which a concept is translated to a question or series of questions plays a key role in the reliability of the designed questionnaire. To address this issue, Blalock (1990) emphasizes on differentiating between two types of concepts: *concepts-by-intuition* and *concepts-by-postulation*.

Concepts-by-intuition are simple concepts whose meaning is immediately obvious and can normally be inquired with a single question. Examples of concepts-by-intuition include judgements, feelings, evaluations, norms, and behaviours, which can easily be presented with text such as: *x likes y*, or *x does y*.

Concepts-by-postulation are less obvious concepts that require explicit definitions—such as different forms of racism, or "attitudes" toward different objects. In this example, it is almost impossible to identify an attitude, or any racism, through just one item in the survey, so more items would need to be defined for such complex concepts (Saris & Gallhofer, 2007).

To present concepts-by-postulation, a set of items, each of which represent a concept-by-intuition, should be employed. This process is called the *operationalization* of a concept-by-postulation. Figure 3.3 illustrates an example of the operationalization of a concept-by-postulation (attitudes towards Candidate X) through a set of concepts-by-intuition.

As shown in Figure 3.3, in order to operationalize the concept of *attitude*, three concepts-by-intuition namely *cognitive judgement*, *feeling*, and *action tendency*, each being inquired by a single survey item, have been used.

Saris and Gallhofer (2007) have summarized the process into three steps:

1. Specification of the concept-by-postulation into concepts-by-intuition
2. Transformation of concepts-by-intuition in statements indicating the requested concepts
3. Transformation of the statement into a question

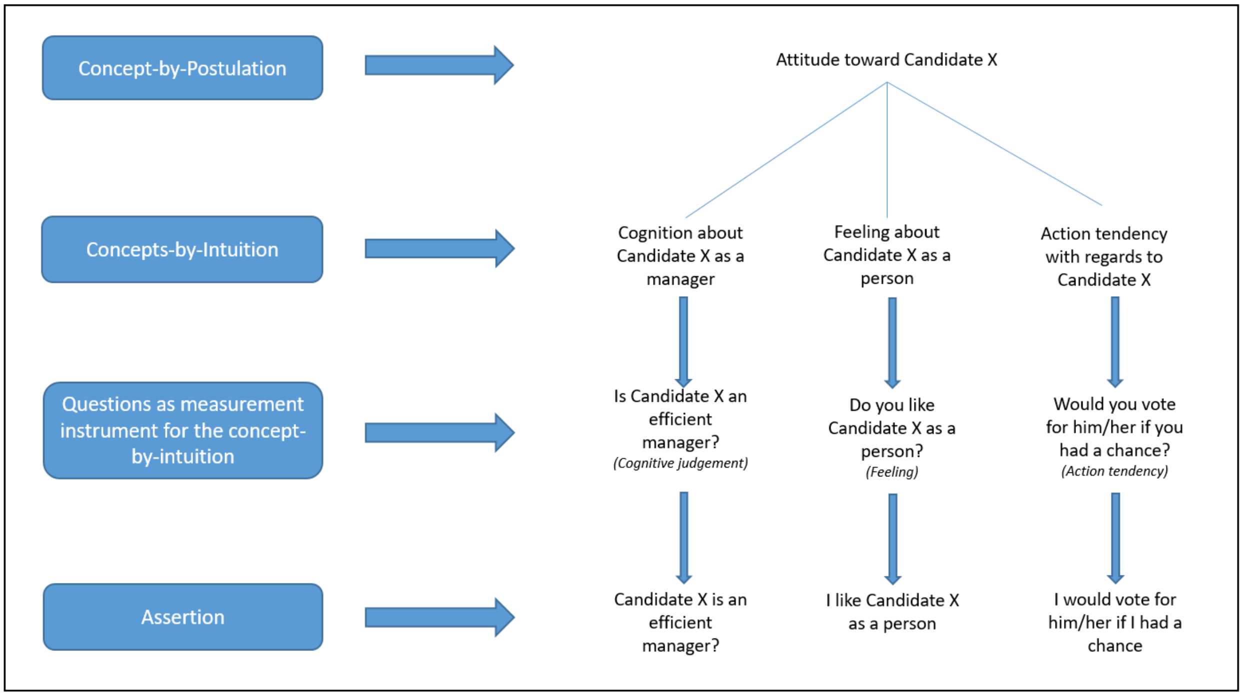


Figure 3.3: Example of operationalization of a concept-by-postulation

It is always necessary to ask whether the concepts to be measured are really measured by the way the questions are formulated.

A similar strategy is used to operationalize the concept *measuring the opinion of project professionals about engineering deliverables-related effects on construction performance*, using sets of questions that address each of the 12 factors by scaling their impact on cost, their impact on schedule, and their commonality, as shown in Figure 3.4.

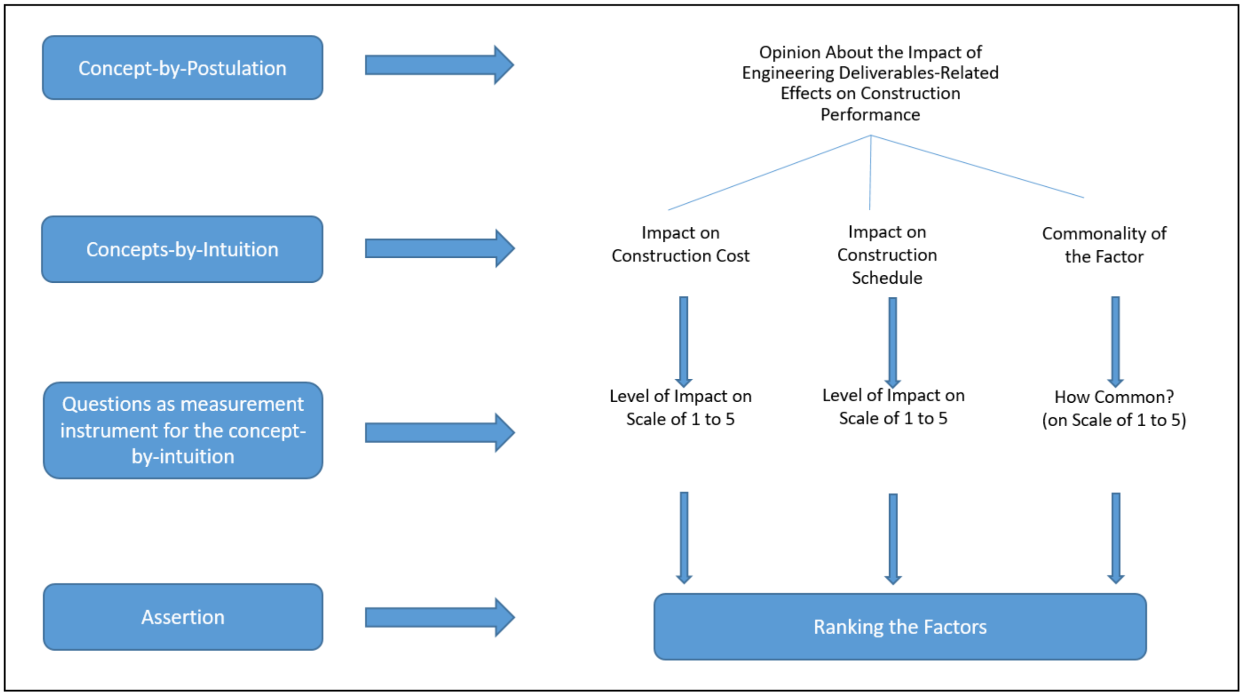


Figure 3.4: Operationalization of the concept of Phase I research question

3.4.1.3 Measurement Scale

Measurement means assigning numbers to properties of an object or phenomena. In the case of the questionnaire survey designed for Phase I, this number indicates the level of impact on construction performance, associated for each factor in engineering deliverables. According to Fellows and Liu (2015), the four primary measurement scales are *nominal* (e.g. 1, 3, 10,… used for identifying or classifying objects), *ordinal* (e.g. 1^{st}, 3^{rd}, … to indicate relative position), *interval* (e.g. performance rating on 1-10 scale), and *ratio* scales.

For the purpose of this phase of the research, a non-comparative scaling technique has been employed, meaning that each factor is scaled independently of others, using the Likert 5-point scale, where the respondent is asked to indicate the level of impact (or commonality) of each factor on scale of 1 to 5.

Likert is one of the most common non-comparative scaling methods, which considers the respondent’s level of agreement usually on a 5 or 7-point scale, where the definition associated with the low and high values is provided by the researcher. The number of the points is generally chosen to be an odd number to provide a central point (Fellows & Liu, 2015) so that the participant is able to give neutral response or indicate an average degree of agreement by choosing the middle number.

3.4.2 Sampling Design for Phase I

The main purpose of any survey is to produce information that is valid for entire population. However, since the size of the population is often too large to for any full survey to be even possible, a process of sampling is employed in such a way that the size and the structure of sample is sufficient to produce reliable information that can be representative of the population at a required and specified level of confidence (Fellows & Liu, 2015).

3.4.2.1 Probabilistic Sampling

Selecting the sample from the population can be done using *probabilistic sampling*, where every part of the sample has equal probability to be selected (Knight & Ruddock, 2009). In this type of sampling, care should be taken that sampling is carried out in such a way the researcher does not influence the selection of respondents. One suggested procedure to fulfill this criteria is *random* sampling, meaning that the respondents are selected at random. For the Phase I of the research, the process of distributing questionnaires among potential participants (through LinkedIn and Web-based survey discussed later) indicates an acceptable level of randomness and thus can be considered random sampling.

Using the definitions presented by Lohr (2010), the sampling parameters used for the purpose of current research are as follows:

- Observation Unit: an object on which a measurement is taken
- Target Population: The complete collection of observation units we want to study. This definition is an important and yet difficult part of sampling decisions.
- Sample: A subset of population.
- Sampling Unit: A unit that can be selected as a sample. Observation units are individuals in a sampling unit. In Simple Random Sampling (SRS), the sampling unit and the observation unit coincide.
- Sampling Frame: A list of all sampling units in a population

As discussed, sampling is a procedure to select a limited number of units from the population in order to describe the population (Saris & Gallhofer, 2007). With this definition, once the population is selected, the next step is to determine what size of sample is needed to provide sufficient data to represent the total population, or to get to a saturated point of data.

3.4.2.2 Sample Size (Quantitative Approach)

Similar to other research methods, an imperative decision for sampling strategy is the size.

The decision regarding the sample size must balance the precision of the survey with available resources such as cost and time allocated for the survey.

The required precision for sampling is often expressed as in Equation 3-1:

$$P\left(\left|\frac{\bar{y}-\bar{y}_U}{\bar{y}_U}\right| \leq e\right) = 1-\alpha$$

Where:

- $\bar{y}$ is the mean of sample
- $\bar{y}_U$ is the mean of population

- e is the margin of error
- α is determined so that $100(1-\alpha)\%$ indicated the desired confidence interval (CI)

For a margin of error of e=0.03, and an α=0.05 (a 95% confidence interval), the equation 3.1 can be interpreted as: *the probability of the sample mean being* $\pm$*3% different than the population mean is 95%*. That is, with this precision, we can be 95% sure that the mean of the sample we selected will be $\pm$3% different than the population mean.

To obtain a statistically representative sample of the population in an SRS, for a given margin of error and confidence interval, Lohr (2010), as well as some researchers in construction studies including Jarkas and Bitar (2014), and Zadeh, Dehghan, Ruwanpura, and Jergeas (2014) have used the formula as in Equation 3-2.

$$n = \frac{Z^2 p(1-p)}{e^2} \tag{3-2}$$

Where:

- n is the sample size
- Z is a statistic value for a given confidence interval. For 90%, 95%, and 99% confidence interval, the values of Z are 1.645, 1.96, and 2.575 respectively
- p is the value of proportion of population. For large populations, $S^2 \approx p(1-p)$, which gets its maximum value when p is conservatively taken as 0.5

Using Equation 3-2 for different precision parameters will yield in different sample sizes which are shown in Table 3.2.

Table 3.2: Sample Size for Different Margins of Error and Confidence Intervals

Margin of Error	Confidence Interval (CI)	Statistical Value Z	Sample Size n
$e = 0.05$	99%	2.575	663
	95%	1.96	384
	90%	1.645	270
	85%	1.44	208
	80%	1.28	183
$e = 0.1$	99%	2.575	166
	95%	1.96	96
	90%	1.645	68
	85%	1.44	52
	80%	1.28	46

Discussion:

As discussed earlier, the decision on the selected sample size depends on the availability of the resources, and the time and budget allocated for the research. Furthermore, as suggested by Lohr (2010), the purpose of the study for which the sampling is carried out or, in other words, what is expected from the sample and how much precision is needed may determine the factors related to evaluating the size of the selected sample. A monthly survey of unemployment, for example, needs to be as precise as possible to obtain reliable results to monitor changes in the unemployment on a monthly basis. A preliminary investigation, on the other hand, may require less precision than a monthly survey.

In order to conduct the Phase I of the current research, the designed questionnaire was directly sent to 119 potential participants. Additionally, the same questionnaire was also developed in a web-based survey software available at SurveyMonkey.com, and the link was distributed through professional social networks such as LinkedIn, as well as the author's own professional network, to an unknown number of potential participants. After more than three months, the number of complete responses received was 60. Using Table 3.2 determines that a sample of size 60 corresponds to a confidence interval of approximately 87% with 10% margin of error.

This amount of precision is deemed to be sufficient for Phase I of the current research, based on the objective of this phase, which is to identify and prioritize the factors that have negative impact on construction performance, and considering the sample sizes used in similar dissertations presented in some Master's and PhD theses in Project Management studies already known to the author.

3.4.3 Data Analysis

In order to rank the factors of engineering deliverables with negative impact on construction performance, in terms of their significance (i.e. level of impact on construction cost and schedule, and their commonality), the factor ranking method, which quantifies the significance of each factor through calculating and comparing the *relative importance index (RII)* for those factors, will be applied to analyze the Likert scale data collected through the questionnaire survey. The reliability and internal consistency of the results obtained through the survey will be verified by using Cronbach's Alpha coefficient. The data analysis for this part of the research is elaborated in full detail in Chapter 4.

3.5 Phase II: Framework for Enhancing Engineering Deliverables

As mentioned in section 3.2, the research question in Phase II is "How can engineering deliverables be enhanced to improve construction performance?" Unlike Phase I, the nature of the question in Phase II does not involve identifying an existing phenomena or measuring attributes. Instead, this phase is about developing a better understanding of why the issues identified in Phase I are happening, discovering methods to improve the engineering deliverables, and building a theory for enhancing them. Based on what was covered in section 3.1 regarding qualitative and quantitative research approaches, it is clear that this part of the research complies with qualitative research characteristics, and, hence, should be tackled using qualitative study tools and techniques which can be generalized in data collection and analysis techniques, sampling, and sample size decisions. The methodology used in this phase is shown in Figure 3.5.

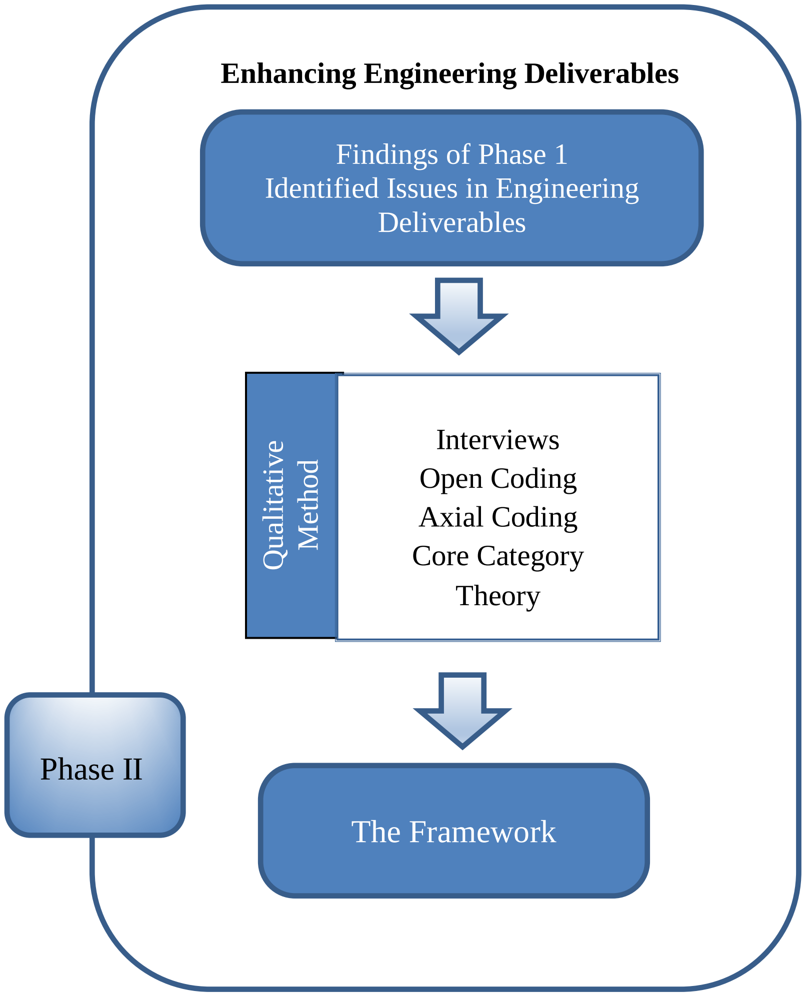


Figure 3.5: Methodology used in Phase II

Grounded Theory

Grounded Theory is one form of the qualitative research methodologies first coined by Glaser and Strauss in 1967. This qualitative research method seeks to construct theory grounded in data (Corbin & Strauss, 2014). Instead of approaching the data with pre-existing theories and concepts, and applying these theories to the data, the researcher begins, on the contrary, by collecting data, creating larger themes from these data, and integrating them into concepts around a core category, which in turn, produces Grounded Theory (Tracy, 2012).

Although the Grounded Theory approach was originally developed to be used in social science, its capability for allowing for identification of general concepts and development of theoretical explanations and insight for variety of experiences of phenomena, has made it applicable for many other disciplines.

3.5.1 Data Collection

As mentioned earlier, the Phase II of this research is conducted through an approach that borrows major concepts and techniques from the Grounded Theory qualitative research method. The Grounded Theory is unique from other qualitative research methods in that the concepts from which the theory is constructed are derived from the very data collected during the research process. In other words, the data provides the ground for the derived theory.

Types of data, collecting methods, and analysis of collected data in Grounded Theory are also different from other forms of qualitative research. The type of data looked for in Grounded Theory primarily are in the nature of opinions, concepts, viewpoints, behaviours, patterns, and the like. The main instruments for gathering data in Grounded Theory are interviews and observations. However, other means such as collecting written material or recorded material including videos, journals, documents, etc. can be used as well.

3.5.1.1 Theoretical Sampling

Theoretical sampling refers to a method of data collection that is based on concepts derived from data during analysis, where further questions about those concepts drive the next round of data collection (Corbin & Strauss, 2014). Researchers and authors have presented similar definitions for theoretical sampling. Glaser, Strauss, and Strutzel (1968), among the pioneers in the Grounded Theory methodology, defined theoretical sampling as “the process of data collection for generating theory whereby the analyst jointly collects, codes, and analyses his data and decides what data to collect and where to find them in order to develop his theory as it emerges” (p. 45). In a more concise fashion, but conveying the same concept, Birks and Mills (2015) explain theoretical sampling to be the process of identifying and pursuing ideas and clues that come up during analysis in Grounded Theory study. The process can be considered as the constant comparison of findings of analysis against the actual data, and accordingly, making necessary modifications on the interpretations based on those comparisons (Corbin & Strauss, 2014).

Unlike the quantitative approach, which intends to generalize information, qualitative research seeks to crystallise particular information regarding phenomena, by using sampling approaches that allow for theoretical and conceptual explanation. Creswell (2012) envisaged the theoretical sampling and data gathering in Grounded Theory as theoretically choosing the participants and following a “zigzag” process of gathering information from the participants, then analysing them in the office, then back to the participants for more information, then back to the office for further analysis, and so forth.

Theoretical sampling is among the most common sampling approaches, which is also known as *purposive sampling*, meaning that the sample is selected with a background purpose, and not random. In this approach, the individuals (people, documents, texts, etc.) are selected from a pre-defined group, and are chosen because they meet some specific criteria needed for that particular research (Corbin & Strauss, 2014; Given, 2015). Examples of those inclusion criteria include a certain level or field of experience, particular job title, etc. (Trochim, 2006).

Theoretical sampling is not used for purposes such as testing hypotheses about concepts or describe a phenomena, where plans as to what to collect, where to go, who to talk, etc. are decided by the researcher at the very beginning of the research. Rather, theoretical sampling is used to find concepts, understand their properties, and shape theory directly from data. It allows for discovery, especially when new areas are studied. Figure 3.6 illustrates the data collection and analysis processes and their interrelation in Grounded Theory.

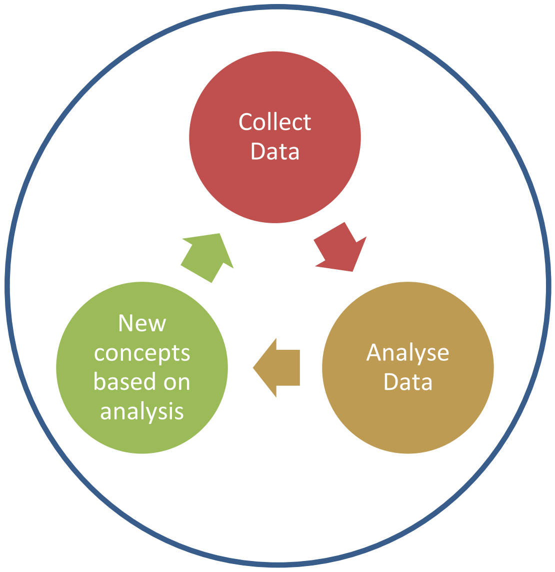


Figure 3.6: Data collection and analysis interrelation in Grounded Theory

3.5.1.2 Interview Design

The main instrument for data gathering for this phase of the research is the interview. The sample population from which the interviewees were selected was essentially the project professionals that had participated in Phase II questionnaire survey, as well as other project specialists who had not been approached in Phase I, but had similar years of experience, positions, and other such qualifications.

In general, three types of interviews are used in qualitative research: *unstructured interviews*, *semi-structured interviews*, and *structured interviews*.

Unstructured Interviews: In this type of interview, participants have more control over the course of the interview and talk more freely about the problem or issue under the study. Hence, Corbin & Strauss, 2014 suggest that unstructured interviews provide the richest source of data for theory building. In an unstructured interview, the topic may have not been chosen before beginning the research. Thus this type of interview is ideal for developing research problems and identifying the main research question.

Semi-Structured Interviews: In semi-structured interviews, some topics are chosen before the beginning of research but the topics are not presented in the interview in any structured way. This type of interview enables the researcher to maintain some level of consistency through covering the same topics in each interview. Participants can later add anything to the interview that they think is relevant to the discussion, once the questions of the topics are covered.

Structured Interviews: In Structured Interview, the interview is conducted using an interview guide with the same set of questions in each interview. Participants usually respond only to the questions that are asked without adding any other topic relevant subjects.

For the current research in Phase II, a semi-structured interview approach was adopted. The reason behind this resolution is first, that the topic and the subject around which interview questions are revolving is already known both to the researcher and the interviewee; and second, the questions must be open-ended, yet giving the interviewee enough space to add new but relevant ideas and feedback (unlike structured interviews). This is a basic concept in the Grounded Theory method.

A semi-structured interview was used to develop an understanding of the construct the participant used as the basis of their opinion and beliefs (Love et al., 1999) regarding the way in which each engineering deliverables-related issue can be mitigated or eliminated.

3.5.2 Sampling Design for Phase II

The term *sample* can also be used to refer to that part of the total population with which the research is in interaction. As noted earlier, in Phase II of this research, the *Theoretical Sampling* concept is used, in which data is collected through a back-and-forth iteration of data gathering and data analysis which, to a great extent, removes the randomness of selecting the participants. Therefore the probability of the sampling units within the sampling population is not equal. This type of sampling is known as *non-probabilistic* sampling.

3.5.2.1 Non-probabilistic Sampling

In non-probabilistic sampling, a predefined set of criteria (Trochim, 2006) or a well-informed judgment (Fellows & Liu, 2015) determines which part of the population should be selected. This sampling approach is also referred to as *non-random* sampling. Qualitative research normally is designed to use non-probabilistic sampling methods (Given, 2015), which means that the sampling does not involve random selection.

3.5.2.2 Sample Size (Qualitative Approach)

As discussed in earlier, the Theoretical Sampling approach involves some iteration of collecting data form participants, analysing the data, and going back to participants for more data. The question is, how much of this type of sampling needs to be done to be sufficient for building theory. The answer to this question can be that the researcher should continue to gather data until reaching a certain level which is called the level of *data saturation*.

Point of Saturation

According to Corbin and Strauss (2014), *Theoretical Saturation* occurs when further data gathering does not yield in new category or relevant theme, whether it be emerging new categories or themes, or new properties and dimensions of categories and themes including variations, possible relations etc. In simpler terms, *saturation point* means a level in data collection where further data gathering does not add to what researcher has already found. At the saturation point, the data repeat themselves and provide confirming evidence of the identified themes (Given, 2015). This level is reached when the researcher can consider the concept to be sufficiently well developed for the purpose of the research, and what has not been covered by that level of data can be considered as limitations of the study.

Arriving at Point of Saturation

In order to decide the number of interviews to reach to the point of saturation, one general approach can be the recommendations provided for different qualitative methods, found in literature. For Grounded Theory, according to Creswell (2012), the number of required interviews in the process of constant comparative data analysis, which depends on whether the particular category of information become saturated and whether theory is sufficiently elaborated, is suggested to be 20 to 30 interviews to develop a well-saturated theory.

An interesting study was conducted by Mason (2010) to investigate the number of interviews performed in PhD studies that have used qualitative approach. The study involved content analysis of PhD databases of comprehensive listing of PhD theses accepted in the universities of Great Britain and Ireland. The result showed that, of the 560 studies analysed, the median and mean for the number of interviews undertaken for PhD research were 28 and 31 respectively.

Notably, for the research works that used Grounded Theory design (174 studies), the median and mean were 32 and 30 respectively.

Discussion

For the current research, as many as 25 to 35 interviews was originally targeted. This number for interviews was consistent with the recommendations by renowned authors in Grounded Theory, and with the sample sizes used in similar academic dissertations known to the author, as well as the findings of the research by Mason mentioned above. However, as will be shown in next chapters, the saturation point occurred after 25 interviews, where no further information was obtained from the interview.

3.5.3 Data Analysis and Framework Development

Analysis of data in Grounded Theory, irrespective of type and method of collection, is performed by means of a process called *constant comparison* (Corbin & Strauss, 2014), in which the data is broken down to more manageable pieces, which are later compared for similarities and differences. Data with similarities are grouped under the same conceptual heading, which will form different categories, and eventually different categories are integrated around the core category. The core category describes what the researcher identifies as the major theme of the research. The core category, together with the other categories, constitutes the structure of the theory (Corbin & Strauss, 2014).

The data analysis process in Grounded Theory is illustrated in Figure 3.7.

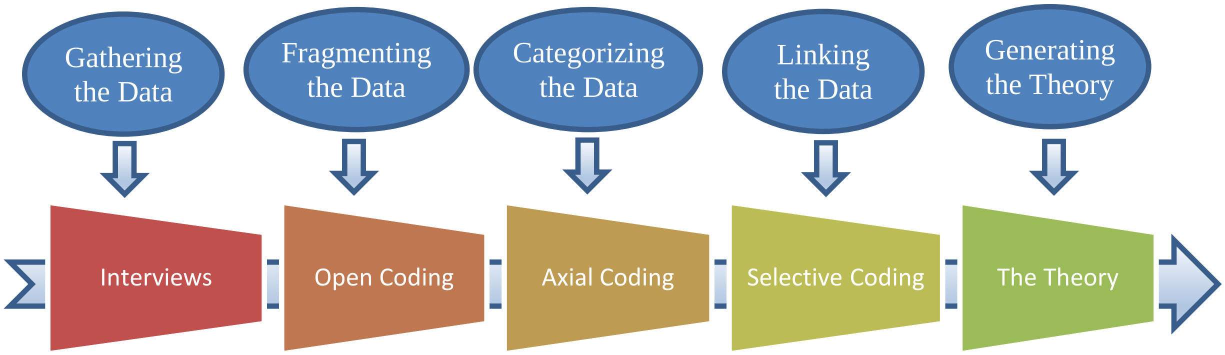


Figure 3.7: Data analysis process in Grounded Theory methodology

Data analysis in Grounded Theory involves what is commonly referred to as *coding*. According to Corbin and Strauss (2014) coding involves interacting with data using analytic tools which are mental (or thinking) strategies used by the researcher when coding. Analytic tools used in various qualitative research include:

- The use of questions
- Making constant comparison
- Considering different meaning of words
- Drawing upon personal experience
- Looking for negative cases

Concepts: Concepts are derived from raw data by analysts. They express the understanding of the analyst from what is experienced as actions, interaction, problems, and issues by the participants. Concepts can facilitate grouping or organizing data if that group of data actually share the concept (as birds, planes and kites broadly share *flight* as a concept) (Corbin & Strauss, 2014). Concepts can be considered as the building blocks of theory, because, once established, they can receive focus and provoke questions, which eventually may lead to hypothesis or propositions.

Open Coding: In Grounded Theory, data analysis starts immediately after the first interview. Open coding is generally seen as breaking down data into more manageable pieces and examining them closely, and comparing for possible relations, similarities, and dissimilarities. In other words, it is the first step of making sense of data (Priest, Roberts, & Woods, 2002). *Data* here means a sentence or paragraph of speech from an interview or an observation. More precise definition of open coding is presented by Strauss and Corbin (1998) as "the analytic process through which concepts are identified, and their properties and dimensions are discovered in data" (p. 101). In open coding, the researcher looks for distinct first-level categories of data which will form the basic unit of the analysis. The coding at this stage is unfocused and "open", and the researcher may recognise hundreds of codes which might have potential meaning and relevance (Goulding, 1999). Coding may start with a full transcription of an interview. The text is then thoroughly analysed to identify key words or phrases which connect the participant's description to the experience under study (Moghaddam, 2006). When the analyst uses the words of the interviewee as a code, the code type is called *in-vivo*, indicating that the code is a term used by the interviewee.

Axial Coding: The act of relating categories to subcategories is usually referred to as *axial coding*. This act of relating is along the lines of the properties and dimensions. The purpose of axial coding is to reassemble data and put back together what was fractured in open coding, by relating concepts. This is done by relating categories and concepts to form more precise and complete explanation about phenomena (Strauss & Corbin, 1998). Note, however, that open coding and axial coding go hand in hand and happen almost at the same time. Some Grounded Theory literature have separated the two types of coding, but only for explanatory purposes in order to indicate the thought process of breaking down the data and relating them together. From a different perspective, one can notice that the mind will automatically make the connections between categories while they are being developed.

Selective Coding: Selective coding is the final stage of data analysis in Grounded Theory. As concisely defined by Strauss and Corbin (1998), selective coding is the process of integrating and refining theory. Once the coded data categories and subcategories are identified through open coding and axial coding, the core category, which represents the main theme of research, is identified through selective coding. The core concepts are then abstracted and Grounded Theory is empirically generated (Mills, Durepos, & Wiebe, 2010). In selective coding, the researcher acts as an author and uses all the categories, coding notes, memos, and diagrams gathered so far, as a starting point to develop the main phenomenon of the research—which is same as the core category. However, it is possible during the research process that a category different from what was originally assumed will take the central or core importance. It is, therefore, recommended in Grounded Theory to ask repeatedly during the course of research which categories are central, and prepare appropriate memos accordingly (Böhm, 2004).

Strauss and Corbin (1998) identified the following criteria for choosing a central category:

a) It must be central; that is, all other major categories can relate to it.
b) It must appear frequently in the data. There should be indicators pointing to that concept in all or almost all cases.
c) There is no forcing of data; that is, the explanation that evolves by relating the categories is logical and consistent.
d) The name or phrase used to describe the central category should be abstract.

e) As the concept is refined through integration with other concepts, the theory grows in depth.

f) The concept is able to explain variation, as well as the main point made by the data.

3.6 Validation of the Results

Validation of an analysis is a crucial part of the study leading to theory building. In Grounded Theory methodology, considering the philosophy of theoretical sampling discussed in section 3.5.1, which aims at maximizing the opportunities for comparative analysis, validation is built into each step of analysis and sampling. The researcher, in Grounded Theory method, is constantly comparing the output of their analysis against actual data, and during each iteration, the researcher makes modifications and additions against incoming data. Therefore, the researcher is continuously validating their interpretation, or sometimes negating prior findings. The results that eventually become part of the theory have already stood up against this rigorous comparison process (Strauss & Corbin, 1998).

However, the final product of this research is a framework which is based on the theory itself, built through the Grounded Theory method and the information and interpretations obtained from the participants, and is to be used in order to enhance the engineering deliverables. Therefore the following methods (Leedy & Ormrod, 2013) were adopted to validate the findings of this research:

- **Internal Validation:** This method is also known as *respondent validation*. To validate a qualitative research, the findings are sent back to the participants to determine if the participants are in agreement with the findings and conclusions.
- **External Validation:** Also referred to as *feedback from others*, this method requires that the results of the study be shared with other members of the target population (in this case,

other experts in oil and gas projects who were not participating in the interviews), to examine whether they agree or disagree with the findings of the study.

Validation process for this study and the corresponding results will be discussed in detail in Chapter 6.

Chapter Four: **Data Collection and Analysis for Phase I**

4.1 Introduction

This chapter presents the data gathering and data analysis process to address the Phase I of this research. As discussed in Chapter 3, Phase I of the research aims at identifying and ranking major factors related to the engineering deliverables that may have negative impact on construction performance.

This phase of the research complies with descriptive research characteristics as discussed in section 3.1, and hence a quantitative approach is adopted for this part of the research. A questionnaire survey was conducted for data collection purposes, and 60 responses were obtained for which a proper quantitative analysis was performed to rank the factors, and eventually identify major engineering deliverables issues affecting construction performance.

4.2 Questionnaire Design

As discussed in section 3.4.1 of the previous chapter, a list of 12 factors in engineering deliverables which could have negative impact on construction performance was developed based on a comprehensive literature review (see chapter 2), as well as discussions in focus groups consisting of experts in oil and gas EPC projects (see chapter 3). The factors are shown in Table 4.1.

A questionnaire was designed and conducted with three main objectives as follows:

1. To validate that the identified 12 factors have negative impact on construction performance
2. To find out if there are more factors that have significant negative impact on construction performance.
3. To rank those factors based on the level of impact on construction performance, and their commonality in oil industry projects.

Table 4.1: Identified Factors of Engineering Deliverables with Negative Impact on Construction Performance.

Factors with Negative Impact on Construction Performance			
1	Design scope change	7	Design complexity
2	Design inadequacy	8	Inadequate engineering knowledge
3	Design errors	9	Late deliverables *(schedule delays)*
4	Design omissions	10	Untimely deliverables *(faulty schedule)*
5	Design with constructability issues	11	Inefficient format/Unclear information
6	Design inconsistency	12	Issues with vendor drawing

In order to reduce the potential risk of the respondents' different interpretation of the meaning or context of the above-mentioned factors, they were clearly defined and elaborated in the body of the questionnaire, as also explained in the following:

- **Design scope change:** changes in the engineering deliverables after IFC, due to change in design scope
- **Design inadequacy:** changes in engineering deliverables after IFC, due to inadequacy of original design.
- **Design errors:** errors depicted in IFC engineering deliverables during construction. Errors are items in the deliverables that are shown incorrectly.
- **Design omissions:** information or items that need to be shown in engineering deliverables but are not shown at all.
- **Design with constructability issues:** engineering deliverables that fail to address constructability requirements.

- **Design inconsistency:** inconsistent or contradicting information on different engineering deliverables.
- **Design complexity:** complex design, details, or presentation of information, where a less complex solution could have been used or was proposed by construction.
- **Inadequate engineering knowledge/skills:** engineering deliverables generated by less experienced engineering team.
- **Late deliverables (schedule delay):** engineering deliverables that are not available to construction at the scheduled time.
- **Untimely deliverable (faulty schedule):** engineering deliverables that are not scheduled properly therefore not available to construction when needed. (This is distinct from schedule delays).
- **Inefficient format of deliverables:** engineering deliverables that are difficult to use in construction due to poor format such as size, font size, scale of drawing, etc.
- **Issues with vendor documents:** any problems such as errors and omissions, changes, incompleteness, etc., in the deliverables that are directly supplied by vendors.

Figure 4.1 shows different sections of the applied questionnaire in the survey.

Measurement Scale: For the purpose of this phase of the research, a non-comparative scaling technique has been employed, using a Likert 5-point scale, where the respondent is asked to indicate the level of impact (or commonality) of each factor on scale of 1 to 5. The Likert scale is one of the most common non-comparative scaling methods, which considers the respondent's level of agreement usually on a 5 or 7-point scale. The definition as to what is lowest value and what is the highest value is provided by the researcher. In this research 1 is defined as *No Impact*, and 5 is defined as *Significant Impact* (for commonality evaluation, those definitions are *Rare* and *Very Common* respectively).

Pretesting the Questionnaire:

Pretesting questionnaires is an essential step in the survey design process. It increases the validity and reliability of the survey evidence. The purpose of the questionnaire pretest is to determine if respondents understand the questions and to ensure that respondents interpret and answer questions in the way in which the research intended.

For pretesting, the designed questionnaire was sent to twelve respondents. The pretest respondents were selected in a way that they had similar roles and experiences in oil and gas projects to the target participants of the survey.

The pretest respondents were asked to answer the survey questions and give their feedback on whether the questions and the definitions of the factors of engineering deliverables were clear and easy to understand.

Questionnaire Survey

Impact of Engineering Deliverables on Construction Performance

Dear Survey Participant,

You have been invited to participate in a research survey which intends to identify the level of impact of some engineering deliverable-related factors contributing to poor construction cost and schedule performances in oil and gas projects. The main objective of the broader research being conducted is to develop a framework to enhance engineering deliverables to improve construction performance in oil and gas industry projects.

This survey is part of a PhD research work being undertaken by Farshid Gholami at the University of Calgary. The research supervisor is Dr. George Jergeas. This survey has been approved by the Conjoint Faculties Ethics Board of the University of Calgary. Participation in the survey is completely voluntary and the contents of this form will be confidential. Information identifying the respondent will not be disclosed under any circumstances, and will remain with the University of Calgary. Please note that submission of the completed survey will be taken as an indication of your consent to participate in the survey.

Your cooperation and contribution is highly appreciated.

Regards,
Farshid Gholami

Center for Project Management Excellence
Schulich School of Engineering
University of Calgary
2500, University Drive NW
Calgary AB T2N 1N4, Canada.
Phone: 403 481 1970
Email: fgholami@ucalgary.ca

Figure 4.1: Different sections of the applied questionnaire in the survey

SECTION A: Demographic Information of the Participant

Code:
To be filled by research team

Please provide the information requested below:

1- Total years of professional experience

☐ Less than 5 years ☐ 5-10 years ☐ 10-15 years ☐ 15-20 years ☐ More than 20 years

2- What position(s) have you had in your career? *(Select all that apply)*

☐ Design Engineer / Senior Engineer
☐ Discipline Lead Engineer
☐ Project Engineer
☐ Project Engineering Manager
☐ Project Procurement Manager
☐ Project Controls Manager
☐ Project Manager
☐ Program Manager
☐ Engineering Department Manager
☐ Corporate Engineering Manager
☐ Site Superintendent
☐ Field Engineer /Senior Engineer
☐ Field Engineering Manager
☐ Field Project Engineer
☐ Construction Coordinator
☐ Construction Lead
☐ Construction Manager
☐ Quality Inspector
☐ Supervisor
☐ Other *(Please specify):* ____________________

3- What is your current/most recent position?

____

4- How many oil and gas projects have you been involved with?

☐ Less than 5 ☐ 5-10 ☐ 10-15 years ☐ 15-20 ☐ 20 or more

5- What is the type of your current/most recent organization?

☐ Owner
☐ General Contractor
☐ Construction Management
☐ Construction Contractor/Subcontractor
☐ EPC/EPCM
☐ Engineering Consultant
☐ Other *(Please specify):* ____________________

Figure 4.1: Different sections of the applied questionnaire in the survey. (Contd.)

SECTION B: Impact of Engineering Deliverables on Construction Cost Performance

1) *Shown below is a list of factors related to engineering deliverables that may have negative impact on construction cost performance. On scale of 1 to 5, please indicate the level of impact of each factor, where:*

1 is "No Impact" or "Negligible Impact", meaning that the factor does not result in construction cost overrun, or the incurred extra cost is negligible.

5 is "Significant Impact", meaning that the factor may cause huge construction cost overrun that may jeopardise construction project success.

	Factors Affecting Construction Cost Performance	**Level of Impact**				
		1	**2**	**3**	**4**	**5**
1	Design Scope Change *Changes in the engineering deliverables after IFC, due to change in design scope.*	☐	☐	☐	☐	☐
2	Design Inadequacy *Changes in engineering deliverables after IFC, due to inadequacy of original design.*	☐	☐	☐	☐	☐
3	Design Errors *Errors depicted in IFC engineering deliverables during construction. Errors are items in the deliverables that are shown incorrectly.*	☐	☐	☐	☐	☐
4	Design Omissions *Information or items that need to be shown in engineering deliverables but are not shown at all.*	☐	☐	☐	☐	☐
5	Design with Constructability Issues *Engineering deliverables that fail to address constructability requirements.*	☐	☐	☐	☐	☐
6	Design Inconsistency *Inconsistent or contradicting information on different engineering deliverables.*	☐	☐	☐	☐	☐
7	Design Complexity *Complex design, details, or presentation of information, where less complex solution could have been used or were proposed by construction.*	☐	☐	☐	☐	☐
8	Inadequate Engineering Knowledge/Skills *Engineering deliverables generated by less experienced engineering team.*	☐	☐	☐	☐	☐
9	Late Deliverables *(Schedule delay)* *Engineering deliverables that are not available to construction at the scheduled time.*	☐	☐	☐	☐	☐
10	Untimely Deliverable *(Faulty Schedule)* *Engineering deliverables that are not scheduled properly therefore not available to construction when needed. (Please note that this is different than schedule delays).*	☐	☐	☐	☐	☐
11	Inefficient Format of Deliverables *Engineering deliverables that are difficult to use in construction due to poor format such as size, font size, scale of drawing, etc. .*	☐	☐	☐	☐	☐
12	Issues with Vendor Documents *Any problems such as errors and omissions, changes, incompleteness, etc., in the deliverables that are directly supplied by vendors.*	☐	☐	☐	☐	☐

Figure 4.1: Different sections of the applied questionnaire in the survey. (Contd.)

2) Based on your own experience and knowledge of projects, please indicate other factors regarding engineering deliverables, that you think may have negative impact on construction cost performance, and should be considered if any improvement in construction cost performance is sought.

Please provide a brief description of each factor as well as the level of impact, on scale of 1 to 5, on construction cost performance, in the table below. (See previous page for definitions of the rates 1 and 5)

	Other Factors Related to Engineering Deliverables Affecting Construction Cost Performance	**Level of Impact**				
		1	**2**	**3**	**4**	**5**
1		☐	☐	☐	☐	☐
2		☐	☐	☐	☐	☐
3		☐	☐	☐	☐	☐
…		☐	☐	☐	☐	☐
…		☐	☐	☐	☐	☐

Figure 4.1: Different sections of the applied questionnaire in the survey. (Contd.)

SECTION C: Impact of Engineering Deliverables on Construction Schedule Performance

1) *Shown below is a list of factors related to engineering deliverables that may have negative impact on construction schedule performance. On scale of 1 to 5, please indicate the level of impact of each factor, where:*

1 is "No Impact" or "Negligible Impact", meaning that the factor does not result in construction delay, or the incurred schedule delay is negligible.

5 is "Significant Impact", meaning that the factor may cause huge construction schedule delays that may jeopardise construction project success.

	Factors Affecting Construction Schedule Performance	**Level of Impact**				
		1	**2**	**3**	**4**	**5**
1	Design Scope Change *Changes in the engineering deliverables after IFC, due to change in design scope.*	☐	☐	☐	☐	☐
2	Design Inadequacy *Changes in Engineering deliverables after IFC, due to inadequacy of original design.*	☐	☐	☐	☐	☐
3	Design Errors *Errors depicted in IFC engineering deliverables during construction. Errors are items in the deliverables that are shown incorrectly.*	☐	☐	☐	☐	☐
4	Design Omissions *Information or items that need to be shown in engineering deliverables but are not shown at all.*	☐	☐	☐	☐	☐
5	Design with Constructability Issues *Engineering deliverables that fail to address constructability requirements.*	☐	☐	☐	☐	☐
6	Design Inconsistency *Inconsistent or contradicting information on different engineering deliverables.*	☐	☐	☐	☐	☐
7	Design Complexity *Complex design, details, or presentation of information, where less complex solution could have been used or were proposed by construction.*	☐	☐	☐	☐	☐
8	Inadequate Engineering Knowledge/Skills *Engineering deliverables generated by less experienced engineering team.*	☐	☐	☐	☐	☐
9	Late Deliverables *(Schedule delay)* *Engineering deliverables that are not available to construction at the scheduled time.*	☐	☐	☐	☐	☐
10	Untimely Deliverable *(Faulty Schedule)* *Engineering deliverables that are not scheduled properly therefore not available to construction when needed. (Please note that this is different than schedule delays).*	☐	☐	☐	☐	☐
11	Inefficient Format of Deliverables *Engineering deliverables that are difficult to use in construction due to poor format such as size, font size, scale of drawing, etc.*	☐	☐	☐	☐	☐
12	Issues with Vendor Documents *Any problems such as errors and omissions, changes, incompleteness, etc., in the deliverables that are directly supplied by vendors.*	☐	☐	☐	☐	☐

Figure 4.1: Different sections of the applied questionnaire in the survey. (Contd.)

2) *Based on your own experience and knowledge of projects, please indicate other factors regarding* ***engineering deliverables*** *, that you think may have negative impact on construction schedule performance , and should be considered if any improvement in construction schedule performance is sought.*

Please provide a brief description of each factor as well as the level of impact, on scale of 1 to 5, on construction schedule performance, in the table below. (See previous page for definitions of the rates 1 and 5)

	Other Factors Related to Engineering Deliverables, Affecting Construction Schedule Performance	Level of Impact				
		1	2	3	4	5
1		☐	☐	☐	☐	☐
2		☐	☐	☐	☐	☐
3		☐	☐	☐	☐	☐
…		☐	☐	☐	☐	☐
…		☐	☐	☐	☐	☐

Figure 4.1: Different sections of the applied questionnaire in the survey. (Contd.)

SECTION D: Commonality of the Factors Related to Engineering Deliverables Affecting Construction Performance

Based on your experience and the projects you were involved with or know of, please indicate, on scale of 1 to 5, how common it was to have each of the factors shown below, in the engineering deliverables of those projects, where:

1 means: "Rare. This factor was rarely an issue in the engineering deliverables of the projects I was involved with."

5 means: "Very common. This factor was a very common issue in the engineering deliverables of the projects I was involved with."

	Factors Affecting Construction Cost/ Schedule Performance	**How Common**				
		1	**2**	**3**	**4**	**5**
1	Design Scope Change *Changes in the engineering deliverables after IFC, due to change in design scope.*	☐	☐	☐	☐	☐
2	Design Inadequacy *Changes in Engineering deliverables after IFC, due to inadequacy of original design.*	☐	☐	☐	☐	☐
3	Design Errors *Errors depicted in IFC engineering deliverables during construction. Errors are items in the deliverables that are shown incorrectly.*	☐	☐	☐	☐	☐
4	Design Omissions *Information or items that need to be shown in engineering deliverables but are not shown at all.*	☐	☐	☐	☐	☐
5	Design with Constructability Issues *Engineering deliverables that fail to address constructability requirements.*	☐	☐	☐	☐	☐
6	Design Inconsistency *Inconsistent or contradicting information on different engineering deliverables.*	☐	☐	☐	☐	☐
7	Design Complexity *Complex design, details, or presentation of information, where less complex solution could have been used or were proposed by construction.*	☐	☐	☐	☐	☐
8	Inadequate Engineering Knowledge/Skills *Engineering deliverables generated by less experienced engineering team.*	☐	☐	☐	☐	☐
9	Late Deliverables *(Schedule delay)* *Engineering deliverables that are not available to construction at the scheduled time.*	☐	☐	☐	☐	☐
10	Untimely Deliverable *(Faulty Schedule)* *Engineering deliverables that are not scheduled properly therefore not available to construction when needed.*	☐	☐	☐	☐	☐
11	Inefficient Format of Deliverables *Engineering deliverables that are difficult to use in construction due to poor format such as size, font size, scale of drawing, etc.*	☐	☐	☐	☐	☐
12	Issues with Vendor Documents *Any problems such as errors and omissions, changes, incompleteness, etc., in the deliverables that are directly supplied by vendors.*	☐	☐	☐	☐	☐

Figure 4.1: Different sections of the applied questionnaire in the survey. (Contd.)

4.3 Sampling and Sample Size

The calculations and other considerations leading to the decision about sample size for this phase of the research is elaborated in detail in section 3.4.2 of Chapter 3. As noted above, the questionnaire was sent directly to 119 potential participants. Additionally, the same questionnaire was also developed in a web-based survey software available at SurveyMonkey.com, and the link distributed through social networks such as LinkedIn, to an unknown number of potential participants. After more than three months, the number of complete responses received was 60. Using the formulation presented in Chapter 3, one can determine that a sample of size 60 corresponds to an 88% confidence interval (CI) with 10% margin of error, which is deemed to be adequate for the purpose of this research.

4.4 Analysis of Survey Results

4.4.1 Respondents' Demographic Information

The target population for this survey were individuals from oil and gas industry projects with positions relevant to engineering and construction. The survey asks the participant's current position as well as positions they might have had in the past, as for example a project manager may have had a senior engineer position in previous projects. Figure 4.2 shows different positions in oil and gas projects that the respondents currently have or have had in their previous career.

Figure 4.3 illustrates the distribution of the total years of experience among the respondents. As can be seen, a majority of the respondents have more than 15 years of experience, and only 6.67% of the respondents have less than 10 years of experience in oil and gas projects.

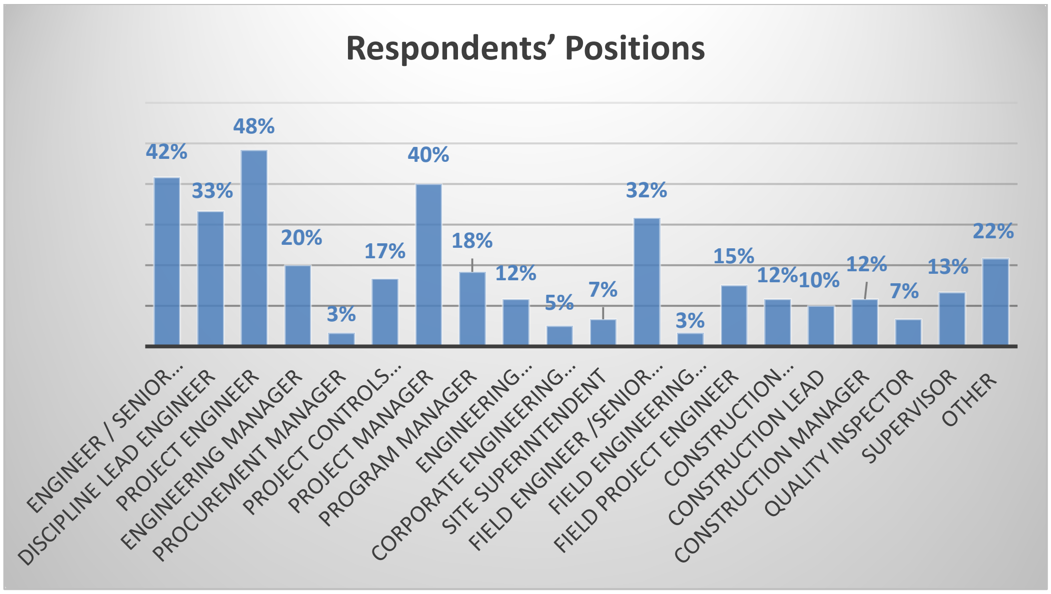


Figure 4.2: Positions that respondents have had in projects

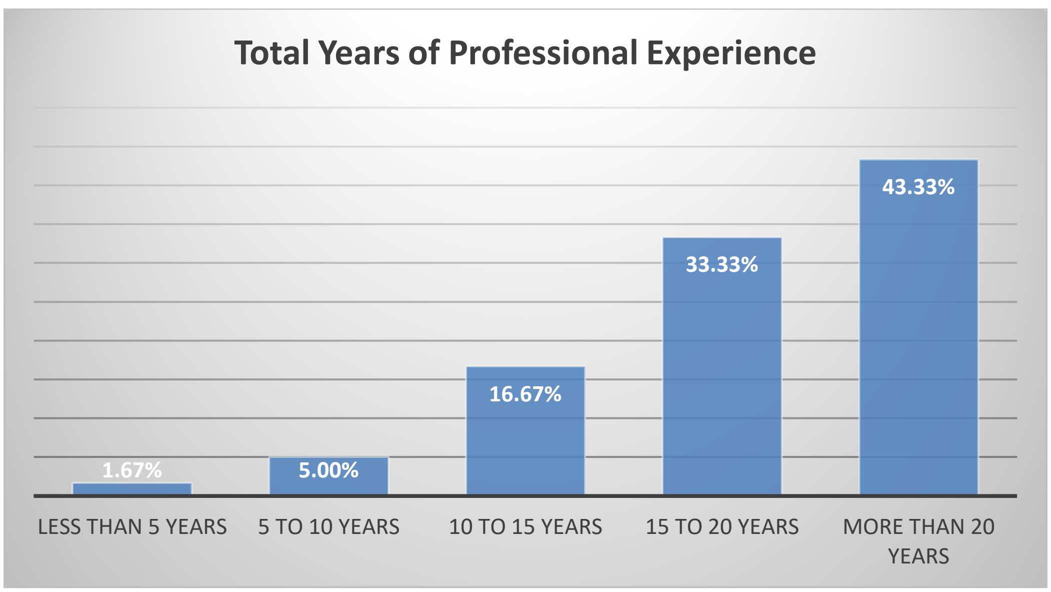


Figure 4.3: Respondents' total years of experience

The number of oil and gas projects that the respondents were involved in, was also asked in the questionnaire. The results are demonstrated in Figure 4.4.

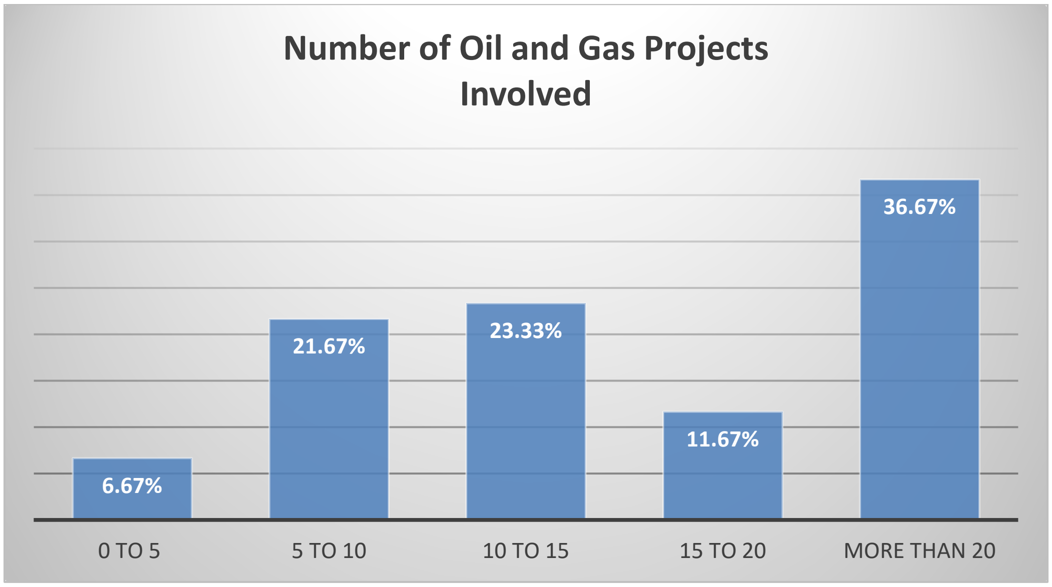


Figure 4.4: Number of oil and gas projects involved by the respondents

Figure 4:5 illustrates the type of organizations the respondents were working with at the time of the survey. As shown, 55% of the respondents were from owner organizations and 45% were from different types of contractor organizations.

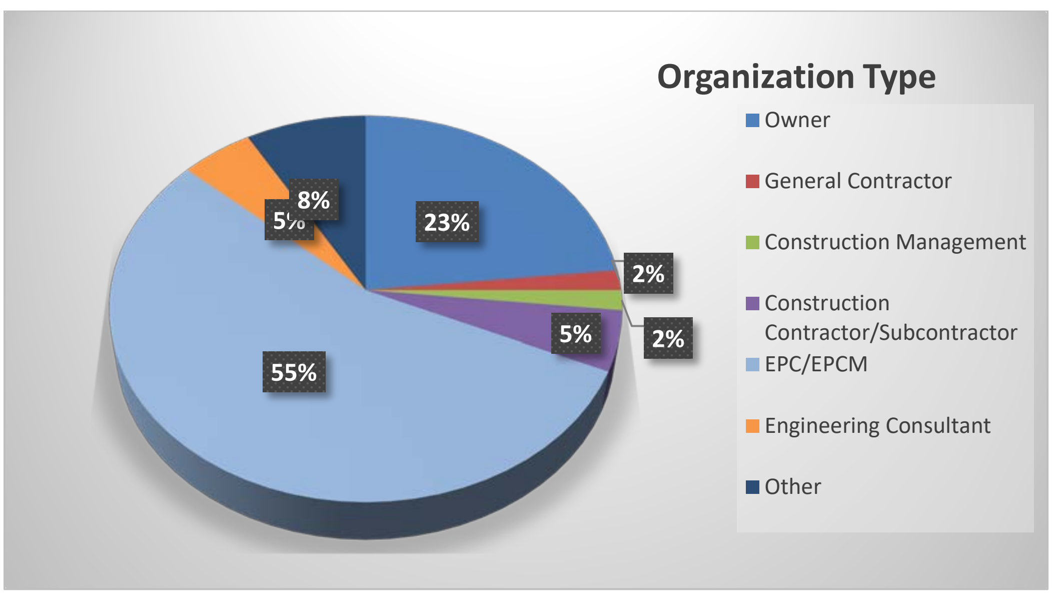


Figure 4.5: Type of organizations participants were working with

4.4.2 Relative Importance Index Calculations

In order to rank the factors of engineering deliverables with negative impact on construction performance by their significance (i.e. level of impact on construction cost and schedule, and their commonality), the factor ranking method, which quantifies the significance of each factor through calculating and comparing the relative importance index (RII) for those factors, was applied to analyze the Likert scale data collected through the questionnaire survey. The RII index is calculated using Equations 4.1 and 4.2 below:

$$RII = \left[\sum_{i=1}^{5} w_i f_i\right] \times \frac{100\%}{n} \tag{4.1}$$

$$w_i = \frac{i}{A} \tag{4.2}$$

Where:

RII = Relative Importance Index for each factor

i = rating 1 to 5

w_i = weight for the rating point i in the scale

f_i = number of times (frequency) that the responses are i

n = total number of responses

A = highest possible score (rating point) which in this case is 5

Reliability of the results: The reliability and internal consistency of the results obtained through the survey needs to be verified. Gwet (2014) defined internal consistency as "the extent to which all questions contribute positively towards measuring the same concept" (p. 242). Cronbach's α is one of the most frequently used methods of estimating internal consistency reliability (Ekolu, 2016). Cronbach's α is a coefficient that ranges between 0 and 1. The closer α is to 1.0, the greater the internal consistency of the items in the scale. There is no official and widely-accepted threshold that α must exceed before concluding that the items are internally consistent. However, a rule of thumb supported in the literature is that α should equal or exceed 0.70 before the items are considered internally consistent (Gwet, 2014). Cronbach's α is calculated using Equation 4.3 below:

$$\alpha = \frac{k}{1-k}\left(1 - \frac{1}{S_T^2}\sum_{i=1}^{k} S_i^2\right) \tag{4.3}$$

Where:

α = Cronbach's α reliability coefficient

k = number of items measured by Likert scale (in this case 12)

S_T^2 = variance of the total sums of scores given by each respondent

S_i^2 = variance of the scores given to item i by all respondents

The analysis of the results for Section B, C, and D of the questionnaire (refer to Figure 4.1) are presented in Table 4.2 through Table 4.4. Shown in the tables are the scores given by the respondents and corresponding RII for each item (factor) as well as a calculated Cronbach's α for that section of the data.

Table 4.2: Relative Importance Index for Engineering Deliverables Factors Affecting Construction Cost Performance

	Section B: Impact of Factors Related to Engineering Deliverables on Construction Cost Performance (Responses to Section B Questions)												Total
Respondent #	B1	B2	B3	B4	B5	B6	B7	B8	B9	B10	B11	B12	
1	5	4	4	4	5	3	3	4	5	5	3	4	49
2	5	3	3	3	3	4	4	4	4	4	3	3	43
3	5	4	4	4	3	2	3	4	3	4	3	3	42
4	4	3	3	2	4	2	2	4	3	3	3	2	35
5	2	2	4	2	4	3	3	4	4	3	3	4	38
6	4	5	5	5	5	4	4	4	3	3	3	4	49
7	4	4	4	2	3	4	5	4	2	4	2	2	40
8	4	5	4	5	4	5	5	5	3	4	5	3	52
9	5	4	4	4	5	4	2	2	5	5	1	2	43
10	5	4	2	4	4	2	2	3	3	4	3	3	39
11	5	4	5	5	5	5	5	4	4	5	5	3	55
12	4	2	2	3	2	2	3	5	4	4	2	2	35
13	5	5	4	4	4	3	4	3	4	3	3	2	44
14	4	4	3	3	2	2	3	3	3	3	2	3	35
15	5	5	4	4	4	4	3	4	5	5	3	3	49
16	3	4	4	5	5	4	1	2	2	2	1	2	35
17	5	5	5	4	4	5	4	4	4	4	4	4	52
18	5	5	4	4	5	4	4	4	5	5	5	5	55
19	5	4	4	4	3	3	4	4	3	4	2	3	43
20	3	4	5	5	5	5	3	4	4	4	4	3	49
21	2	3	5	3	5	4	3	4	3	3	3	4	42
22	2	2	4	2	2	2	2	4	2	4	2	2	30
23	5	3	3	2	3	3	4	2	4	3	2	4	38
24	5	5	5	3	5	4	4	5	4	4	4	5	53
25	5	4	4	5	4	4	3	4	5	3	2	3	46
26	5	5	5	3	5	4	4	4	5	3	4	3	50
27	5	5	5	5	5	5	5	3	5	5	3	2	53
28	4	4	3	4	4	3	4	4	5	5	4	3	47
29	5	5	3	4	3	4	3	5	4	4	3	3	46
30	5	4	2	2	4	2	2	2	3	4	1	3	34
31	4	4	4	4	4	3	4	4	4	3	3	4	45
32	4	4	4	4	5	4	4	4	3	3	2	3	44
33	5	3	4	3	4	2	3	4	3	3	3	2	39
34	4	3	3	3	5	3	4	5	3	4	3	4	44
35	5	5	4	2	3	3	4	4	5	4	2	2	43
36	5	5	5	5	4	4	4	5	4	4	3	4	52
37	5	5	5	4	5	5	4	5	4	4	4	4	54
38	5	4	4	3	3	2	2	4	4	3	4	5	43
39	5	5	4	3	5	4	4	4	5	5	3	3	50

Table 4.2: Relative Importance Index for Engineering Deliverables Factors Affecting Construction Cost Performance (Contd.)

Respondent #	Section B: Impact of Factors Related to Engineering Deliverables on Construction Cost Performance (Responses to Section B Questions)												Total
	B1	B2	B3	B4	B5	B6	B7	B8	B9	B10	B11	B12	
40	5	3	4	4	3	3	5	4	2	3	1	4	41
41	5	5	5	5	4	4	4	4	4	4	4	4	52
42	5	4	3	3	4	4	3	3	4	5	4	3	45
43	4	4	4	3	4	3	2	3	2	2	3	2	36
44	5	5	4	5	5	5	4	4	5	5	5	4	56
45	4	4	4	3	4	3	2	3	3	2	3	3	38
46	4	5	3	5	4	4	3	3	3	4	3	2	43
47	3	5	3	2	4	1	5	5	5	5	2	2	42
48	3	4	4	3	5	3	3	5	3	4	3	2	42
49	5	4	5	5	5	5	4	5	4	5	4	4	55
50	4	5	4	4	5	4	4	4	5	5	4	4	52
51	5	5	3	3	3	2	2	2	4	4	1	4	38
52	5	3	3	3	4	3	3	4	4	3	2	3	40
53	4	4	4	4	4	4	4	4	3	3	5	4	47
54	4	4	2	4	4	4	2	4	1	4	1	2	36
55	3	4	5	5	4	4	2	4	5	5	2	3	46
56	4	5	5	5	5	3	5	4	5	5	5	5	56
57	5	5	5	5	5	5	5	5	5	5	5	5	60
58	4	5	4	3	3	2	2	4	5	3	3	3	41
59	4	3	3	3	4	3	3	3	4	4	3	3	40
60	5	5	5	5	4	4	3	3	5	5	3	4	51

Number of "1"s	0	0	0	0	0	1	1	0	1	0	6	0	
Number of "2"s	3	3	4	8	3	11	12	5	5	3	12	15	
Number of "3"s	5	9	13	18	11	16	17	10	16	17	24	22	
Number of "4"s	19	24	27	18	25	23	22	34	20	23	11	18	
Number of "5"s	33	24	16	16	21	9	8	11	18	17	7	5	
Total Response	60	60	60	60	60	60	60	60	60	60	60	60	
%RII	87.33	83.00	78.33	74.00	81.33	69.33	68.00	77.00	76.33	78.00	60.33	64.33	
Adjusted %RII	68.52	56.50	52.42	53.22	57.25	44.27	38.97	44.42	56.96	53.40	31.79	44.04	
Variance	0.71	0.74	0.76	1.03	0.74	1.03	1.02	0.67	1.03	0.77	1.27	0.85	46.22

Cronbach's Alpha:	0.84

Table 4.3: Relative Importance Index for Engineering Deliverables Factors Affecting Construction Schedule Performance

	Section C: Impact of Factors Related to Engineering Deliverables on Construction Schedule Performance (Responses to Section C Questions)												Total
Respondent #	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	
1	5	5	5	4	5	3	4	4	5	5	3	4	52
2	5	4	4	4	3	4	4	3	4	5	4	3	47
3	5	3	3	3	2	2	3	3	4	4	3	3	38
4	3	3	4	4	3	3	3	3	2	2	3	3	36
5	3	3	3	4	4	4	3	4	4	4	4	3	43
6	5	5	5	5	5	5	4	4	5	5	3	5	56
7	4	3	4	3	4	4	4	3	3	4	2	3	41
8	5	5	5	5	5	5	5	5	4	4	5	3	56
9	5	5	4	4	4	5	2	2	5	5	1	3	45
10	4	3	3	3	3	3	2	3	3	4	2	3	36
12	5	4	4	4	4	4	4	5	4	3	2	2	45
13	5	3	5	4	3	3	3	3	3	3	3	3	41
15	5	5	5	5	5	4	3	3	5	5	3	4	52
19	5	3	3	4	4	3	4	4	5	5	2	4	46
21	4	3	4	3	4	2	2	3	4	4	2	3	38
22	3	3	3	3	3	4	4	4	4	5	2	4	42
23	5	4	4	4	4	2	3	2	4	3	2	2	39
24	5	5	5	4	4	4	4	5	5	5	4	5	55
25	5	4	4	4	4	3	3	3	5	4	3	3	45
26	5	5	5	4	5	4	5	3	5	3	3	3	50
27	5	5	5	5	5	5	5	5	5	5	5	5	60
28	3	3	4	4	4	3	3	3	5	4	3	3	42
29	3	3	4	4	4	4	3	4	5	5	4	3	46
30	5	5	4	4	3	2	2	2	5	5	3	5	45
31	4	4	4	4	4	4	4	4	4	4	4	3	47
32	4	4	4	4	5	4	4	4	3	3	2	3	44
33	5	3	4	2	5	2	3	5	5	3	3	2	42
34	5	4	4	4	5	4	4	4	4	4	3	4	49
35	4	4	2	2	4	3	4	3	5	5	1	2	39
36	5	5	5	5	5	4	2	5	5	4	4	5	54
37	5	4	4	4	4	3	4	4	4	4	3	2	45
38	4	4	5	4	5	3	4	3	5	5	2	3	47
39	4	5	5	4	5	4	4	4	5	5	4	4	53
40	5	4	3	3	3	2	5	3	4	4	2	4	42
41	5	5	5	5	5	5	5	5	5	5	4	5	59
42	5	4	4	4	5	4	3	4	5	5	5	3	51
43	3	4	4	4	4	3	3	2	2	4	3	3	39
44	5	5	5	5	4	4	3	4	5	5	5	5	55
45	4	4	4	5	5	3	3	3	3	3	3	3	43

Table 4.3: Relative Importance Index for Engineering Deliverables Factors Affecting Construction Schedule Performance

(Contd.)

	Section C: Impact of Factors Related to Engineering Deliverables on Construction Schedule Performance (Responses to Section C Questions)												Total
Respondent #	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	
46	4	4	3	4	4	4	3	3	4	4	4	3	44
47	3	5	3	3	5	2	3	3	4	5	2	2	40
48	4	3	3	4	2	4	5	5	4	4	3	2	43
50	5	4	4	5	5	4	4	5	5	4	4	4	53
51	3	3	3	2	3	2	2	2	4	5	2	3	34
52	5	3	3	4	4	3	3	3	3	3	3	3	40
53	5	5	5	5	4	5	4	4	3	3	5	3	51
54	4	4	4	2	2	2	4	4	4	4	2	4	40
55	4	5	5	5	4	4	3	3	5	5	2	4	49
56	4	4	4	4	4	4	4	4	5	5	4	3	49
57	5	5	5	5	5	5	5	5	5	5	5	5	60
58	5	4	3	2	5	2	4	4	3	2	3	2	39
59	4	3	3	4	3	3	3	3	3	4	3	3	39
60	5	5	5	5	4	3	3	2	5	5	3	4	49

Number of "1"s	0	0	0	0	0	0	0	0	0	0	2	0	
Number of "2"s	0	0	1	5	3	10	6	6	2	2	14	8	
Number of "3"s	8	16	13	7	9	15	20	20	9	9	20	26	
Number of "4"s	15	19	22	28	22	21	20	17	17	19	11	11	
Number of "5"s	30	18	17	13	19	7	7	10	25	23	6	8	
Total Response	53	53	53	53	53	53	53	53	53	53	53	53	
%RII	88.30	80.75	80.75	78.49	81.51	69.43	70.57	71.70	84.53	83.77	61.89	67.17	
Adjusted %RII	69.28	54.98	54.04	56.45	57.37	44.33	40.44	41.36	63.07	57.35	32.61	45.99	
Variance	0.56	0.65	0.65	0.76	0.76	0.91	0.75	0.86	0.76	0.73	1.09	0.85	43.09

Cronbach's Alpha:	0.85

Table 4.4: Relative Importance Index for Commonality of Engineering Deliverables Factors Affecting Construction Performance

	Section D:Commonality of the Factors Related to Engineering Deliverables Affecting Construction Performance (Responses to Section D Questions)												Total
Respondent #	D1	D2	D3	D4	D5	D6	D7	D8	D9	D10	D11	D12	
1	2	3	3	4	3	5	4	2	4	4	4	4	42
2	4	5	4	4	4	4	5	4	4	4	5	5	52
3	5	3	4	4	4	4	2	4	4	3	2	3	42
4	3	3	4	4	3	3	4	3	2	3	3	2	37
5	4	3	3	4	3	4	3	3	3	3	2	3	38
6	5	5	5	5	4	4	4	4	4	4	3	3	50
7	5	4	3	4	3	3	3	3	3	4	2	3	40
8	5	4	4	4	4	4	5	5	4	4	4	3	50
9	5	4	4	4	5	4	1	1	5	4	2	4	43
10	4	3	4	3	3	3	1	3	3	3	1	3	34
13	5	4	4	4	3	3	3	3	4	3	3	5	44
15	5	5	5	5	5	5	4	4	5	5	3	3	54
19	3	4	4	5	4	3	3	2	4	3	2	4	41
21	3	4	4	4	3	2	4	4	2	2	3	5	40
22	4	3	3	4	3	3	3	3	5	3	2	4	40
23	2	3	4	2	3	1	3	1	4	4	3	3	33
24	3	3	3	3	4	3	2	3	4	4	3	5	40
25	4	5	5	4	5	4	3	3	5	5	3	4	50
26	4	5	5	4	3	5	3	3	5	2	2	2	43
27	5	4	3	5	5	5	2	4	5	3	1	3	45
28	4	4	3	3	3	3	2	3	3	3	3	2	36
29	4	2	2	3	3	1	1	2	2	2	1	2	25
30	5	2	4	4	5	4	2	3	5	3	1	5	43
31	1	2	2	4	2	3	2	1	2	2	2	3	26
32	5	2	2	3	2	2	2	2	3	2	2	2	29
33	3	2	3	3	2	4	2	3	3	3	2	4	34
34	5	4	3	4	3	3	3	3	5	4	3	3	43
35	5	4	3	4	3	3	3	2	3	3	3	3	39
36	5	2	3	4	4	4	3	2	5	5	2	4	43
37	5	4	5	4	4	4	4	4	4	4	3	3	48
38	4	4	5	4	4	3	3	4	4	4	3	4	46
39	5	4	5	4	5	4	4	4	5	5	4	4	53
40	2	3	2	3	4	2	2	2	4	3	2	3	32
41	5	4	3	3	2	2	2	2	2	2	1	3	31
42	4	4	3	4	4	3	3	4	4	4	4	4	45
43	3	4	4	4	3	4	3	3	2	2	4	3	39
44	5	3	4	4	4	3	3	3	3	3	3	4	42
45	4	3	3	3	4	2	3	2	3	4	4	4	39
47	3	4	2	2	4	2	2	4	3	3	1	1	31

Table 4.4: Relative Importance Index for Commonality of Engineering Deliverables Factors Affecting Construction Performance (Contd.)

Respondent #	Section D:Commonality of the Factors Related to Engineering Deliverables Affecting Construction Performance (Responses to Section D Questions)												Total
	D1	D2	D3	D4	D5	D6	D7	D8	D9	D10	D11	D12	
48	3	2	4	5	5	4	4	3	3	4	2	3	42
49	3	2	2	2	2	2	2	3	3	1	1	1	24
50	3	3	4	4	4	4	3	3	5	3	3	3	42
51	4	4	4	4	4	4	2	2	5	3	3	5	44
52	2	2	3	4	2	2	3	3	2	3	1	2	29
53	3	4	4	2	2	5	4	4	4	5	5	3	45
54	5	2	2	2	2	1	2	1	4	3	1	4	29
55	5	3	3	3	3	3	2	2	4	4	2	5	39
56	3	5	3	3	5	2	4	4	5	5	4	5	48
57	3	3	1	2	5	5	5	4	5	5	5	5	48
58	5	3	2	2	3	1	1	1	4	3	3	4	32
59	3	2	1	2	2	1	2	1	2	4	3	3	26
60	5	4	2	5	5	4	4	4	4	4	3	3	47

Number of "1"s	1	0	2	0	0	5	4	6	0	1	9	2	
Number of "2"s	4	11	9	8	9	9	16	11	8	7	14	6	
Number of "3"s	14	15	17	11	17	15	18	19	12	20	19	21	
Number of "4"s	12	20	17	27	16	17	11	15	18	17	7	14	
Number of "5"s	21	6	7	6	10	6	3	1	14	7	3	9	
Total Response	52	52	52	52	52	52	52	52	52	52	52	52	
%RII	78.46	68.08	66.92	71.92	70.38	63.85	57.31	57.69	74.62	68.46	52.69	68.46	
Adjusted %RII	-	-	-	-	-	-	-	-	-	-	-	-	
Variance	1.17	0.91	1.09	0.79	1.00	1.33	1.06	1.05	1.06	0.92	1.22	1.07	57.62

Cronbach's Alpha:	0.85

4.4.3 Ranking of Factors

The results of the calculations of relative importance index (RII) for the factors related to engineering deliverables with negative impact on construction cost and schedule, and their commonality in oil and gas projects can be illustrated in the diagram shown in Figure 4.6:

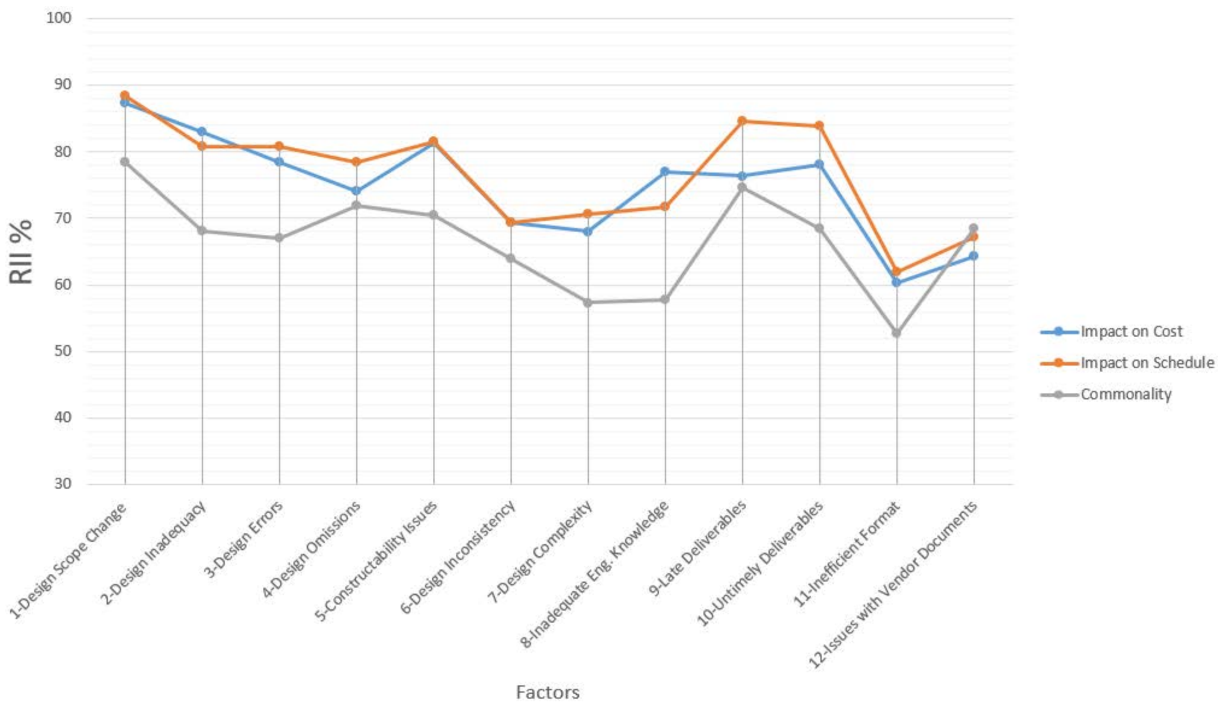


Figure 4.6: RII for factors affecting construction performance and their commonality

Adjusted Relative Importance Index

The chart shown in Figure 4.6 facilitates comparison between the engineering deliverables factors in terms of their level of impact on construction cost and schedule as well as their commonality. However, it cannot be used, the way it is, to truly rank the factors and find the most significant issues in engineering deliverables to enhance, with the goal of improving construction, which is the ultimate goal of this research. Certain factors, for example, may have relatively high impact on construction cost or schedule, but may be less common in oil and gas projects, rendering the factor less significant. To address this issue, the RII's for impact on construction cost and impact on construction schedule are adjusted to encompass and indicate the commonality of the factors. The adjustment is made using the Equation 4.4

$$Adjusted\ RII_i^{C\ or\ S} = RII_i^{C\ or\ S} \times RII_i^{Commonality} \tag{4.4}$$

Where:

$Adjusted\ RII_i^{C\ or\ S}$ = Adjusted RII for factor *i* for impact on cost or schedule

$RII_i^{C\ or\ S}$ = Original RII for factor *i* for impact on cost or schedule

$RII_i^{Commonality}$ = RII for factor *i* for commonality

The results for calculation of adjusted RII are also shown in Table 4.2 and Table 4.3. For example, the RII for factor #1, which is "Design Scope Change", for impact on cost (Table 4.1) is 87.33%, and the RII for the commonality of the same factor (Table 4.4) is 78.46%. Therefore, using Equation 4.4, the adjusted RII for "Design Scope Change" for impact on cost will be:

$$87.33\% \times 78.46\% = 68.52\%$$

The adjusted RII for factors affecting construction cost and schedule are also shown in Table 4.2 and Table 4.3 respectively.

The diagram shown in Figure 4.7 illustrates the adjusted RII for factors affecting construction cost and schedule.

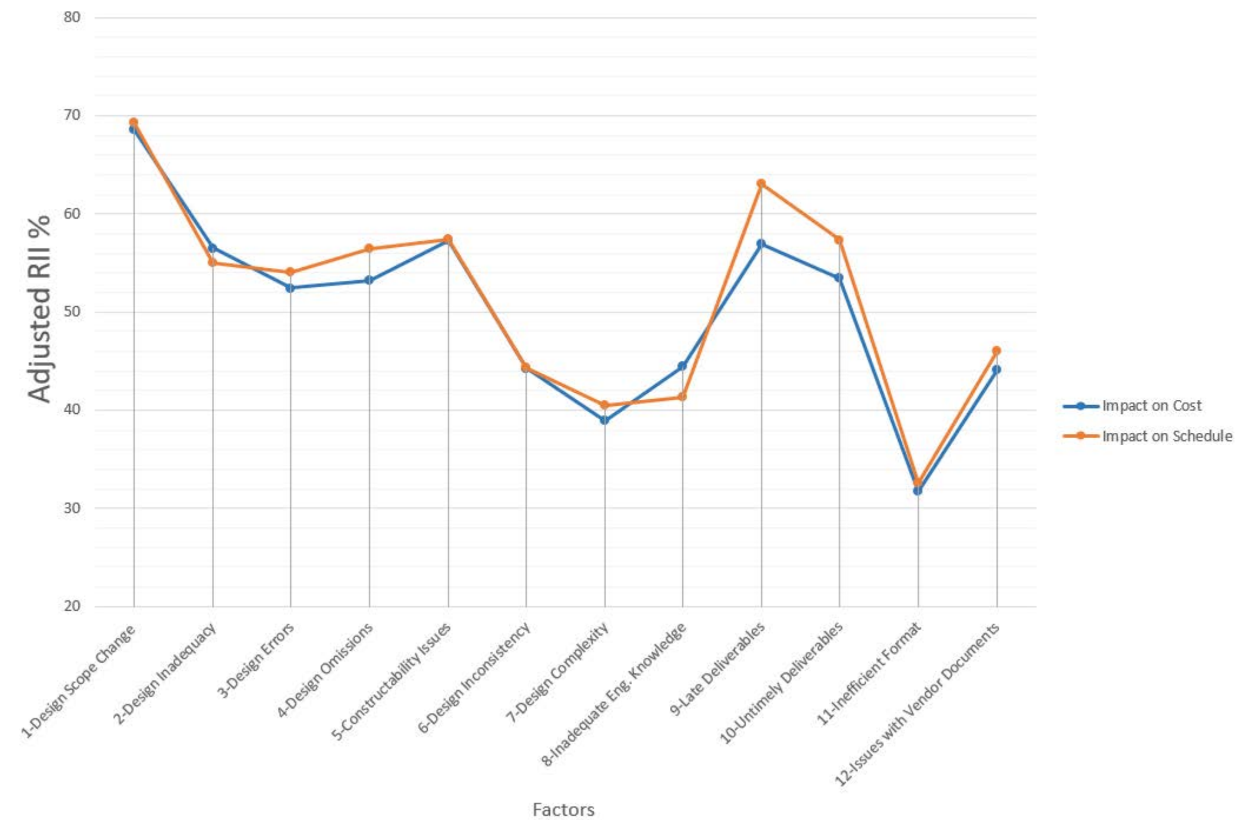


Figure 4.7: Adjusted RII for factors affecting construction cost and schedule

Using the results of adjusted RII calculation, the engineering deliverables factors with negative impact on construction cost and schedule can be ranked based on their significance as shown in Table 4.5.

4.5 Discussion

As seen in Table 4.4, according to the results obtained through the questionnaire survey, design scope change is, by far, the most significant factor that affects both construction cost performance and construction schedule performance. However, the RII corresponding to rank #2 to rank #7 for cost and rank #3 to rank #7 for schedule, range only between 52% and 58%. In other words, the RII of those factors are within 6% difference interval from each other, which, for the purpose of this research, can be considered to have no meaningful difference.

Table 4.5: Ranking of Factors for Impact on Construction Cost and Schedule Performance

Impact on Construction Cost		
Rank	Factor	Adjusted RII%
1	*Design scope change*	*68.52*
2	*Constructability issues*	*57.25*
3	*Late deliverables*	*56.96*
4	*Design inadequacy*	*56.50*
5	*Untimely deliverables*	*53.40*
6	*Design omissions*	*53.22*
7	*Design errors*	*52.42*
8	*Inadequate engineering knowledge*	*44.42*
9	*Design inconsistency*	*44.27*
10	*Issues with vendor documents*	*44.04*
11	*Design complexity*	*38.97*
12	*Inefficient format*	*31.79*

Impact on Construction Schedule		
Rank	Factor	Adjusted RII%
1	*Design scope change*	*69.28*
2	*Late deliverables*	*63.07*
3	*Constructability issues*	*57.37*
4	*Untimely deliverables*	*57.35*
5	*Design omissions*	*56.45*
6	*Design inadequacy*	*54.98*
7	*Design errors*	*54.04*
8	*Issues with vendor documents*	*45.99*
9	*Design inconsistency*	*44.33*
10	*Inadequate engineering knowledge*	*41.36*
11	*Design complexity*	*40.44*
12	*Inefficient format*	*32.61*

Furthermore, the RII for rank #8, in both cost and schedule, drops down to the vicinity of 45%. Therefore it is reasonable to consider rank #1 to rank #7 to be the major factors of engineering deliverables that have negative impact on construction performance.

On the other hand, referring to section 4.2 for the definitions of the factors, the first 7 factors affecting both construction cost and schedule performances can further be grouped based on the similarities in the nature of those factors, as follows:

- <u>Changes after IFC</u>
    - **Design Scope Change:** changes in the engineering deliverables after IFC, due to change in design scope.

- **Design Inadequacy:** changes in engineering deliverables after IFC, due to inadequacy of original design (note that this is ultimately a design issue).

- Engineering Schedule Issues
  - **Late Deliverables (Schedule delay):** engineering deliverables that are not available to construction at the scheduled time.
  - **Untimely Deliverable (Faulty Schedule):** engineering deliverables that are not scheduled properly therefore not available to construction when needed.
- Engineering Design Issues
  - **Design Errors:** errors depicted in IFC engineering deliverables during construction. Errors are items in the deliverables that are shown incorrectly.
  - **Design Omissions:** information or items that need to be shown in engineering deliverables but are not shown at all.
  - **Design with Constructability Issues:** engineering deliverables that fail to address constructability requirements.
  - **Design Inadequacy:** This factor, as defined above, contributes to *changes after IFC*, but it is ultimately a technical design problem which should be addressed under engineering design issues (See Figure 4.8).

The discussion presented in this section is visualized in Figure 4.8 where the major engineering deliverables factors that have significant impact on construction performance have been highlighted.

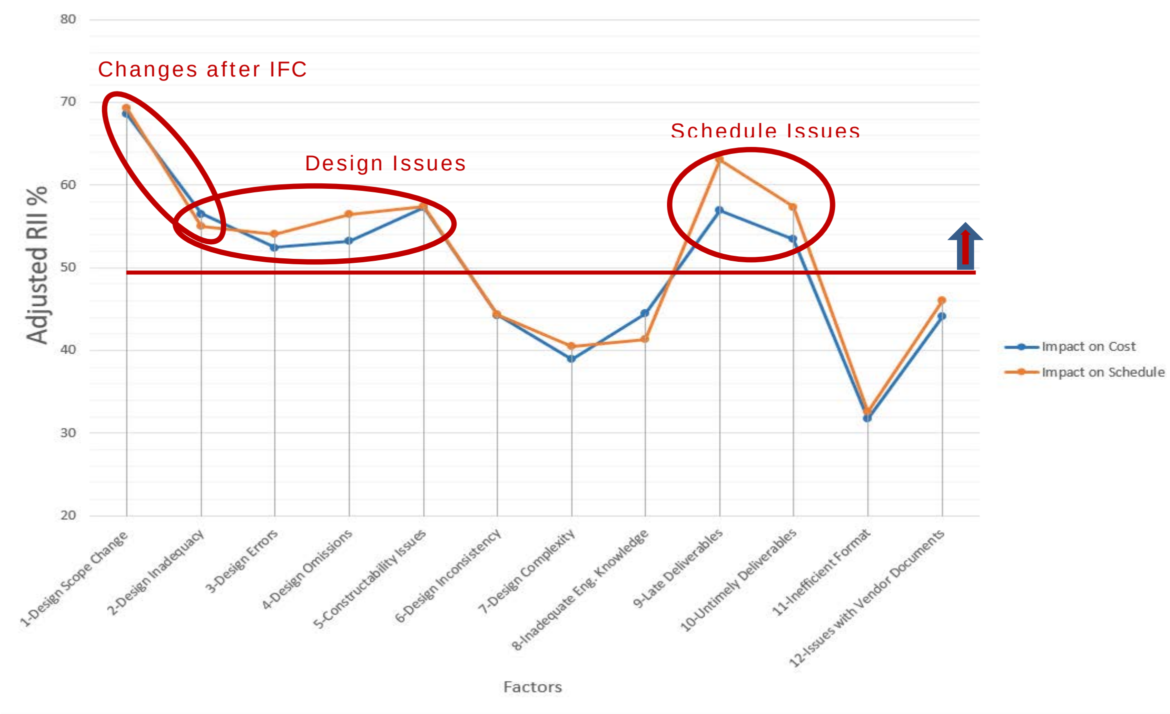


Figure 4.8: Major factors with significant impact on construction performance

4.6 Summary

This chapter presented a quantitative approach to completing Phase I of the research, which is identifying and ranking the factors affecting construction performance. A preliminary list of factors related to engineering deliverables that have negative impact on construction performance was prepared based on the literature review and the results of discussions in some focus groups.

A questionnaire survey was design in order to validate the list of factors, and to rank those factors based on the significance of their impact on construction performance.

A 5-point Likert measuring scale was employed to determine the level of impact on construction costs, level of impact on construction schedule, and the commonality of each factor in oil and gas projects. The factor ranking method including calculation of the relative importance index was used to rank the engineering deliverables factors separately based on their impact on cost, impact on schedule, and commonality. The calculated cost and schedule RII's for each factor were then adjusted to incorporate the commonality of each factor, by multiplying the cost and schedule RII's by the corresponding RII for commonality. The adjusted RII's were ultimately used to rank the engineering deliverables factor affecting construction performance. Finally, the top seven factors were identified as *major*, and then were grouped based on the similarities in the nature of the factors. The results are shown in Figure 4.9. Shown in Figure 4.9 are the three major engineering deliverables issues that need to be mitigated in order to improve construction performance.

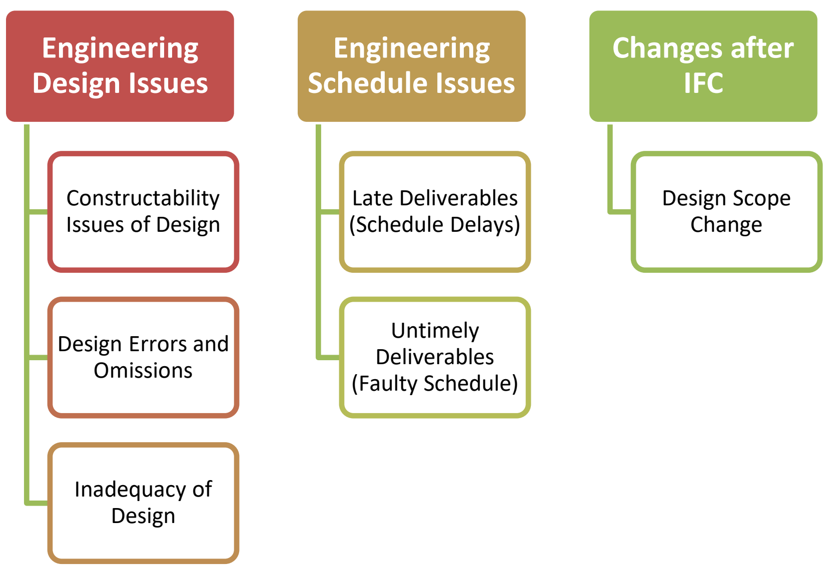


Figure 4.9: Three major engineering deliverables issues

In the next chapters a qualitative approach will be employed to enhance engineering deliverables by mitigating the three major issues identified in this chapter as shown in Figure 4.9.

Chapter Five: **Data Collection and Analysis for Phase II**

5.1 Introduction

In the previous chapter, Phase I of the research was discussed, through which the major issues in the engineering deliverables were identified based on the combined effect of their impact on construction performance, and their commonality among projects.

This chapter elaborates Phase II of the research, and the qualitative research methodology employed to find solutions to mitigate the issues identified in Phase I, and eventually develop the framework to enhance engineering deliverables. The goal is to explore the understanding and perception of the experts in oil industry project regarding the root causes of engineering deliverables issues, and to extract the accumulated project knowledge, gained over years of experience in oil and gas projects, with regard to those issues in engineering deliverables. As will be shown later in this chapter, this phase of study revealed the facts, grounded in the data from the opinion of the project experts, that play an important role in improving engineering deliverables.

It should be noted that the main body of the data analysis performed for this research, including open coding, memos, and axial coding for all the interviews, is presented in Appendix A. Therefore this chapter should be studied with a close attention to the information provided there.

5.2 Grounded Theory Approach in the Current Research

As mentioned in Chapter 3, this phase of the research uses major concepts of the Grounded Theory method for data gathering and analysis. This method enables systematic collection and analysis of data and facilitates developing a framework that can be used to frame the research findings. A series of 26 qualitative interviews was conducted with selected individuals involved in oil industry projects. Sample selection was based on the theoretical sampling philosophy, which aims at maximizing the opportunities for comparative analysis. This means that new interviewees were selected as needed to saturate categories and complete the study (Strauss & Corbin, 1998). In the meantime, it was intended that sampling would provide a variety of perspectives in terms of types of organizations, roles in the projects, etc.

The Grounded Theory methodology implies that the data analysis be conducted in parallel with the data gathering process. As shown in Figure 5.1, the analysis of data started with open coding and axial coding immediately after the first interview. Based on the coding results of the previous interviews, the next interviews were planned as per the theoretical sampling philosophy described above. The selective coding was performed towards the end of data gathering in order to integrate and refine major categories to form a larger theoretical scheme and deliver the findings of research in the form of theory.

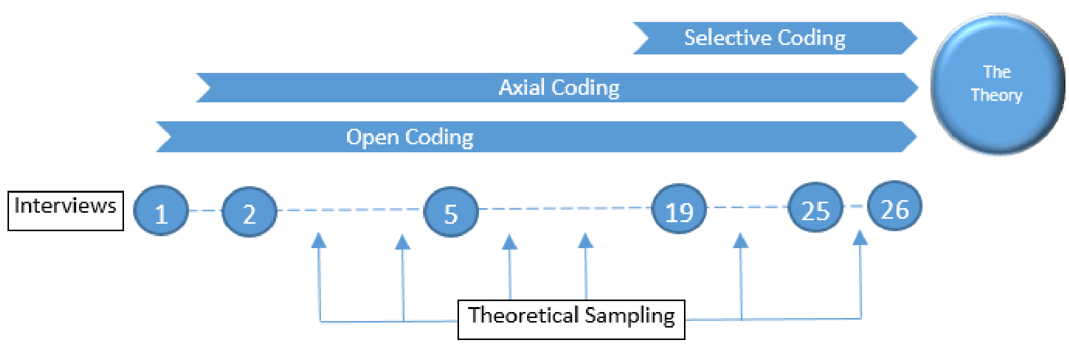


Figure 5.1: Grounded Theory approach in the research

5.3 Interview Design and Process

As mentioned in Chapter 3, the main instrument for data gathering for this phase of the research is interview. The interviews would be of the semi-structured type, because the topics (meaning the major engineering deliverables issues identified in Phase I) were communicated earlier and known to the interviewee at the time of the interview, but not presented in a structured way.

Once the recruitment email was sent to the potential participant, and their consent for participation was received, a brief background of the research, including the overall findings of Phase I, was sent to the participant days before the interview, so that they might have a better idea of what the interview questions would revolve around.

Normally the interviews would start with high-level questions such as:

- *In your opinion, what are the major causes of schedule delays for engineering deliverables?*
- *Based on your experience, what can we do better to minimize design issues?*
- *What causes the changes after IFC?*

As the discussion proceeded and the participant's opinions unfolded, lower-level detailed questions would be asked, as they would come up, to further delve into the participant's thoughts and understand the rationale or experience behind their opinions. A sample of detailed questions that were asked during the interviews are as follows:

- *How do you involve vendors in the EDS phase?*
- *What do you think is missing in 3D model reviews that makes it incapable of identifying all design issues?*
- *If some specific vendor data is not available, why would you ever issue the IFC drawings and not wait for the vendor data?*
- *What design strategy do you use to tackle the insufficient design data?*
- *Electrical heat tracing (EHT) design data is normally available way later in the design phase and causes changes in the IFC drawings. Why is that?*

- *How do you make sure all the predecessor activities for a certain deliverable are considered in the schedule?*
- *Where do planners get the activity duration from? How do they make sure it is accurate?*

As more interviews were conducted and more data categories were identified, the questions for the next interviews would be designed to seek integration and validation (or sometimes negation) of major categories identified in previous interviews. This approach is also consistent with the philosophy of theoretical sampling discussed earlier. Some of the interview questions of this nature are shown below:

- *I have had feed-back from my previous interviews that the project schedule is always dictated by the owners and most of the time is not realistic. Do you think this is a valid statement?*
- *In your opinion why would engineering disciplines not talk to each other?*
- *Do you think the clients are open to contractors' concerns regarding the schedule at the time of bidding?*
- *Do you agree that the involvement of the operation teams in 3D model review sessions are crucial to the success of the model review?*
- *Do you think the engineering weekly meetings, even if managed properly, is enough to maintain adequate communication among the engineering teams?*
- *There is a negative attitude against the effectiveness of email communication. Do you agree with that?*

- *How do you make sure that all other relative disciplines are properly informed about a design change occurred in certain discipline?*
- *Do you think lack of technical knowledge is a significant issue among clients organizations*

The interviews were recorded (using the Voice Memo app in iOS), with the consent of the participants and the emphasis of not mentioning names of people, projects, or companies.

5.4 Participants Demographics

The participants were selected from among experienced project specialists and engineers involved in oil and gas projects. Due to the nature of this research and the topics to be discussed during the interviews, the target positions (job titles) of the interviewees, both in client and contractor organizations, that would encompass the required expertise to address the research objectives, would be discipline lead engineer and higher in engineering houses, project engineer and higher in project management teams, senior planner and higher in project controls, field engineer and higher in project construction, and any positions at corporate level. Table 5.1 provides general information about participants and corresponding interviews in further detail. Distribution of the participants' specialties is also demonstrated in Figure 5.2.

Although the theoretical sampling approach played a key role in determining the type of organization from which the interviewees were selected, the intent was that the selected types of organizations be as inclusive as possible to represent all types involved in oil and gas projects. The organization types included Owner/Client, General Contractor (EPC or EP&C), and Engineering and Procurement (EP).

Table 5.1: General Information about Participants and Corresponding Interviews

Interview No.	Participant				Interview	
	Code	Role	Years of Experience	Company Type	Duration (Min)	Type
1	KH	Project Controls Manager	18	EPC	32	*Face to Face*
2	TC	Corporate Engineering Manager	31	EPC	52	*Face to Face*
3	JR	Senior Planner	22	Owner	48	*Face to Face*
4	LR	Senior Planner	26	Owner		*Face to Face*
5	JA	Project Engineering Manager	30	Owner	42	*Face to Face*
6	SR	Senior Project Engineer	23	Owner	43	*Face to Face*
7	MY	Senior Mechanical Engineer	15	EP&C	51	*Face to Face*
8	MT	Project Controls Manager	19	EP&C	57	*Face to Face*
9	FK	Business Development Manager	14	EPC	39	*Face to Face*
10	ET	Senior Project Manager	30	EPC	49	*Face to Face*
11	JL	Senior Project Engineer	29	Owner	85	*Face to Face*
12	AF	Project Engineer	15	Owner	37	*Face to Face*
13	GL	Senior Civil Engineer	36	EP&C	53	*Face to Face*
14	GO	Project Engineering Manager	35	Owner	27	*Face to Face*
15	ST	Senir Project Engineer	25	EPC	25	*Face to Face*
16	SD	Project Manager	20	EPC	37	*Face to Face*
17	BS	Project Controls Manager	17	Owner	42	*Face to Face*
18	MZ	Senior Mechanical Engineer	37	EPC	52	*Face to Face*
19	NR	Senior Project Manager	27	EPC	33	*Face to Face*
20	NA	Senior Riliability Engineer	22	Owner	33	*Face to Face*
21	PB	Principal, Engineering	23	EP	45	*Face to Face*
22	MF	Project Controls Manager	19	Owner	39	*Face to Face*
23	FT	Senior/Lead Mechanical Engineer	18	EP	30	*Face to Face*
24	SY	Corporate Geotecnical Lead	25	Owner	51	*Face to Face*
25	MM	Project Manager	21	EPC	45	*Face to Face*
26	BM	Senior Project Manager	33	EPC	47	*Face to Face*

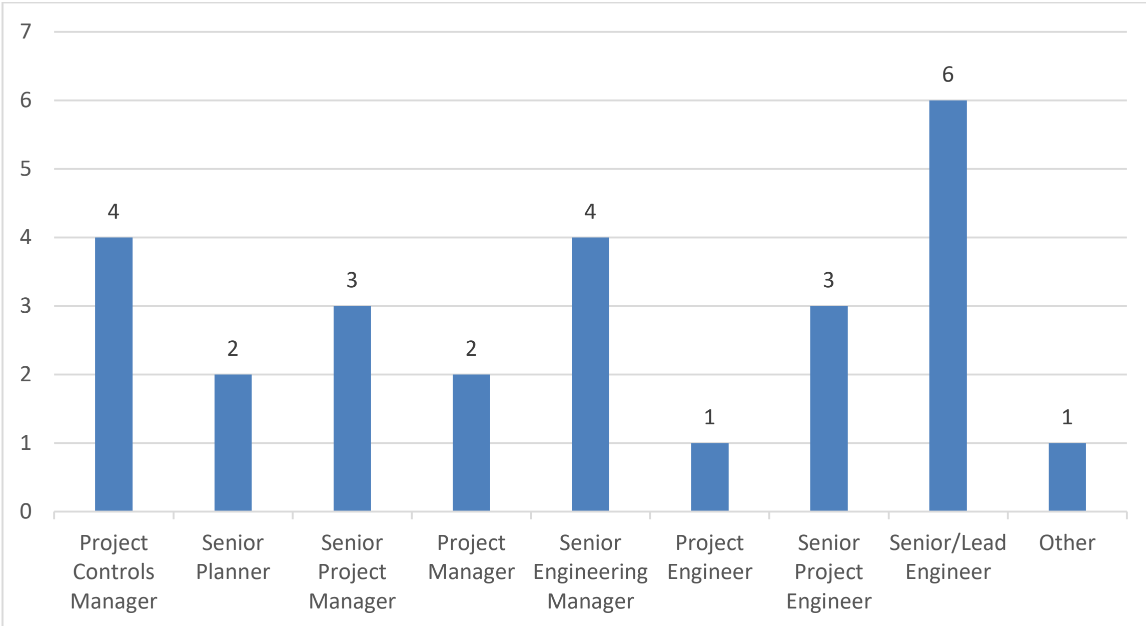


Figure 5.2: Distribution of the positions of the 26 participants

The distribution of the organization types is shown in Figure 5.3. As can be seen, the client and contractor types (all types of contractor) shares are 46% and 54% respectively, which indicates the unbiased presence of both project entities.

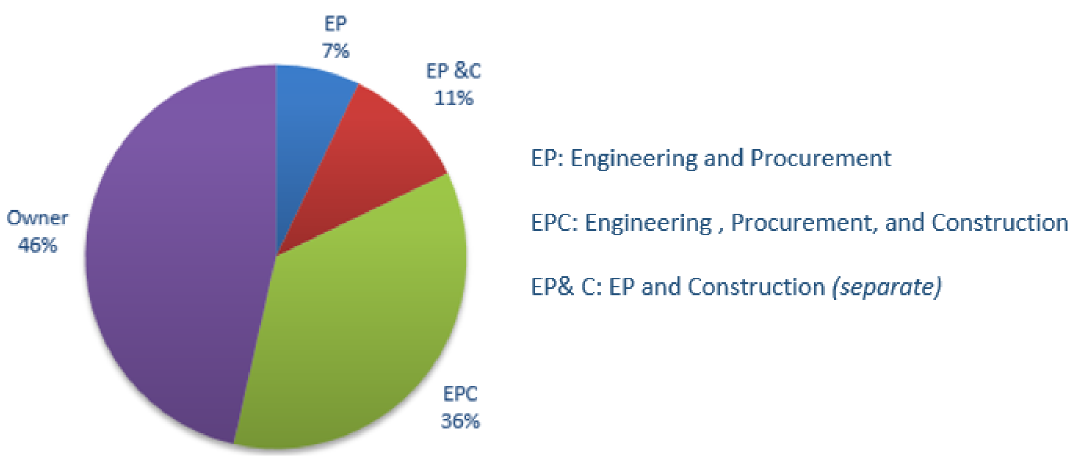


Figure 5.3: Distribution of organization types

5.5 Interview Data Analysis

Analysing the interview data starts with the coding process. Coding involves going through (in this case listening to) the interview in detail, and analyzing and unfolding the concepts.

Open Coding: The content of the interview were broken down to separate manageable concepts which are extracted from the raw data to form categories. As discussed in Chapter 3, *concepts* are groups of words that represent ideas contained in data. The extraction of concepts from the raw data is called *open coding*. There are low-level concepts and high-level concepts. High-level concepts are referred to as *categories*. Categories are those concepts that are more abstract than others. The low-level concepts can be grouped based on the category they are pointing to or indicating. These low-level concepts are referred to as *subcategories*.

In this research, in addition to open coding standard procedure to identify and name concepts, a unique *code* is also assigned to each concept as a means to reference that concept in different stages of the data analysis. The code nomenclature used in this research is demonstrated in Figure 5.4 which, as an example, refers to code number 17 in the interview number 23.

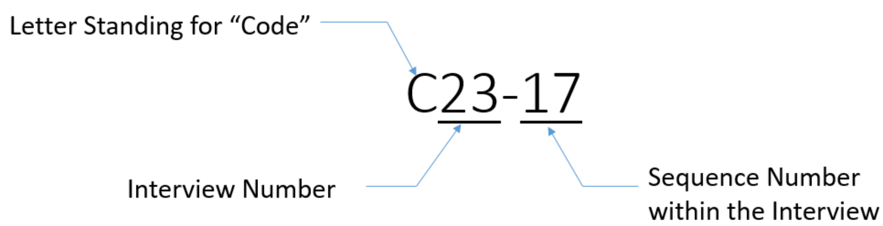


Figure 5.4: Code nomenclature

Axial Coding: Identifying how the concepts are related in one or more of their dimensions is performed in *axial coding*. Through axial coding, the researchers identifies that some of the concepts can be considered as *subcategories* for a more abstract concept or *category*. In other words, as defined by Strauss and Corbin (1998) axial coding is "the process of relating categories to their subcategories" (p. 123).

As discussed earlier, axial coding can be considered as a *fake stage* just for explanatory purposes, because it actually happens hand in hand and almost at the same time as open coding.

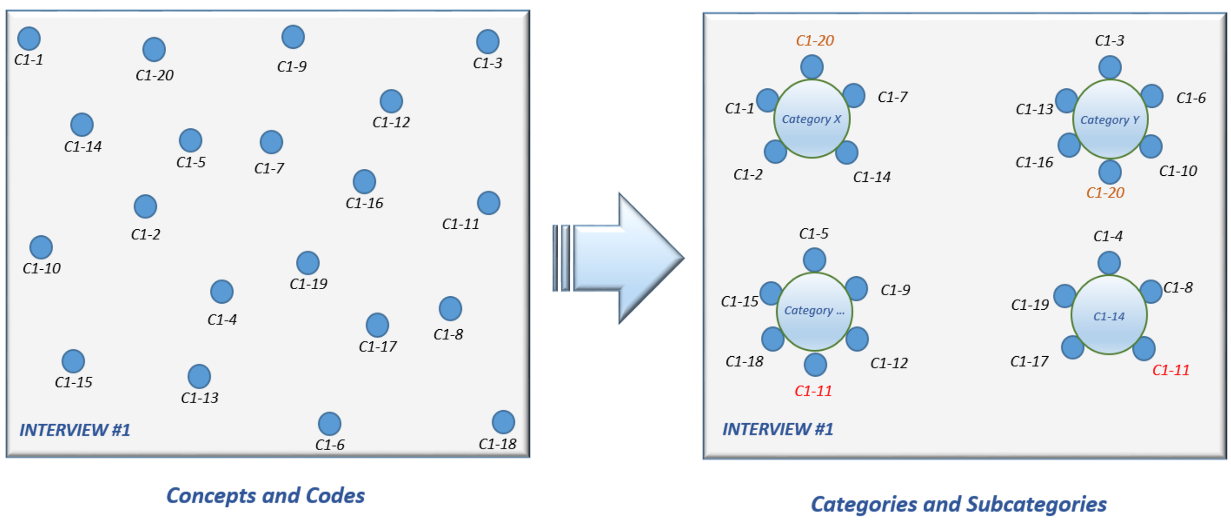


Figure 5.5: Identifying categories and subcategories

A category can be one of the existing concepts that were identified and named during the open coding. However, a category that relates two or more subcategories, may be a totally new concept emerging beyond the subcategories, and not necessarily from the existing concepts identified in open coding. Figure 5.5 illustrates how the concepts and codes developed in open coding of an interview are related based on a category–subcategory relationship through axial coding.

Selective Coding: The last stage of data analysis in the Grounded Theory methodology is integrating the major categories to form a larger theoretical scheme, which is called *core category*, and represents the main theme of the research. This process is also referred to as *selective coding*, the end of the journey through which data evolves into theory. Selective coding is in fact integrating the categories: linking the categories around a core category by unfolding the underlying common dimension that relate them all by a central linking concept, and refining and trimming the resulting framework (Corbin & Strauss, 2008; Strauss & Corbin, 1998).

Memos: The thought process of the researcher during the qualitative data analysis can normally be reflected in the form of *memos*. Memos are not reminder notes. In fact analytical memos show the researcher's rational, interpretations, and understandings of what the interview has unfolded during those questions and answers. Memos are vastly used in this research, especially during axial and selective coding. In other words, memos are the dialogue between the data and the researcher (Corbin & Strauss, 2008). Memos are referred to several time over the course of the research, especially during the selective coding as the researcher is reviewing his or her thoughts to unfold the core category as the main theme of the research.

5.6 How the Data analysis is presented in this Research

This section is dedicated to elaborating how the entire work of data analysis was performed and how the output of coding is presented in this dissertation. The purpose of this section is for the reader to smoothly follow the process through which the actual work has been done, and be able to interpret the information presented for each interview, and relate them to different stages of the Grounded Theory approach discussed above.

The information regarding the participant, including the participant code name (to protect privacy), position, years of experience, and type of organization, were recorded and is presented in this dissertation in a table format for each interview. Figure 5.6 shows a sample of such a table.

Interview #15			
Participant Code: **ST**	*Position:* **Senior Project Engineer**	*Years of Experience:* **25**	*Org. type:* **Owner**

Figure 5.6: Sample of interview participant information presentation

5.6.1 Starting to code; Performing Open Coding

Shortly after each interview session the researcher would start to code by listening carefully to the recorded audio file in order to capture the *concepts* as the first elements required for coding. This would sometimes require several pauses and playbacks to fully grasp the idea.

In the first few interviews the concepts were presented using few words as the selected name for those concepts. For example *Unclear Scope* would be chosen as a concept name. Although this format is a standard practice of coding in the grounded-theory-based research works, it was decided to present concepts using a complete phrase or sentence, and assign a *code* for them as their names, in a format shown in Figure 5.4. The rationale behind this decision is as follows:

- Some concepts were too abstract. That is, due to the nature of this research, some concepts might have many different dimensions that could be applied in different contexts. Therefore, a multi-word name could not always satisfactorily convey the issue behind the concept that the participant was pointing to. This would make it difficult, in later references to that concept, to figure out what issue was that concept depicting. For example, *Unclear Scope* may refer to project scope not clearly defined by the owner, or it may refer to incomplete process design data for a vendor to fabricate the ordered item. So instead of using *Unclear Scope* as the code name, a full sentence such as *Scope is not clearly defined by the client* was used and a code (here C2-9) was assigned as a name for that concept.

- Some of the concepts simply couldn't be summarized and squeezed to few words; for example code C5-23, which reads *Big problem is integration between vendor package and the rest of the project*.
- As will be seen in the later sections, using code names provides a much more convenient way to refer to and tabulate the concepts during the axial and selective coding.

For each interview, the list of concepts and the corresponding codes were tabulated as shown in Figure 5.7 below. A complete list of codes and concepts for each interview is provided in Appendix A.

Code No.	Concept
C15-1	We cannot avoid engineering delays but we can minimize that
C15-2	All the project stakeholders impact the schedule
C15-3	Sometime client delay in disclosing the information (delays the start)
C15-4	Then the vendor information maybe late

Figure 5.7: Sample list of codes and corresponding concepts

It was observed that some concepts were repeated by the participants when talking about different topics. For example consider the below concept from Interview #24:

C24-4: Sometimes people work in isolation (in vivo) Stakeholders not engaged

The participants actually mentioned this in-vivo concept during the interview, indicating that this problem may result in an unrealistic schedule for the project and it might as well lead to many changes in the design in the later stages of the project.

In order to capture this multiple-referencing nature of some concepts, as well as facilitating the process of identifying the existing underlying relation between the concepts, it was decided to group the concepts identified in each interview based on the topic of the discussion during the interview in which this concept was depicted. Therefore it was quite possible that a given concept be grouped under different topics. For example, the above-mentioned concept (C24-4) in Interview #24, was grouped as *Unrealistic scheduling* and *Minimizing design changes* simultaneously. Such grouping was also applied in cases where it could be indirectly deduced (not necessarily mentioned directly) that a given concept could clearly apply to different topics.

As mentioned in section 5.3, all interviews revolved around the engineering deliverables issues detected in Phase I of the research (Chapter 4), and those issues were already communicated to the participants prior to each interview. Hence the topics discussed during each interview were, to a great extent, similar with those in other interviews conducted in this research. This similarity of the topics of discussions, in combination with grouping the concepts under those discussion topics, provided great ease and smoothness of process during the axial coding of the data, discussed later in this chapter.

A sample showing how the concepts were grouped based on the discussion topic is shown in Figure 5.8 below.

Discussion	Concept	
Unrealistic Scheduling	*C23-19*	Unrealistic schedules due to inadequate time for preparing the proposal to the client
	C23-20	Sit with the client and come up with the mitigation plan
	C23-21	Take a practical innovative approach to keep our milestones even if they is not so perfect (in vivo)
Reducing Scheduling Delay	*C23-17*	Challenge of getting right/sufficient resources to deliver on time
	C23-18	Establish informal discipline interface to get information ahead of time
Minimizing Design Change	*C23-9*	Communication is very important. Inputs of design are not properly communicated among disciplines
	C23-13	Changes due to not finalizing agreements with third party (in vivo)
	C23-14	Not initiating vendor POs in proper time. Deign based on assumptions
	C23-15	Engaging stakeholders in every related decisions

Figure 5.8: Grouping the concepts under the topic of discussion

5.6.2 Writing Memos

As mentioned in section 5.5, memos are the streams of thoughts occurring to the researchers about the concepts. In this research, memos for each interview were written primarily on one or more of the following conditions:

- The content of the memos for each interview would add up to those in previous interviews
- A deduction, or inference can be made based on the identified concept or interpretation of what the participant stated
- A recommendation or remedy to an issue could be identified
- New dimensions for a concept or category would be detected
- One or more new relationship between a group of concepts would be identified
- Content of the memo would validate the rational in previous memos
- There was more to delve into in one or more concepts depicted in the interview that would unfold deeper meaning of those concepts

Each memo was numbered based on the interview it pertained to, and the sequence number within each interview. For example **Memo 24-3** refers to Memo #3 in the Interview #24. As some samples of all the memos written over the course of this research, three memos from Interview #11, Interview #19, and Interview #21 are presented here:

> ***Memo 11-1***
>
> *Engaging stakeholders in early stages of the project where client is doing most of the job (e.g. FELL phases) has it is own challenges. This is the time where hardly any contractual relationship exists between the client and any other project entity. Some sort of contracts e.g. a master agreement, or alliance supplier relationship*

may be beneficial in this kind of situations. In any case, availability of such information (e.g. vendor data) was again emphasised in order to have a realistic schedule. Lack of control over vendor work and timing is a major contributor to schedule delays for engineering deliverables (similar concerns discussed in interviews 5 and 8; categories C5-23 and C8-10). Therefore proper risk management should be in place at the time of finalizing the details with the selected vendor. One mitigation strategy, though, can be establishing more effective communication all through the time during vendors' design and fabrication stage, to obtain regular updates and implement those updates into risk response plan.

Memo 19-1

A big portion of seemingly unavailable information may exist in sources which is already accessible to the project. They just need to be discovered. They might be buried somewhere deep in archives, in personal folders, or even in the form of undocumented experience of a senior member of project tem. To unfold those valuable information, you need to get people to talk! As also mentioned in the interviews #3 and #17, running brainstorming workshops, for example in scheduling sessions is a good strategy. Systematic documentation and review of the lessons-learned from the current and previous projects (also emphasized in interview # 5), or referring to As-built documents of previous projects can provide information that can directly be used in current project, be it for the design, or the scheduling of the project. Promoting interpersonal communication to enhance team dynamic, or just to break the ice among team members, fosters further collaboration of more senior members with the rest of the team, and facilitates the *circulation of accumulated knowledge and experience among project team. This concept is also emphasized here in codes C19-1 to C19-4 by the participant.*

Memo 21-1

The participant of this interview had an executive role in the organization as Engineering Principal, and therefore his viewpoint towards the topics under discussion were coming from high-level strategic and business-oriented visions he had for the company, rather than from pure practical project experiences as with other interviewees. Concepts such as "flexibility to accept late changes becoming a competitive advantage" (code C21-12), or "End user's ability to customize and change as they wish becoming a societal expectation" (code C21-11) are some examples that can represent his vantage point towards engineering issues which in those cases is scope change. Yet, to a great extent, those ideas still supported major aspects that were discussed in previous interviews. For example "integrated project delivery" (code C21-17) which is a method that brings all project parties to the table much earlier in the project, is a response to the need for proper stakeholder engagement which was emphasised by many participants in various contexts over the course of this research. So are "maintaining regular and close dialog with stakeholders" (code C21-21), and "using augmented reality" (code C21-4) to convey the design to all stakeholders.

5.6.3 Performing Axial Coding

The purpose of axial coding is to relate categories with their subcategories. As discussed earlier axial coding is almost done concurrently with open coding during the research. For each interview conducted in this research, once the concepts were identified and named (open coding), and the grouping of the concepts were completed as shown in Figure 5.8, the researcher would try to identify high-level and more abstract concepts (*categories*) which were pointed to or indicated by a number of lower-level concepts (*subcategories*). To do this, the researcher would refer to the memos written for the interviews as discussed above, review all the identified concepts, and if required listen again to the interviews to find even more clues.

As illustrated in Figure 5.5, categories may or may not be identified among the existing concepts. Categories may be totally new concepts emerging from the new thoughts or new relationship identified between the concepts: for example, *Project Context* is a concept that was found to be one of the major categories in this research. However, this concept does not directly exist among the listed concepts identified in the interviews.

5.6.4 Identifying Major Categories

Categories for each interview were detected through axial coding which was conducted alongside the open coding. Although only a number of categories were unfolded during each interview analysis, it was observed after analysing all the interviews that 98% of the concepts identified in all 26 interviews relate, as *subcategories*, to one or more of the following 11 *categories*:

1. Scope Definition/Understanding
2. Insufficient Time
3. Knowledge and Experience
4. Stakeholder Engagement
5. Communication
6. Design Strategies
7. Client-Contractor Collaboration

8. Resource Planning
9. Unavailable/Incomplete Information
10. Alignment/Coordination
11. Project Context

The remaining 2% were scattered stand-alone concepts that could not be related to any of the above-mentioned categories, and are put under *Other* category. The identified major categories are briefly explained below.

Scope Definition/Understanding: refers to unclear scope, scope open to interpretation, not finalized scope, and the like. This category also encompasses cases where there is a lack of understanding of *expectations* among different stakeholders. Sample of subcategories related to this category are as follows:

C5-12: Scope clarification between vendor and in-house engineering

C10-5: Client does not know what it wants until after seeing the result (in vivo)

C17-8: At some point engineering should be frozen

C24-1: It should be clear to everybody if the project is cost-driven or schedule-driven

Insufficient Time: refers to situations where it was argued or indicated that the time invested/allocated/spent to certain activity during different phases of the project is not enough and adequate, or certain precautions or measures were recommended to improve this issue. Sample subcategories related to this category are as follows:

C2-4: Pre-determined dates are the cause of unrealistic schedule

C6-22: Schedules are driven by end date. Sometimes it is a matter of resource planning

C12-11: Clients consider a bit of contingency for the schedule that is assigned to contractor

C25-8: Inadequate time allocation for detailed design phase

Knowledge and Experience: refers to lack of knowledge and experience among the individuals that are involved in different roles in project teams, or a consequence of this, or any precautions or measures recommended to improve this issue. Sample subcategories related to this category are as follows:

C1-3: Good logic in schedule reduce lots of changes and rework in project

C3-16: More expertise in model review sessions (even operation and fabrication)

C13-5: Mentoring and site tours for less experienced engineers

C20-5: One year experience at site is equivalent to say 5 years at office in terms of engineering information (in vivo)

Stakeholder Engagement: refers to lack/necessity of engaging/consulting relevant stakeholders in different phases of project, or any precautions or measures recommended to improve this issue. Sample subcategories related to this category are as follows:

C26-6: Presence of the vendor in FEED can help process design be more reliable.

C9-2: Stakeholders engagement by client in DBM

C20-1: Engineering is not available at the time of construction

C14-10: Full involvement of construction, operation, and maintenance in 3D model reviews

Communication: refers to lack of adequate communication between project entities including clients, contractors, engineering disciplines, vendors, construction, etc., or any precautions or measures recommended to improve this issue. Any concepts in which communication was directly mentioned as a source of issue would also fall in this category. Sample subcategories related to this category are as follows:

C3-6: Schedule sensitivity of deliverables not communicated to engineering

C11-25: Disciplines don't communicate changes with impacted disciplines

C9-12: The one thing to improve is communication between disciplines (in vivo)

C18-13: 90% of the problems we have in big projects is communication (in vivo)

Design Strategies: refers to design strategies (including design process) that should be adopted to address engineering deliverables issues or to mitigate the impact of those issues. Sample subcategories related to this category are as follows:

C21-12: Flexibility to accept late changes is becoming a competitive advantage

C23-21: Take a practical innovative approach to keep our milestones even if they is not so perfect (in vivo)

C8-14: Care should be taken that main engineering documents (e.g. P&ID, PFD, and Plot plans) are not delayed

C10-13: "Overdesign" and "flexible design" strategy to cover uncertainty

Client-Contractor Collaboration: refers to any cooperation and collaboration (or lack of such cooperation), or any interaction that can have an impact on any of the engineering deliverables issues that are being studied in this research. Sample subcategories related to this category are as follows:

C14-16: Working as team is major component to success–client, contractor

C16-5: "You are as good as your client" (in vivo)

C5-4: Owners are normally open for contractor argues over schedule

C21-20: Put some caveat in agreements over schedule (in vivo)

Resource Planning: Refers to the necessity (or lack) of adequate resource planning or related challenges. Sample subcategories related to this category are as follows:

C18-20: Unrealistic schedule may or may not be fixed by more staffing

C23-17: Challenge of getting right/sufficient resources to deliver on time

C10-14: Pour resource planning is another major cause of engineering delay

C5-24: Understand the project and assign proper resource (quantity and quality wise)

Unavailable/Incomplete Information: Refers to conditions where the data or information required for project activities such as scheduling, defining scope, design activities, procurement, and the like, do not exist or are not adequate. This category includes any precautions or measures recommended to improve this issue. Sample subcategories related to this category are as follows:

C2-10: Incomplete information for proper scheduling at FEL

C24-21: Client information may come from "experience-based design" which may not be proper solution for the project

C14-5: Design should be based on final approved vendor information

C13-14: IFC based on incomplete information – e.g. working with a third party

Alignment/Coordination: Refers to the alignment and coordination between project stakeholders in various disciplines such as client, contractor engineering disciplines, vendors, construction, and the like, and existing shortcomings in this regard. This category includes any precautions or measures recommended to improve this issue. Sample subcategories related to this category are as follows:

C6-29: Nobody cares about engineering (in vivo)

C15-8: Discipline coordination is very important in output of design

C17-7: Lack of alignment between project team in FEED phase

C22-4: Disciplines making promises on someone else's (vendor) behalf

Project Context: Refers to the context in which the project is executed, that may have impact on the engineering deliverables issues under the study. Examples include different pricing arrangement, client norms, certain design philosophy, project battery limits, specific bottlenecks, and the like. This category includes any precautions or measures recommended to improve this issue. Sample subcategories related to this category are as follows:

C17-1: Not enough emphasis on FEL activities

C20-8: Defining systems by engineering should consider construction needs, and even contracting strategies

C11-21: More omissions and errors in engineering drawings in lump-sum contracts

C19-15: IFC-with-hold is issued just to meet the deadline, to get paid

5.6.5 Presenting Categories and Subcategories

To further elaborate how the categories and subcategories are related, it was decided to also demonstrate which engineering deliverable issue the subcategory relates to. Therefore the axial coding results were tabulated in such a way that not only would show the subcategories of each category, but it also would visualize which engineering deliverables issue is affected by subcategories. This further segregation of subcategories would later facilitate the development of the framework for the research findings described in next chapter.

Recalling from Chapter 4, the three engineering deliverables issues identified for this research are:

1. Engineering Design Issues
2. Engineering Schedule Issues

3. Changes after IFC

Figure 5.9 shows how the results of axial coding are tabulated for each interview, considering also the engineering deliverables issues that are impacted.

Category *(Relating Concept)*	Subcategory		
	Eng. Design Issues	**Eng. Schedule Issues**	**Changes after IFC**
Scope Definition/Understanding		*(C10-2)*	*(C10-1) (C10-4) (C10-5)*
Unavailable/Incomplete Information		*(C10-16)*	*(C10-3)*
Knowledge and Experience	*(C10-17)*	*(C10-11) (C10-12) (C10-15)*	*(C10-6) (C10-7) (C10-8)*
Stakeholder Engagement			*(C10-9) (C10-10)*

Figure 5.9: Example of tabulation of the results in axial coding

Observing Figure 5.9, one can notice that subcategory C10-17 appears under both *Engineering Design Issues* and *Changes after IFC.* This means that subcategory C10-17 (about design engineers' construction experience) can lead to more constructible design and consequently less potential changes after IFC, so, therefore C10-17 is shown under both issues.

5.7 Sample of Complete Analysis of Selected Interview

In this section the whole process of data analysis for interview #11 is presented as a sample (a complete analysis of all 26 interviews is presented in Appendix A). Refer to section 5.6 of this chapter for further clarification on the process used for the analysis of this interview. This interview was conducted at the participant's business office downtown Calgary. Although a 45-minute interview was originally requested, the interview took 84 minutes thanks to the participant's eagerness to contribute to and support the research. The interview was audio-recorded. Table 5.2 shows the participant information.

Table 5.2: Participant Information for Interview #11

Interview #11			
Participant Code: **JL**	*Position:* **Senior Project Engineer**	*Years of Experience:* **29**	*Org. type:* **Owner**

5.7.1 Open Coding for Interview #11

To start coding, the researcher would playback the audio file and listen carefully to the interview. Once a concept was detected, it might be necessary to repeat the corresponding section of the audio a couple of times more to unfold what was behind what the participant was talking about, or until a new concept was revealed based on what was discussed. Table 5.3 presents the list of 34 concept identified in this interview.

Table 5.3: Identifying and Numbering Concepts for Interview #11 (Open coding)

Code No.	Concept
C11-1	*Price arrangement has impact on schedule delays*
C11-2	*Poor planning in contractor side, inexperienced planners*
C11-3	*Not adequate staffing for planning department*
C11-4	*Delays because scope not well defined or not well understood*
C11-5	*Company standards are subjected to interpretation*
C11-6	*Suggest meetings to see if everybody understands the scope of work*
C11-7	*We don't give the contractor a lot of time for engineering (in vivo)*
C11-8	*Engineering, most of the time, is squeezed a lot (in vivo)*
C11-9	*Contractor would have to rush issuing deliverables because they are running against time (in vivo)*
C11-10	*Contractor needs to resource properly*
C11-11	*Lump-sum contract comes in the way of adequate resourcing*
C11-12	*Owners are open to contractors criticism about the schedule in the bidding phase*
C11-13	*Schedule delays due to inefficient internal processes (client and contractor) e.g. review and squad check process, QA process, etc.*
C11-14	*Schedule delay due to lack of control over vendor work (dependence on vendor timing) (in vivo)*
C11-15	*It is unlikely to be able to engage vendor in FEED unless you pay them*

C11-16	*IFCs are changed because of omission of vendor information*
C11-17	*IFCs are changed mostly at construction site not during the design*
C11-18	*The problem with 3d model review is that at the time the model is not complete. Not everything is modeled (including vendor package)*
C11-19	*The level of detail in the drawings is more in reimbursable contracts compared to lump-sum, and they are more reliable (in vivo)*
C11-20	*In lump-sum contracts, they issue the drawing and transfer the problem to construction (in vivo)*
C11-21	*More omissions and errors in engineering drawings in lump-sum contracts*
C11-22	*Operation and maintenance people should be involved in 3D model review*
C11-23	*The real client is the operation section*
C11-24	*The first thing to improve (for design issues) is communication (in vivo)*
C11-25	*Disciplines don't communicate changes with impacted disciplines*
C11-26	*RACI charts and document review matrix are not functional (in vivo)*
C11-27	*It takes lot of time for new hires to get to know the system, which causes some issues (Rotation of people)*
C11-28	*Minimum expectation for IFA content should be defined*
C11-29	*Owners should also communicate design decisions with operation*
C11-30	*You need to bring operation and maintenance onboard to freeze the plot plan (in vivo)*
C11-31	*Even bringing people form Asset Integrity can benefit the project*
C11-32	*It is both owner side, and contractor side. They should be one solid team*
C11-33	*Projects that have disciplines in remote or different locations*
C11-34	*Drawings should leave no room for inquiry of clarification to the end user*

5.7.2 Grouping the Concepts

As discussed in section 5.6.1 and demonstrated in Figure 5.8, the concepts were grouped based on the topic of the discussion during which the concept was detected. The grouping made it possible to realize and identify those concepts that appeared under different discussion topics, which later facilitate the axial coding of the data. Table 5.4 shows the grouping of the concepts for interview #11.

Table 5.4: Grouping Concepts for Interview #11

Discussion	Concept	
Insufficient Information	*C11-15*	*It is unlikely to be able to engage vendor in FEED unless you pay them*
Unrealistic Schedule	*C11-12*	*Owners are open to contractors criticism about the schedule in the bidding phase*
	C11-15	*It is unlikely to be able to engage vendor in FEED unless you pay them*
Design Issues	*C11-5*	*Company standards are subjected to interpretation*
	C11-8	*Engineering, most of the time, is squeezed a lot (in vivo)*
	C11-9	*Contractor would have to rush issuing deliverables because they are running against time (in vivo)*
	C11-18	*The problem with 3D model review is that at the time the model is not complete. Not everything is modeled (including vendor package)*
	C11-20	*In lump-sum contracts, they issue the drawing and transfer the problem to construction (in vivo)*
	C11-21	*More omissions and errors in engineering drawings in lump-sum contracts*
	C11-24	*The first thing to improve (for design issues) is communication*
	C11-25	*Disciplines don't communicate changes with impacted disciplines*
	C11-26	*RACI charts and document review matrix are not functional (in vivo)*
	C11-33	*Projects that have disciplines in remote or different locations*
	C11-34	*Drawings should leave no room for inquiry of clarification to the end user*
Minimizing Design Change	*C11-5*	*Company standards are subjected to interpretation*
	C11-15	*It is unlikely to be able to engage vendor in FEED unless you pay them*
	C11-16	*IFCs are changed because of omission of vendor information*
	C11-17	*IFCs are changed mostly at construction site not during the design*
	C11-18	*The problem with 3d model review is that at the time the model is not complete. Not everything is modeled (including vendor package)*
	C11-19	*The level of detail in the drawings is more in reimbursable contracts compared to lump-sum, and they are more reliable*
	C11-20	*In lump-sum contracts, they issue the drawing and transfer the problem to construction (in vivo)*
	C11-22	*Operation and maintenance people should be involved in 3D model review*
	C11-23	*The real client is the operation section*
	C11-28	*Minimum expectation for IFA content should be defined*
	C11-29	*Owners should also communicate design decisions with operation*
	C11-30	*You need to bring operation and maintenance onboard to freeze the plot plan*
	C11-31	*Even bringing people from Asset Integrity can benefit the project*
	C11-32	*It is both owner side, and contractor side. They should be one solid team*

	C11-33	*Projects that have disciplines in remote or different locations*
	C11-34	*Drawings should leave no room for inquiry of clarification to the end user*
Reasons of Scheduling Delay	*C11-1*	*Price arrangement has impact on schedule delays*
	C11-2	*Poor planning in contractor side, inexperienced planners*
	C11-3	*Not adequate staffing for planning department*
	C11-4	*Delays because scope not well defined or not well understood*
	C11-5	*Company standards are subjected to interpretation*
	C11-6	*Suggest meetings to see if everybody understands the scope of work*
	C11-7	*We don't give the contractor a lot of time for engineering (in vivo)*
	C11-8	*Engineering, most of the time, is squeezed a lot (in vivo)*
	C11-9	*Contractor would have to rush issuing deliverables because they are running against time (in vivo)*
	C11-10	*Contractor needs to resource properly*
	C11-11	*Lump-sum contract comes in the way of adequate resourcing*
	C11-13	*Schedule delays due to inefficient internal processes (client and contractor)*
	C11-14	*Schedule delay due to lack of control over vendor work (dependence on vendor timing) (in vivo)*
	C11-25	*Disciplines don't communicate changes with impacted disciplines*
	C11-27	*It takes lot of time for new hires to get to know the system, which causes some issues (Rotation of people)*
	C11-32	*It is both owner side, and contractor side. They should be one solid team*
	C11-33	*Projects that have disciplines in remote or different locations*

5.7.3 Writing Memos for Interview #11

Below are the Memos written for the interview #11. Writing memos are discussed in detail in section 5.6.2

Memo 11-1

Engaging stakeholders in early stages of the project where client is doing most of the job (e.g. FEL phases) has it is own challenges. This is the time where hardly any contractual relationship exists between the client and any other project entity. Some sort of contract e.g. a master agreement, or alliance supplier relationship may be beneficial in this kind of situations. In any case, availability of such information (e.g. vendor data) was again emphasised in order to have a realistic schedule. Lack of control over vendor work and timing is a major contributor to schedule delays for engineering deliverables (similar *concerns discussed in interviews 5 and 8; categories C5-23 and C8-10). Therefore proper risk management should be in place at the time of finalizing the details with the selected vendor. One mitigation strategy, though, can be establishing more effective communication all through the time during vendors' design and fabrication stage, to obtain regular updates and implement those updates into risk response plan.*

Memo 11-2

A not-well-defined scope is also a source of schedule delays as well as design issues. Understanding the scope by the contractor may be compromised when the client design specifications is subjected to interpretation. This is a classic example of not understanding the scope by the contractor due to inadequate quality of communication. This issue was also addressed in previous interviews.

Memo 11-3

Insufficient time allocated for engineering, which may result in rushing design activities has adverse impact on the design. As discussed in the previous interviews, a good resource planning can alleviate the impact of squeezed schedule. However, some project context, pricing arrangement for example, might come in the way of proper resource planning. With lump-sum contracts, issues with resource planning are more than in reimbursable contracts. Therefore, eventually more design issues such as errors and omissions can be detected in lump-sum contacts. Additionally, the level of detail in the drawings are lower (more detailed) in reimbursable contracts compared to lump-sum contracts. Poor staffing in combination of squeezed schedule can result in incomplete vital deliverables such as 3D models. Which do not contain key elements such as vendor package, secondary steel for cable racks, heat tracing panels, and the like.

Enhancing communication within engineering discipline has been said to have great impact in achieving mature design deliverables. This can be more highlighted in cases where design disciplines are located in different or remote locations. Multi-operating centre project are subjected to big risks of misunderstanding the divisions of responsibilities, misinterpreting the design specs, and other similar issues due to poor quality communication. The ultimate goal in enhancing design issues is that the final drawing does not have any room for inquiry at the time of construction.

Memo 11-4

Clarity of expectation is another term to describe understanding the scope. One major reason for document changes after IFC is that the completeness of the information and thoroughness of review process in earlier revisions are taken for granted. For example the IFA revisions are carelessly issued and reviewed, assuming that at the time of IFC it would be more complete and worth of more attention at that time! A good strategy to tackle this issue is that the minimum expectation in terms of levels of details, reliability of design input, and degree of completeness should be defined by clients to prevent earlier issuance of document without adding value to contribute to the progress.

A point worth noticing mentioned here was addressing the operation team as the real owner (i.e. customer /end-user) of the project, which emphasises the necessity of engagement of operation team in various stages of the design.

5.7.4 Axial Coding for Interview #11:

Categories and their subcategories for this interview were identified. This is done through reviewing the concepts, the concept groups, memos, and sometimes the audio files. Categories sometimes would emerge during writing memos where the researcher was trying to relate the concepts to each other. Table 5.5 shows the result of Axial coding for the interview #11.

Table 5.5: Categories and Subcategories for Interview #11 *(axial coding)*

Category *(Relating Concept)*	Subcategory		
	Eng. Design Issues	**Eng. Schedule Issues**	**Changes after IFC**
Scope Definition/Understanding	*(C11-5)*	*(C11-4) (C11-5)*	*(C11-5)*
Insufficient Time	*(C11-7) (C11-8) (C11-9) (C11-26)*	*(C11-7) (C11-8) (C11-9)*	*(C11-17)*
Knowledge and Experience		*(C11-2) (C11-13) (C11-27)*	
Stakeholder Engagement		*(C11-15)*	*(C11-15) (C11-22) (C11-23) (C11-29) (C11-30) (C11-31)*
Communication	*(C11-24) (C11-25) (C11-33)*	*(C11-6) (C11-25) (C11-33)*	*(C11-33)*
Design Strategies	*(C11-20)*		*(C11-28)*
Client-Contractor Collaboration		*(C11-12) (C11-32)*	*(C11-32)*
Resource Planning		*(C11-3) (C11-10)*	
Unavailable/Incomplete Information	*(C11-18) (C11-34)*	*(C11-14)*	*(C11-16) (C11-18) (C11-34)*
Alignment/Coordination			
Project Context	*(C11-20) (C11-21)*	*(C11-1) (C11-11) (C11-13)*	*(C11-19) (C11-20)*
Other			

As discussed in 5.6.5, within each category, the subcategories are further segregated based on the engineering deliverable issue they address. With this philosophy in mind, some subcategories, given that they address more than one engineering deliverable issue, may therefore appear (be repeated) under two or all of the engineering deliverable issue within a category.

For example, subcategory C11-25 in the *Communication* category can be seen under both *Engineering Design Issues* and *Engineering Schedule Issues*, because supposedly C11-25, which is a communication-related concept, can have impact on both design and schedule issues of engineering deliverables.

5.8 Saturation of Data

As discussed in Chapter 3, *theoretical saturation* occurs when further data collection fails to add properties or dimensions to an established category (Birks & Mills, 2015), and no new data seem to emerge regarding a category. In other words, after the point of the theoretical saturation, further interviews will not provide new data.

In the current research, repeating data start to occur in the last few interviews. However, point of saturation was reached in Interview #25. This observation has also been discussed in Memo 25-1 and Memo 25-2 which are presented in Appendix A.

5.9 Summary of Coding Results

The results of axial coding of all the 26 interviews conducted for this research are shown in Table 5.6 below.

Table 5.6: Axial Coding Table for all Interviews

Category *(Relating Concept)*	Subcategory		
	Eng. Design Issues	**Eng. Schedule Issues**	**Changes after IFC**
Scope Definition/Understanding	*(C5-12) (C11-5) (C12-13) (C18-8) (C23-5) (C24-8) (C24-9)(C24-13) (C24-18)*	*(C2-1) (C2-7) (C2-9) (C5-24) (C6-1) (C6-3) (C10-2) (C11-4) (C11-5) (C13-1) (C13-2) (C16-1) (C16-2) (C16-3) (C16-6) (C17-3)(C24-1)(C26-1) (C26-2)(C26-4)*	*(C2-9) (C9-1) (C10-1) (C10-4) (C10-5) (C11-5) (C12-9) (C13-17)(C17-2)(C17-8) (C19-14) (C21-5) (C21-6) (C21-7)(C21-8) (C23-13) (C24-1)(C24-2) (C24-3)(C24-7) (C24-14) (C25-10)*
Insufficient Time	*(C1-8) (C1-9) (C2-4) (C2-12) (C1-11) (C6-27)(C6-28) (C6-29) (C11-7) (C11-8) (C11-9) (C11-26) (C18-1) (C18-2)(C18-19)(C19-6) (C20-9)(C21-15)(C23-3) (C23-4)(C23-6) (C25-8) (C25-9)*	*(C1-7)(C1-9)(C2-4)(C2-8) (C2-9)(C3-10)(C5-3)(C6-22) (C6-2)(C6-4)(C7-1)(C8-1) (C11-7) (C11-8)(C11-9) (C12-11) (C13-7)(C14-2) (C19-8) (C21-15) (C23-19)(C26-8)*	*(C5-13)(C5-14)(C11-17) (C21-15)(C26-17)*
Knowledge and Experience	*(C5-10)(C5-15)(C7-10) (C7-11)(C8-20) (C10-17) (C13-4)(C13-5)(C14-14) (C16-7)(C17-6) (C18-3) (C19-16)(C20-5)(C24-6) (C25-14)*	*(C1-3)(C2-5)(C3-4)(C8-20) (C8-19)(C9-6) (C9-8)(C10-11) (C10-12)(C10-15)(C11-2) (C11-13)(C11-27) (C13-4) (C16-9)(C22-8)(C24-6) (C25-1) (C25-7)(C26-7)*	*(C3-16)(C5-10)(C6-17)(C6-18) (C7-17)(C8-19)(C10-6)(C10-7) (C10-8)(C14-10)(C18-14) (C18-12)(C24-19)*
Stakeholder Engagement	*(C1-5)(C5-18)(C13-5)(C14-10) (C15-6)(C16-15) (C17-10) (C19-7) (C20-1)(C20-3) (C20-11)(C21-14)(C21-17) (C21-18) (C23-1) (C23-2) (C24-10) (C24-16) (C24-17) (C26-6)*	*(C1-1)(C1-5)(C1-17)(C2-2) (C3-5)(C5-7)(C6-9)(C6-18) (C6-19) (C7-15)(C7-16)(C8-13)(C8-16) (C8-18)(C11-15)(C12-4)(C12-5) (C12-6)(C15-2) (C16-8) (C19-9) (C22-5)(C22-2)(C22-3) (C22-9) (C24-4) (C25-6)*	*(C1-5)(C5-18)(C5-21)(C6-12) (C6-21)(C8-25)(C9-2)(C10-9) (C10-10)(C11-15)(C11-22) (C11-23)(C11-29)(C11-30) (C11-31)(C12-6)(C13-12) (C13-13)(C16-8)(C16-14) (C16-15)(C23-15)(C24-4) (C24-15) (C24-19)(C26-6)*
Communication	*(C1-12)(C1-16)(C5-11)(C7-3) (C7-8)(C7-18)(C8-10)(C8-23) (C8-26) (C9-9)(C9-10)(C9-12) (C9-8)(C11-24)(C11-25) (C11-33)(C12-7)(C13-11) (C13-18) (C13-19)(C14-15) (C14-17) (C16-10)(C16-11) (C16-12) (C16-16)(C16-17) (C16-18)(C16-19) (C16-20) (C17-4)(C17-5) (C18-13) (C18-4) (C18-5) (C18-6) (C18-7)(C19-1)(C19-3) (C20-7)(C20-8)(C20-4) (C21-4) (C21-16)(C23-7) (C23-8)(C23-10)(C23-11) (C23-12)(C23-16)(C24-20) (C24-5) (C25-5) (C26-11) (C26-14)(C26-12)*	*(C1-16)(C3-1)(C3-3)(C3-2) (C3-6) (C3-7) (C3-8)(C3-9) (C6-24)(C6-30)(C7-2)(C7-3) (C7-14)(C7-9)(C8-21)(C9-7) (C9-8)(C9-10)(C9-12)(C11-6) (C11-25)(C11-33)(C13-10) (C13-11)(C16-4)(C16-16) (C16-17)(C17-5)(C18-18) (C18-13) (C19-9)(C19-10) (C19-12)(C19-4)(C19-5)(C19-3) (C21-21)(C23-18)(C24-4) (C25-13)(C25-4)(C26-3) (C26-10) (C26-12)(C26-13)*	*(C1-13)(C1-15)(C3-17) (C5-17)(C6-13)(C6-15)(C6-20) (C6-21)(C7-3)(C7-6)(C7-7) (C8-23)(C8-26)(C8-12)(C9-11) (C9-9)(C9-10)(C9-12)(C11-33) (C12-10)(C13-15)(C13-16) (C18-21)(C19-3)(C21-13) (C23-9)(C24-11) (C24-12) (C26-16) (C26-12) (C26-13)*
Design Strategies	*(C7-12)(C20-10)(C21-2)*	*(C8-14)(C8-16)(C23-21)*	*(C1-2)(C2-15)(C2-17)(C2-18) (C3-15)(C6-14)(C7-13)(C8-14) (C9-13) (C9-14) (C10-13) (C11-28)(C12-3) (C12-8) (C14-12)(C17-9)(C21-12)*

Client-Contractor Collaboration	*(C14-16)(C16-5)*	*(C2-6)(C3-12)(C3-13)(C3-14) (C5-4)(C5-22)(C6-23)(C6-25) (C6-26) (C8-7) (C11-12) (C11-32)(C12-12)(C14-6) (C14-7)(C14-16)(C15-3)(C16-5) (C21-19)(C21-20)(C23-20) (C25-12)(C26-9)*	*(C5-16)(C5-22)(C7-19) (C7-20) (C8-24)(C11-32)(C14-13)*
Resource Planning		*(C3-11)(C5-5)(C5-8)(C5-24) (C8-3) (C8-4) (C6-22) (C10-14)(C11-3) (C11-10)(C13-3)(C18-20) (C22-6)(C23-17)*	
Unavailable/Incomplete Information	*(C1-4)(C2-10)(C2-11) (C5-19)(C6-10) (C11-18) (C11-34)(C14-5) (C14-8) (C14-9)(C19-2) (C20-2) (C20-6) (C24-6)(C24-21)*	*(C5-1) (C5-6) (C5-19) (C6-5) (C6-6) (C6-7)(C6-8)(C8-15) (C8-5)(C8-6)(C8-8) (C8-11) (C10-16)(C11-14) (C13-6) (C14-1)(C14-4) (C14-8) (C14-9) (C15-4) (C15-10)(C15-7) (C17-12)(C19-11)(C22-1) (C22-3)(C24-6)(C24-21) (C25-2)(C26-5)*	*(C2-13)(C2-11)(C2-14) (C3-18)(C3-19)(C5-9)(C5-19) (C5-20)(C6-11)(C7-18)(C8-22) (C9-3)(C9-2) (C9-4)(C9-5) (C10-3) (C11-16)(C11-18) (C11-34) (C13-14)(C14-4) (C14-5)(C14-11)(C15-11) (C15-12) (C16-13)(C18-22) (C18-23) (C23-14)(C25-11)*
Alignment/Coordination	*(C6-29)(C14-3)(C15-8) (C15-9)(C17-7)(C18-9) (C18-10)(C18-11)(C20-12) (C21-3)*	*(C5-2)(C8-2)(C8-16)(C8-17) (C12-2)(C13-9)(C14-3)(C15-5) (C17-7)(C18-16) (C18-17) (C22-4)*	*(C5-23)(C7-4)(C7-5) C8-9)*
Project Context	*(C11-20)(C11-21) (C17-1) (C20-8)*	*(C11-1)(C11-11)(C11-13) (C12-1)(C13-8)(C17-1)(C17-11) (C19-15)*	*(C11-19)(C11-20)(C18-15)*
Other	*(C21-1)*	*(C15-1)(C21-22)(C22-7)(C25-3)*	*(C19-13)(C21-9)(C21-10) (C21-11) (C26-15)*

The table includes all the concepts that were identified during all the 26 interviews, categorized under 11 identified major categories (plus the “Other” category), and segregated based on the engineering deliverables issues they address. There are a total of 550 subcategories under the 12 categories. This number includes the repeating subcategories as discussed earlier in sections 5.6.5 and 5.7.4.

Table 5.7 demonstrates the same results in terms of the number of subcategories under each category and each engineering deliverables issue. For example, there are 51 subcategories under “*Scope Definition/Understanding*” category in Table 5.7. However, referring to Table 5.6 under the same category, one can note that subcategories (C11-5) and (C24-1) have been repeated 3 and 2 times respectively under different engineering issues.

It can be noted that the *Scope Definition/Understanding* category has been pointed to by subcategories in 51 occurrences, or that indications of the category *Scope Definition/Understanding* have happened 51 times.

Table 5.7: Number of Subcategories under each Category

Category	**No. of Subcategories**			**Sub Total**	**%**
	Design Issues	Schedule Issues	Changes after IFC		
Scope Definition/Understanding	*9*	*20*	*22*	**51**	**9%**
Insufficient Time	*23*	*22*	*5*	**50**	**9%**
Knowledge and Experience	*16*	*20*	*13*	**49**	**9%**
Stakeholder Engagement	*20*	*27*	*26*	**73**	**13%**
Communication	*55*	*46*	*31*	**132**	**24%**
Design Strategies	*3*	*3*	*17*	**23**	**4%**
Client-Contractor Collaboration	*2*	*23*	*7*	**32**	**6%**
Resource Planning		*14*		**14**	**3%**
Unavailable/Incomplete Information	*15*	*30*	*30*	**75**	**14%**
Alignment/Coordination	*10*	*12*	*4*	**26**	**5%**
Project Context	*4*	*8*	*3*	**15**	**3%**
Other	*1*	*4*	*5*	**10**	**2%**
			TOTAL	***550***	

5.10 Category Integration: Identifying the Core Category

As mentioned in section 5.5 the last stage of data analysis is to integrate and link the categories around a central or *core category,* and fine-tune the resulting theoretical construction. This is also referred to as *selective coding*. A core category is the one that has analytical power which comes from its ability to pull together all other categories and explain them all as a whole (Strauss & Corbin, 1998). In other words, other major categories can be related to the core category. A *storyline memo,* which tells the story using the categories and their linkage, is used to identify the core category.

Storyline Memo

As discussed in section 3.5.3 of Chapter 3, one noticeable characteristic of a core (central) category is that it appears with sufficient frequency in the data. That is, a significant majority of the concepts (subcategories) have indicators pointing to the core category. One of the categories in Table 5.7 is *Communication* which is by far the biggest category in terms of the number of subcategories referring to it. Twenty-four percent (24%) of the subcategories directly refer to some aspects of communication such as lack of adequate communication between project entities including clients, contractors, engineering disciplines, vendors, construction, etc., or any precautions or measures recommended to improve this issue. Therefore it seems that the *Communication* category has a potential for being the core category.

In order for the *Communication* category to qualify as a core category, most of the other major categories should be able to relate to it. Below, some of the major categories identified during the axial coding are scrutinized regarding their relation to communication.

1. **Stakeholder Engagement**: In the context of a project, engaging stakeholders means bringing them in the picture, consulting them, involving them in the decisions, using their knowledge, have them review, have them participate in meetings, and the like. The key factor to accomplish all those forms of engagement is to establish a clear and well-defined line of communication along with systematic flow of information.

   From a different point of view, we can deduce that what makes the stakeholder engagement insufficient or ineffective is inadequate communication with them. Concept (C6-16), for example, reads: *Construction and operation knowledge should be present in engineering*. It indicates that the *knowledge* is already existing in the project team (in construction and operation teams), and it only needs to be *communicated* to the engineering team to be used to solve/avoid/mitigate certain problems. In other words, engineering team has to ask the right question from the right people in the right time, and in order to make that happen, those people (here the construction and operation teams) should systematically to be communicated with clear lines of communication.

2. **Unavailable/Incomplete Information:** Lack of vendor information and unavailable vendor data in different stages of the project has been mentioned several times and in most of the interviews. Good communication, to a great extent, can alleviate this problem. As an example, consider concept (C6-5) which reads: *Lack of vendor data are not considered in schedule (floats are not realistic).* It means that unavailability of data is not considered during the preparation of the project schedule. In other words, it is assumed that the prerequisite vendor data would be available in a certain time, rendering activity floats unrealistic. Concepts (C22-3) *We do interactive planning in big board rooms only making assumptions regarding vendor data availability* and (C22-4) *Disciplines making promises on someone else's (vendor) behalf* are referring to the same issue. A good strategy to tackle this particular problem is to involve and ask vendors the right question, which basically means maintaining effective communication with vendor.

   Vendor design data may not be available at the required time by engineering. In these cases too, the situation can be improved to a great extent by a good level of communication while the vendor design is being developed, including regular follow-ups, ensuring validity of data, monitoring vendor design process, and if possible, obtaining required design data, piece by piece, as the vendor design is being evolved.

   One other set of concepts, with regard to unavailable data, concerns the interdisciplinary flow of data in the engineering teams or between engineering and construction teams. In other words, the data exists within a certain discipline but it is not communicated properly with other disciplines or relevant stakeholders. This problem is also related to inadequate communication among those disciples.

3. **Scope Definition/Understanding:** Almost all the subcategories of this category revolve around stakeholders not understanding each other. Contractors claim that the scope is not clearly defined by the clients, and clients say the scope is not clearly understood by the contractor. Some of the concepts indicated that clients do not know what they want from the beginning. Others mentioned that project scope is not finalized before the detailed design. What all of those issues have in common is an element of "not understanding one another" or "not understanding something". In other words, somewhere at some point of time, a certain piece of information is not properly communicated**,** and hence, that piece of information is either missed or not understood.

   Unclear scope means "I don't know what you want exactly" and to make a clear scope "you have to tell me what you want exactly". As an example one can note the concept C18-14 form the interview #18: *What do you mean by fit-for-purpose?* The phrase *fit-for-purpose* appears in many scopes of work in procurement documents, and this interviewee is arguing that phrases like this leave everything unclear and open for interpretation. Instead, the client should clearly indicate the expectations or detailed specification. Again the concept of communication shows itself as an underlying concept related to poor scope definition.

4. **Knowledge and Experience:** Lack of knowledge can be a problem in all phases of the project from FEL to detailed design phase. The majority of the concepts that refer to this

category indicate insufficient knowledge and experience among design engineers, planners, project engineers, and even the client's project team during FEL. Some concepts also indicate the unavailability of experienced individuals at a time of economic boom. In this type of situations, one strategy can be connecting the less experienced team members to those with more knowledge and experience. Similar to the discussion under *stakeholder engagement* presented earlier in this section, involving more experienced individuals can be augmented through improving communication. A less experienced engineer, for example, should be in continuous communication with a senior one. This level of communication can suffer due to team dynamics issues (for example C7-18: *Design problems because people are shy and don't go ask a knowledgeable persons in the engineering teams*), or lack of a systematic approach such as supervision, review process, mentoring, and the like (for example C13-5: *Mentoring and site tours for less experienced engineers*). In both cases, the missing link is communication. Therefore, improving communication, although not being a definitive solution for the knowledge and experience problem, can outstandingly improve this issue. From a different perspective, other forms of communication, such as reminders, checklists, posters, toolbox meetings, etc., can considerably mitigate issues related to human factors due to lack of knowledge and experience in individuals.

5. **Client-Contractor Collaboration:** There is a crucial element of communication in any collaboration among different entities. Client-contractor collaboration requires a good relationship between the two, which in turn, involves a good interface, and clear and honest communication of concerns, expectations, and understandings. No collaboration is achieved in vacuum. If contractors see any constraints, bottlenecks, or obstacles in the

project, they should openly and clearly explain the situation and potential consequences as well as proposed solutions to the client before getting to any collaboration.

Some subcategories within this category such as C3-13 (*Communication between the client and contractor over logical (realistic) schedule*), C5-4 (*Owners are normally open for contractor argues over schedule*), and C14-7 (*They (contractors) should voice it if the schedule doesn't look realistic*) indicates that contractors should effectively talk about the problems, and clients are normally open to listen.

While it might be argued that this issue is instead about negotiation skills required in order to get to any collaboration, it remains undeniable that negotiation skills are themselves a discipline in communication.

6. **Alignment/Coordination:** Alignment and coordination are all about being consistent, being on the same page, having the same understanding, following the same strategy and the like. Obviously, the key factor in gaining alignment is communication. Knowing what to communicate, when to communicate, and with whom to communicate is vital in achieving alignment.

Subcategories such as C5-2 (*Assumptions should be agreed upon by both client and EPC contractor*), and C8-16 (*EWP should be defined based on CWP*) are some example of misalignment among project teams, in which decision/output from one entity is not aligned with other entity. Essentially, in these cases the disciplines are not communicating with each other, and the decision has been made in a so-called "silo".

7. **Insufficient Time:** Although there are many factors contributing to insufficient time allocated to engineering activities in project, enhanced communication can undeniably have an impact on avoiding this issue or, at least mitigating the consequences.

   One source of insufficient time is an unrealistic schedule, mentioned a number of times over the course of the interviews. As noted previously, effective communication between the client and contractor can help avoid this situation. C6-4 (*Pre-determined date for start of construction*) refers to just such a condition that can be altered through collaboration. Subcategory C26-8 (*Enough time needs to be spent on challenging every aspect of schedule before finalizing it*) also indicates how communication methods can be used to deliver a mutually-agreed schedule for projects. Other examples include developing project schedule based on assumed availability of vendor data, which again, as discussed in this section, can be avoided by establishing effective communication with vendors.

Discussion

Earlier in this section it was discussed that *Communication* is an underlying concept that can relate to 7 of the other categories, and in total, 8 categories out of 11 are related to each other by the concept of *Communication*. Figure 5.10 illustrates this relation.

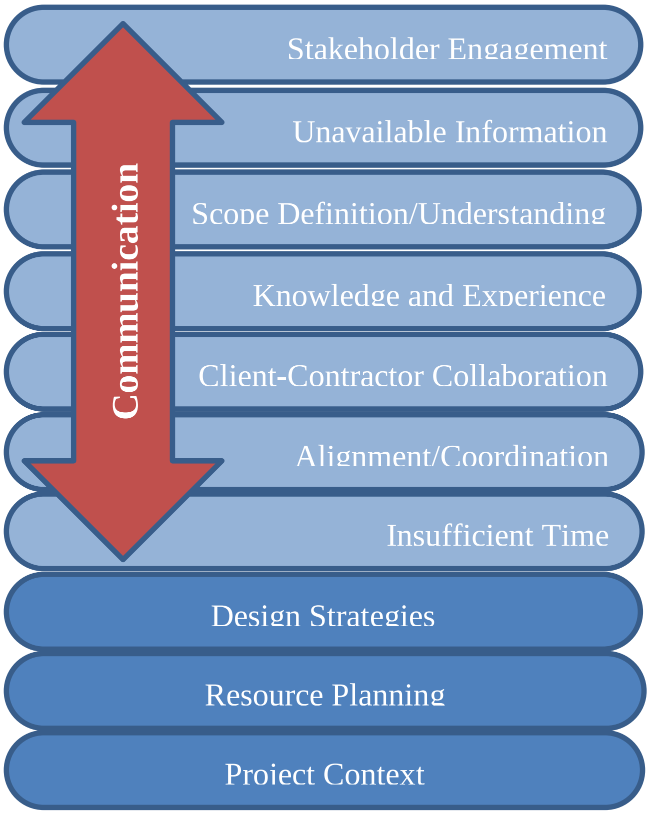


Figure 5.10: Categories related by *Communication* concept

In other words, the 7 categories discussed above are now integrated and linked around the category of *Communication*.

The same discussion can be implemented into the result shown in Table 5.7. If the *Communication* category can, directly or indirectly, address the other seven categories, then it can reasonably be assumed that it can also address their subcategories. Table 5.8 demonstrate the number of subcategories considering the integration of the 7 categories with *Communication* category.

Table 5.8: Number of Subcategories Considering Category Integration

<table>
<tr><th>Category</th><th>Number of Subcategories</th><th colspan="2">Percentage of Total</th></tr>
<tr><td>Communication</td><td>132</td><td>24%</td><td rowspan="8">89%</td></tr>
<tr><td>Stakeholder Engagement</td><td>73</td><td>13%</td></tr>
<tr><td>Unavailable/Incomplete Information</td><td>75</td><td>14%</td></tr>
<tr><td>Scope Definition/Understanding</td><td>51</td><td>9%</td></tr>
<tr><td>Knowledge and Experience</td><td>49</td><td>9%</td></tr>
<tr><td>Client-Contractor Collaboration</td><td>32</td><td>6%</td></tr>
<tr><td>Alignment/Coordination</td><td>26</td><td>5%</td></tr>
<tr><td>Insufficient Time</td><td>50</td><td>9%</td></tr>
<tr><td>Design Strategies</td><td>23</td><td colspan="2">4%</td></tr>
<tr><td>Resource Planning</td><td>14</td><td colspan="2">3%</td></tr>
<tr><td>Project Context</td><td>15</td><td colspan="2">3%</td></tr>
<tr><td>Other</td><td>10</td><td colspan="2">2%</td></tr>
</table>

It can be seen that an outstanding majority of 89% of the subcategories are linked and integrated around the *Communication* category.

It is shown that the *Communication* category: a) can be the underlying concept that relates to 7 other major categories and, b) directly or indirectly addresses the absolute majority of the subcategories identified in this research. Therefore *Communication* can be considered as the core category.

However, upon reviewing the subcategories and how they refer to communication, it becomes clear that the single word *communication* does not capture the essence of what is actually going on. Most of the subcategories directly or indirectly relate an existing issue to a missing or lacking element of communication.

Therefore it was decided to conceptualize the core category and the theoretical scheme that can represent the main theme of the research as follows:

Communication: The One Thing to Enhance

This choice of words for the core category indicates that, firstly, communication needs to be improved, and secondly, it is *the* most crucial of all the categories to be attended to.

Internal Consistency and Logic

A theoretical scheme derived from the core category should follow with internal consistency and in a logical manner (Strauss & Corbin, 1998). To ensure this, a brief discussion is presented as follows:

Enhanced communication leads to a better understanding of the scope of work, and provides a proper avenue to obtain information that would otherwise be insufficient or incomplete. A systematic communication protocol with clear lines of communication ensures proper engagement of the stakeholders across the project. Alignment and coordination among project teams (or stakeholders) can be obtained through effective communication. Promoting communication within project teams can be used to connect individuals with less knowledge and experience to more experienced team members, alleviating the effects of lack of adequate knowledge and experience in the team. With good quality communication in place, it is more probable that a good collaboration between the client and contractor will be achieved. Last but not least, some of the root causes of allocating inadequate time to engineering activities can be eliminated if the relevant information is properly communicated at the time of developing the schedule.

Based on the discussion presented above, it is now clear that other major categories logically fit within the core category. The theoretical scheme is logically developed and consistent for all major categories.

5.11 Summary

This chapter presents the process of data gathering and analysis performed for Phase II of the research to answer the second research question, which is "How can engineering deliverables be enhanced to improve construction performance?"

A qualitative research approach was adopted, borrowing concepts from the Grounded Theory methodology for data gathering and analysis. A total of 26 interviews were conducted. The analysis of data started with open coding and axial coding. Through open coding, a total of 480 concepts were identified. During the axial coding, the relation between those concepts were scrutinized and the categories and subcategories were identified. Additionally, within each category, the subcategories were further segregated based of the engineering deliverable issue they refer to. The engineering deliverables issues identified in Phase I of this research were 1) Engineering Design Issues, 2) Engineering Schedule Issues, and 3) Changes after IFC. Therefore subcategories might be repeated if they addressed more than one engineering deliverables issue. For the 12 detected categories, a sum of 550 subcategories (including repeated cases) was allocated.

Through category integration and selective coding process it was discussed that the *Communication* category has analytical power in that it can pull together other major categories and explain them as a whole. With this understanding, it was further shown that an absolute majority of the subcategories (89%) could be directly or indirectly related by the *Communication* category.

Finally, through reviewing all the subcategories, and in order to capture the essence of what the subcategories were referring to, it was decided to conceptualize the core category as *Communication: The One Thing to Enhance*, to represent the theme of this research.

With conceptualization of the core category as mentioned above, the mission of the Grounded Theory method, in finding an answer to the research question, was accomplished. It is now known that the one thing to enhance in the engineering phases of oil and gas projects, which can lead to better engineering deliverables with mitigated design, schedule and change issues, is communication.

In the next chapter, the framework for enhancing engineering deliverables will be presented, based on the theoretical scheme and the core category developed in this chapter. To develop the framework, the researcher will also refer to the subcategories identified through data analysis, and the way they were regrouped based on the engineering deliverable issue they address.

Chapter Six: **Developing the Framework**

6.1 Introduction

This chapter presents the framework for enhancing engineering deliverables to improve construction performance, which encompasses the findings pursuant to answering the two research questions. The central research questions are "What are the major factors in engineering deliverables that have a negative impact on construction performance?" and "How can engineering deliverables be enhanced to improve construction performance?" which were addressed separately in Phase I and Phase II of this research respectively.

The presented framework captures both of the research questions, in that it utilizes the core category to enhance engineering deliverables identified in Phase II, and links it to the engineering deliverables issues identified in Phase I, through the data collected from the participants throughout the research.

In Chapter 5 it was shown that the core category was conceptualized as *Communication: The One Thing to Enhance*. The wording used in the core category indicates that not only communication needs to be improved, but also it is the most crucial of all the categories to be attended to. The framework developed in this chapter addresses how to improve different dimensions of communication in order to mitigate the deliverables issues identified earlier in this research.

6.2 Communication in Projects; a Brief Background

Communication is generally associated with the transfer of information (Cheng et al., 2001). This information transfer can take place in a one-way process between a sender and receiver, or adopt more complex models that considers multiple input and output systems in different context of the initial communication models (Saidi, Taouali, & Messaoud, 2009).

The Project Management Body of Knowledge (PMBOK) standard prepared by the Project Management Institute (PMI) has a dedicated chapter for project communication management, which includes processes necessary to ensure the information needs of the project and its stakeholders are met. Those processes comprise timely and appropriate generation, collection, distribution, storage, retrieval and ultimately disposition of project information (PMI, 2017).

A number of researchers have also studied communication in project management. Turner and Müller (2004) studied the role of communication between the project owner and the project manager and identified the information needs of the owner and the project manager in different stages of the project. The owner's perspective of communication at a very high level is to address questions of product and process, project performance, and trust and surprise avoidance. The project managers, on the other hand, need to know the owner's requirements, objectives, specifications, priorities, and constraints to develop a big picture of the project during the planning stage. Throughout the implementation stage, communication needs to change to seek owner review and acceptance of plans and deliverables. At the close of the project, the project manager needs information from the owner that indicate the degree to which the overall business objective was achieved (Turner & Müller, 2004).

Within an organization or a project, a communication channel can be upward (from subordinate to supervisor), downward (from supervisor to subordinate) or horizontal (to and from the same hierarchical level) (PMI, 2017). Few researchers have looked at these communication channels in their works. Senaratne and Ruwanpura (2016), for example, discussed that the upward communication within a construction team normally includes requests for information, request for a decision, explanations and progress reports; whereas information such as notices, policy manuals and staff regulations, progress reviews, and instructions flow through the downward communication channel. The capability of organizations to provide communication in the three distinct directions (upward, downward, and horizontal) was emphasised by Lunenburg (2010).

Different perspectives of communication have also been studied in some research works. For example, some human aspects and team-working factors of communication, such as group interaction between project stakeholders, in terms of social interaction and task-based interaction, have been examined by Gorse and Emmitt (2007), in a study to improve communication behaviour during management and design team meetings. This research mentioned that social interaction involves showing support, resolving differences, and establishing values; task-based interaction involves achieving goals, discussing issues, exchanging technical information, and the like. Technological aspects to improve communication by employing ICTs (information communication technologies), on the other hand, has also been attended by other researchers such as Peansupap and Walker (2006) who studied deployment of ICT in Australian construction industry, or Silva, Ruwanpura, Hewage, and Siadat (2010) who introduced the *i-Booth*, a real-time information management system to be used at construction sites to facilitate communication at different levels. Furthermore, Naik and Bobade (2018) studied the adoption of ICT in construction project management organization to enable the digitisation of business activities associated with planning and scheduling, communication and distribution of documents, costing and budgeting, etc., to replace the traditional information and document management, and discussed the benefits as well as the challenges of such a transition.

The impact of poor communication on projects has been the subject of a number of research works. Among the early research works to address communication problems in construction projects is the work of Berntzen (1988), who defined poor communication in a project as *ineffective, unsuccessful, and deficient communication of project information*. Teo (1991) noted that poor communication in the construction industry brought consequences including cost overrun, schedule delay, dispute, and even project failure. In their book *Communication in Construction, Theory and Practice*, Dainty, Moore, and Murray (2007) mentioned several forms of schedule delay caused by poor communication, including slow flow of information, improper communication channels, wrong design and interpretations, rework, and the like. A more recent study by Gamil and Rahman (2018) identified the causes and effects leading to poor communication in construction projects, through a systematic review of previous literature published between the years 1990 and 2017. The authors identified 33 causes of poor communication, as well as 21 effects on construction projects. The top three contributors to poor communication were identified to be *lack of effective communication between parties*, *lack of effective communication system*, and *poor communication skills*. Schedule delays and cost overrun were among the top three effects of poor communication identified.

6.3 The Framework

A framework can be used for providing a conceptual guide for framing the research findings. The core category identified in Phase II, as discussed in detail in Chapter Five, suggests that communication is the one thing to enhance, in order to improve the three engineering deliverables issues identified in Phase I, namely design issues, schedule issues, and changes after IFC, *as* elaborated in Chapter 4. In order to correlate the core category with the engineering deliverables issues, the framework is developed in three different modules:

- **Module 1:** Communication and Enhancing Engineering Design Issues
- **Module 2:** Communication and Enhancing Engineering Schedule Issues
- **Module 3:** Communication and Reducing Changes after IFC

Figure 6.1 illustrates the modules of the framework. Each of those modules is intended to address the communication problems that contribute to the related issue in engineering deliverables, based on the findings from the analysis of the interview results through the axial coding, as well as the results of regrouping the subcategories under each engineering deliverable issue (referring to Table 5.6: Axial coding table for all Interviews).

In order to develop each module, all the subcategories under each engineering deliverables issues (presented in Table 5.6), together with memos prepared during the axial coding (Appendix A) were reviewed again to find out what dimension of communication can be improved and how, in order to improve the corresponding engineering deliverables issue

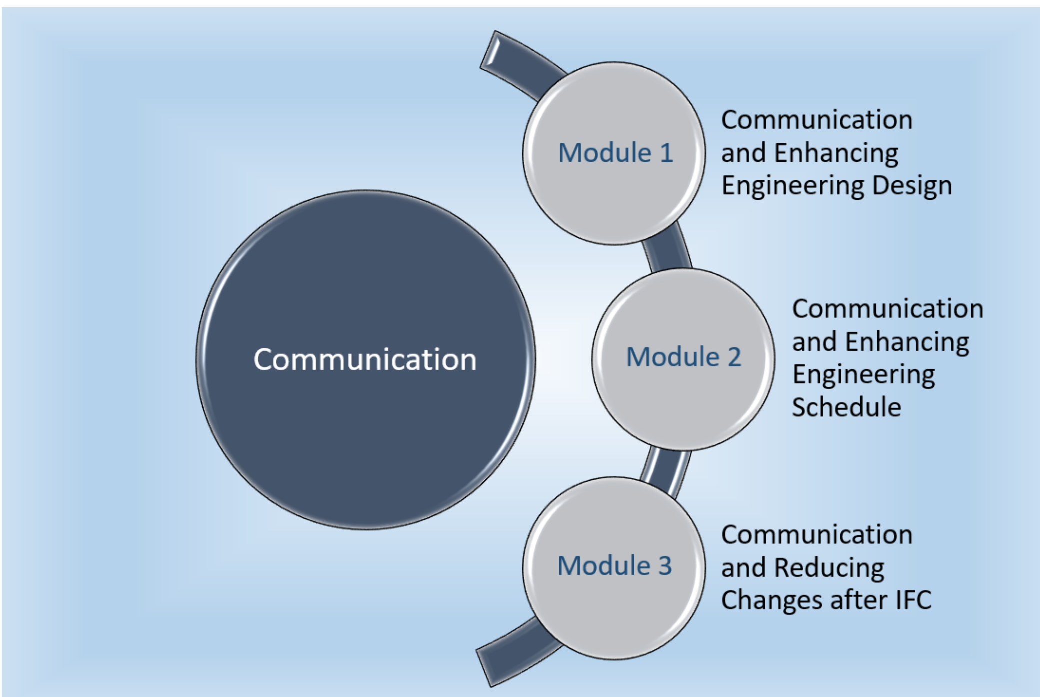


Figure 6.1: Modules of the framework

6.4 Enhancing Communication in the Presented Framework

The framework is developed based on the analysis of data obtained from the participants. Therefore the presented framework considers enhancing communication in oil industry projects, mainly through the following dimensions concerned by the research participants (Figure 6.2):

- What needs to be communicated
- When it needs to be communicated
- Whom it should be communicated to

Other aspects and dimensions of communication including communication systems, procedures and protocols; team dynamics and interpersonal communication; communication and information technology; and the like, may be referred to by terms such as *communication systems*, or similar general terms, throughout the presented framework.

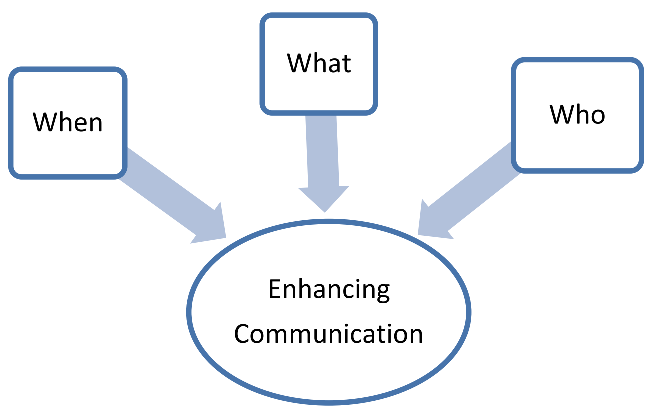


Figure 6.2: Dimensions of communication emphasized in the framework

6.5 Module 1: Communication and Enhancing Engineering Design Issues

In this module the recommendations and guidelines regarding enhancing engineering design issues, which were derived from the analysis of data obtained during the interviews, are presented and grouped based on different applications.

6.5.1 Dealing with inadequate experience

In this section the recommendations regarding lack of experience in teams are presented, with the focus on enhancing engineering design issues.

Dealing with Inadequate Experience	*Related Subcategories:* *(C5-10) (C5-15) (C5-18) (C7-10) (C7-11) (C8-20) (C10-17) (C12-13) (C13-4) (C13-5) (C13-18) (C13-19) (C14-10) (C16-12) (C17-10) (C18-3) (C19-1) (C19-7) (C19-16) (C20-5) (C22-9) (C24-5) (C24-10) (C24-16) (C24-17) (C24-18) (C25-14)*

- Construction knowledge should be present in the engineering design. This can be achieved through the following:
  - Increasing interaction between field/operation and engineering office through employing systematic communication and feedback mechanism
  - Involving construction/operation in engineering design decisions
  - Mobilizing experienced construction personnel in engineering offices
  - Hiring construction specialists, or at least senior design engineers with previous construction experience, for engineering office
  - Regular field visits with mentoring for office engineers
  - Sending engineers to the field for few years (long-term plan for organization)

- Construction, operation, and maintenance experts should be fully involved in the design reviews including 3D model reviews. Clients should facilitate and plan for this involvement earlier in the project.
- Inadequate field experience in engineering disciplines may cause constructability and/or operability issues in corresponding engineering deliverables. In lieu of systematic involvement of construction in design activities, individuals who have little or no field experience should be in continuous communication with senior engineers throughout the development of the design.
- Less-experienced team members may not feel comfortable to approach senior engineers or designers and ask questions. Interpersonal communication among engineering teams needs to be enhanced through teambuilding activities. Officially assigning mentors for less-experienced people may alleviate the communication barriers between them.
- Inadequate knowledge and experience in some of the team members necessitates more interaction and communication between those members and members with more seniority and experience within the project or organization.
    - Work performed by less experienced people needs to be checked by senior people
    - Cold eye review sessions with senior engineers/designers before issuing key deliverables
    - Squad checks using right people from different disciplines
- Best knowledge is needed in the EDS phase, both in client and in contractor teams, to ensure preliminary design philosophy is established properly, and that the knowledge is properly communicated and transferred to EPC phase.

- People with the most project experience and knowledge, both in contractor and client teams, should be either directly assigned for EDS activities or systematically communicated and consulted for EDS decisions.
- Smooth transition between EDS and EPC phases should be planned, with clear communication plan and defined interfaces and lines of communication.
- If EDS and EPC are performed by different contractors, the above-mentioned communication plan and interface design becomes even more crucial.
- Construction experts need to be communicated with, to provide valuable input for EDS phase and preliminary design decisions.

6.5.2 Dealing with Vendor Data and Involvement

In this section the recommendations regarding vendor involvement and vendor data availability are presented, with the focus on enhancing engineering design issues.

Dealing with Vendor Data/ Vendor Involvement	*Related Subcategories:* *(C1-4) (C1-5) (C5-12) (C5-19) (C6-10) (C8-10) (C14-5) (C14-8) (C15-6) (C21-18) (C23-10) (C23-11) (C26-6)*

- A systematic communication with vendors over the course of the detailed design phase, with defined functional interface between vendor and engineering, should be established.
- Continuous communication, check, and follow-up with vendor should be maintained during the vendor's own design activities to ensure alignment in scope and other assumptions, and accuracy of data.

- The scope between vendors and engineering should be clarified. It should also be ensured that the scope is well understood by both parties. This includes clear technical specifications and data sheets.
- Feedback from vendor should be received, to ensure the scope is clearly understood.
- Engineering design is significantly driven by vendor information. Systematic communication between the engineering team and vendors should be established to maintain continuous and effective communication throughout the vendor design process. This will help ensuring access to verified and correct vendor data.
- Vendor information should be incorporated into the design reviews (including 3D model reviews) to assure everything is captured in those reviews. Ideally, vendor information should be present and implemented for the 60% model review. This availability can be facilitated through systematic communication with vendors as described above.
- Relying on vendor's *catalogue information* for design should be avoided. Project-specific vendor design information should be used.
- Vendors should also be communicated and consulted by engineering teams for the related design decisions, to achieve the required alignment between vendors and engineering designs. This can be facilitated and planned by project management team through different mechanisms such as:
    - Contractor-vendor joint venture
    - Engineering contracts with vendors
    - Master agreement with vendors (a corporate strategy)
    - Bringing vendors in model review sessions (requires long-term relationship)

- Vendor presence in the early design phases such as FEED can be facilitated through the above-mentioned mechanisms. Vendors' input in FEED can result in better preliminary engineering and a more robust foundation for detailed engineering.
- Care should be taken that vendor documents be formally distributed in all relevant engineering disciplines.
- A communication protocol can be developed to encompass all the above-mentioned items regarding vendor involvement in the design.

6.5.3 Interdisciplinary Communication

In this section the recommendations regarding interdisciplinary communication are presented, with a focus on enhancing engineering design issues.

Interdisciplinary Communication	*Related Subcategories:* *(C9-9) (C9-10) (C9-12) (C11-24) (C12-7) (C13-11) (C14-17) (C15-8) (C15-9) (C16-16) (C17-4) (C18-4) (C18-6) (C19-3) (C21-14) (C23-12) (C25-4) (C25-5) (C26-11) (C26-12) (C26-14)*

- The one thing to improve in engineering disciplines is interdisciplinary communication, and lack of this communication is said to be the major cause of engineering issues. Maintaining interdisciplinary communication is a challenge, but it is vital for successful engineering.
- Proper interface should be established between engineering disciplines. Project engineers can play an important role in defining the proper interface.
- Direct physical communication between engineering disciplines should be encouraged, through:

- Daily toolbox meetings in which current activities, deadlines, and bottlenecks of each discipline is highlighted
- Informal weekly model reviews to cover recent design progress and capture problems
- Office arrangement to promote better communication between individuals and teams

- Disciplines should talk to each other:
  - They should communicate their design requirements and the supporting information they need from other disciplines, and make sure their needs are understood and acknowledged by other disciplines
  - Information within each discipline such as any design changes, minor technical deviations, change in tolerances, assumptions, change in priorities, change in material, etc. should be communicated with other disciplines as quickly as possible, through formal procedures as well as the informal channels mentioned earlier in this section.
  - Systematic follow-up to get information from other disciplines should be undertaken.
- The project management team and project engineers can play an important role to realize proper interdisciplinary communication, and help engineering disciplines have adequate coordination and alignment.

6.5.4 Engineering Presence in Construction

In this section the recommendations regarding engineering presence in construction are presented, with the focus on enhancing engineering design issues.

Engineering Presence in Construction	*Related Subcategories:* *(C20-1) (C20-2) (C20-3) (C20-4) (C20-6) (C20-7) (C20-11)*

- Engineering needs to maintain effective communication with construction after the engineering is done and during the construction, to respond to construction needs.
- The following challenges must be addressed to facilitate engineering availability during construction:
  - Access to the engineering team during construction when the engineering is performed overseas is a real challenge.
  - Individuals in engineering teams are relocated or laid off at the end of detailed design phase, and they take away project-specific knowledge and therefore are not available for construction when needed.
- A common issue in construction is the difference of conditions at the time of design with the conditions at the time of construction. For example, the material specified in the design may not be available at the time of construction. Adequate engineering services should be available for construction to resolve these types of issues.
- Field engineering teams are normally not capable enough to support construction through major engineering issues.

6.5.5 Other Communication Issues

This section presents general recommendations regarding communication, with the focus on enhancing engineering design issues.

Other Communication Issues	*Related Subcategories:* *(C1-12) (C5-11) (C7-3) (C7-8) (C8-26) (C9-8) (C9-11) (C11-5) (C11-18) (C11-25) (C11-33) (C11-34) (C14-15) (C16-10) (C16-11) (C16-17) (C17-5) (C17-6) (C18-9) (C18-10) (C18-11) (C19-2) (C20-12) (C21-15) (C23-5) (C23-6) (C23-7) (C24-13) (C24-20) (C25-2)*

- Information from previous projects, including lessons learned and as-built information, should be communicated to project teams.
- Lessons learned from previous projects should be thoroughly reviewed and discussed at the beginning of the detailed design phase, possibly during or even before the project kick-off meeting.
- Information from previous projects should be used with great care. Some information may be valid only for the conditions of that particular project, and not for the current project.
- Communication can be used to reduce human errors in design:
    - Daily reminder emails, signs and posters, bulletins and newsletters, regular technical meetings within disciplines, project-related technical workshops, etc.
    - Proper review process by senior engineers/designers, or peer-review sessions within each discipline
- The quality of communication, in terms of exchanging correct, to-the-point, and adequate information should be considered in communication within each discipline, interdisciplinary communication, or communication with a third party. For example during the technical bid evaluation (TBE), the engineering discipline should be able to ask specific questions from the vendor to be able to evaluate vendor's capability to fulfill project needs.
    - In case of recruiting vendors from overseas, the quality of communication as discussed above becomes more crucial. Information such as material data sheets,

technical specification, testing procedures etc., might be different in those areas. All those differences should be captured through maintaining quality communication through experienced engineering teams

    - Local standards should be communicated adequately with project entities in a different region or country (e.g. vendors or engineering disciplines)

- Quality of communication becomes important in understanding client's design scope of work, making sure the client knows what it wants, and highlighting to the client what is needed to achieve the scope.
- Not every detail or every aspect of the design is modeled in the 3D model, and those details may be missed during the model review sessions. Each discipline is responsible for communicating those details that are not captured in the 3D model with other disciplines and for requesting feedback to make sure those details are properly reviewed and there are no remaining issues associated with them.
- Client standards and specifications in many cases may be subject to interpretation. Furthermore, some of those standards and specifications may apply to a certain application that may not be applicable for the current project. Therefore, careless utilization of those specifications may either burden unnecessary cost for construction, or lead to inadequate design for the current project conditions. Adequate communication need to be in place to understand the project's actual needs, and tailor them to the client's specifications effectively and efficiently. Examples of client's specifications that may not work for all projects are: general drawings for light poles, panel foundation pads, access roads, and the like.

- Changes in design are sometimes communicated only within engineering disciplines. Care should be taken to follow exactly the change management procedures to communicate design changes. Design changes should be communicated to the project manager and then down through the project hierarchy, including engineering disciplines.
- Communication, including interdisciplinary, or third-party communication, becomes more important when the project is schedule-driven. Attention should be paid to the quality of communication in tight-schedule projects.
- As a general rule, design should be conveyed to all stakeholders as much as possible, to achieve an integrated delivery of the project. Project managers on both the client and contractor side play a key role in realizing this.

6.6 : Module 2: Communication and Enhancing Engineering Schedule Issues

In this module the recommendations and guidelines regarding enhancing engineering schedule issues, which were derived from the analysis of data obtained during the interviews, are presented and grouped based on different applications.

6.6.1 Unrealistic Schedule / Schedule Problems

In this section the recommendations regarding unrealistic schedule/schedule problems are presented, with the focus on enhancing engineering schedule issues.

Unrealistic Schedule / Schedule Problems	*Related Subcategories:* *(C2-2) (C2-4) (C3-13) (C-14) (C5-1) (C5-2) (C5-3) (C5-4) (C6-4) (C6-23) (C6-25) (C6-26) (C7-2) (C8-7) (C9-7) (C11-12) (C11-32) (C13-7) (C14-7) (C14-16) (C16-5) (C16-9) (C18-16) (C19-5) (C21-19) (C23-19) (C23-20) (C24-1) (C25-13) (C26-1) (C26-8) (C26-10)*

- An unrealistic schedule may be because of insufficient time being allocated in the bid proposal to discuss and investigate a proposed schedule in detail and have the buy-in of other stakeholders.
- An unrealistic schedule may be imposed by the client due to pre-determined dates for construction, commissioning, or other constraints.
    - Communication is the key to avoid/mitigate unrealistic schedule.
    - Enough time needs to be spend on challenging every aspect of schedule before finalizing it .
    - Contractors should communicate their concern to the client regarding the unrealistic schedule, and let client know that the schedule will not work.
    - Clients are (usually) open to contractor's criticism about the schedule in the bidding phase.

    - Assumptions made should be realistic. Proper communication with relevant stakeholder should be in place to verify assumptions.
    - Quality communication needs to be in place to obtain agreement on schedule.
    - In case of unavoidable time constraints, contractor should communicate with client and create a mitigation plan.
- Client-contractor collaboration can lead to a schedule that everybody accepts. Success depends on the two sides.
    - Quality communication is required to maintain a positive relationship, to make the client and contractor into one solid team, and to get a win-win resolution for a project schedule.
- Schedule-related lessons learned should be referred to and communicated with all stakeholders who provide input for project schedule. A client's operation team, for example, can be consulted for things that went wrong in the past and can be prevented in the project.
- The best people from both the client side and contractor side should be involved in EDS. The most experienced and knowledgeable personnel should be communicated with and consulted for planning decisions in EDS.
- Assumptions made during project planning should be communicated and agreed upon by affected stakeholders.
- Project schedule should acknowledge the requirements of the disciplines. Effective interdisciplinary communication, to ensure the requirements and prerequisites are clearly understood and agreed upon by other disciplines, is crucial for developing a good engineering schedule.

- Engineering delays may be because client’s expectation is not communicated with the contractor.
    - From the beginning of the project, it should be quite clear for both client and contractor whether the project is *cost-driven*, or *schedule-driven*. Switching those strategies in the middle of the project may cause significant rework and schedule delays.

6.6.2 Dealing with Inadequate Experience

In this section the recommendations regarding inadequate experience in teams are presented, with the focus on enhancing engineering schedule issues.

Dealing with Inadequate Experience	*Related Subcategories:* *(C1-3) (C2-5) (C3-4) (C8-5) (C8-19) (C8-20) (C9-6) (C10-12) (C10-15) (C11-2) (C11-27) (C13-4) (C22-8) (C25-1) (C25-7)*

- The project manager or project controls manager should encourage communication between senior planners and junior/less-experienced planners.
- The logic in the schedule should be reviewed by senior planners and feedback should be communicated to the junior/less-experienced planners, and lessons learned documented.
- An understanding of EPC relationship is crucial for junior/less-experienced planners. Providing a systematic mentorship by senior planners or other resources within the project/organization should be considered by project managers.
- People with the right expertise in the project/organization should be consulted in certain case if necessary. The project manager should establish a proper line of communication.
- Engineering disciplines may provide inaccurate input for planners.
    - Senior engineers consulted for activity durations

- Senior engineers consulted for activity prerequisites
- Senior engineers consulted for required man-hour

- Inadequate field experience in engineering disciplines may cause schedule delays for engineering deliverables. In lieu of systematic involvement of construction in design activities, those individuals with little or no field experience should be in continuous communication with senior engineers throughout the development of the design.
- Senior planners/schedulers should be encouraged to document their major activities, decisions, resolutions, and lessons learned, and also to make this document available to project controls manager, so that, in case of turnover, the information is not lost.
- Communication between senior people and junior/less-experienced team members, (both in engineering disciplines and in project controls) becomes even more crucial in situations where the schedule is tight.

6.6.3 Dealing with Vendor Data and Involvement

In this section the recommendations regarding the availability of vendor data and vendor involvement are presented, with the focus on enhancing engineering schedule issues.

Dealing with Vendor Data /Vendor Involvement	*Related Subcategories:* *(C1-5) (C5-6) (C5-7) (C5-22) (C6-5) (C6-7) (C6-9) (C7-14) (C8-8) (C8-11) (C8-13) (C11-14) (C11-15) (C11-25) (C12-2) (C12-6) (C14-1) (C14-3) (C14-4) (C14-8) (C15-4) (C19-9) (C19-10) (C19-11) (C22-1) (C21-3) (C21-4) (C25-6) (C26-5)*

- The project schedule developed in early phases (FEED or EDC) of the project should consider the risk of unavailability of vendor data. The availability of data should not be assumed, and should be confirmed by the vendor. Vendors should be involved early in the project to facilitate timely availability of information. Vendor involvement in early phases can be obtained through:

  - Buying vendor data through engineering contract with vendor in EDS (by client)
  - Master agreement or alliance supplier relationship (by client)
  - Forming joint venture between and contractor and vendor in FEED

- Bringing vendor input into the schedule, and not relying solely on engineering disciplines for vendor information, should also be considered. Disciplines may otherwise make promises on the vendor's behalf.
  - Vendor timing information for the major equipment should be captured
  - The amount of lead time for long lead items should be evaluated by vendor
- Delay in vendor data is a major contributor for engineering delay. Systematic communication between the engineering teams and vendor should be established to maintain continuous and effective communication throughout the vendor design process. The benefits of such systematic communication include:
  - Ensuring timely access to vendor's information. Information is available as vendor design activities are performed.
  - Having control/influence over vendor's timing, and preventing vendor delays
  - Ensuring the accuracy of data which are input to vendor's design in advance, avoiding late surprises
  - Late changes in vendor design can be avoided
  - Discrepancies between the earlier vendor data and final vendor data can be minimized

- Business communication with vendors (e.g. Purchase Orders) should be established early enough. Late POs have severe impact on availability of vendor data and therefore cause engineering delays.
- The quality of communication with vendor is also important: for example during the technical bid evaluation (TBE), engineering disciplines should ask the right questions from vendors to capture the right answers required for planning considerations.

6.6.4 Stakeholder Involvement

In this section the recommendations regarding stakeholder involvement are presented, with the focus on enhancing engineering schedule issues.

Stakeholder Involvement	*Related Subcategories:* *(C1-1) (C1-17) (C3-9) (C6-18) (C6-19) (C8-18) (C12-4) (C12-5) (C13-9) (C15-2) (C17-7) (C21-21) (C24-4)*

- It is crucial to maintain regular and close dialog with all related and appropriate stakeholders during project planning and scheduling, either in early stages in FEL or EDS; or in the detailed design phase. All stakeholders impact the schedule.
- All relevant stakeholders should be communicated with and their input should be obtained for developing the project schedule. Conducting scheduling workshops, especially at the end of EDS and before the detailed design phase, is highly recommended.
- At earlier stages, it is more the responsibility of the owner to establish communication with relevant stakeholders for scheduling purposes.
- An integrated master schedule should be developed with all disciplines participating.
- Construction and operation knowledge should be present in scheduling through effective communication, to prevent engineering delays.

- The construction team should be involved in developing the Engineering Work Package (EWP)
- Scheduling performed solely by EP, and not C, should be avoided

- People should not work in isolation in different disciplines. The schedule needs for disciplines should be clearly communicated and respected with other disciplines.

6.6.5 Scope Clarification

In this section the recommendations regarding scope clarification are presented, with the focus on enhancing engineering schedule issues.

Scope Clarification	*Related Subcategories:* *(C2-9) (C3-3) (C6-1) (C10-2) (C11-4) (C11-6) (C13-1) (C13-2) (C16-6) (C17-3) (C26-1) (C26-4)*

- Clients may set dates based on misunderstood scope. Client expectancy may be different from what contractor is delivering. Engineering may be delayed because the scope is not clearly defined (or understood).
- Contractor should clearly communicate to the client what is needed to realize their intended scope, so that clients can make educated decisions for different aspects of the scope.
- Clients should clearly communicate their expectancies of the scope to the contractor, and obtain their feedback about those expectancies.
  - For example, a client's expectancy regarding procuring a certain piece of equipment in the scope may be that it should not take more than 6 months for the contractor to obtain that equipment. This expectancy should be communicated with the contractor and the contractor's feedback obtained.

- Clear understanding of the scope by all the relevant stakeholders should be ensured prior any scope-related decision (design, planning, resource allocation, etc.). This can be achieved through different format of communication including:
    - Scope review meeting
    - Scope definition workshops
    - Kick-off meeting
    - Asking for feedback
- Since the process design deliverables are major input for almost all other engineering disciplines, care should be taken that the process design scope be clearly defined and frozen before major design activities are started. Later modifications in process design can cause significant delays in entire engineering process.
- Design scope for the long-lead items should be as clear as possible and be finalized as early as possible. Otherwise it may delay the procurement and placement of the corresponding purchase orders, which in turn delays both engineering and construction.

6.6.6 Other Communication Issues

In this section the general recommendations regarding communication are presented, with the focus on enhancing engineering schedule issues.

Other Communication Issues	*Related Subcategories:* *(C3-1) (C3-2) (C3-5) (C3-6) (C3-8) (C6-30) (C7-2) (C7-3) (C7-14) (C8-2) (C8-15) (C8-16) (C8-17) (C8-21) (C9-8) (C9-10) (C9-11) (C10-16) (C11-13) (C11-25) (C11-33) (C13-6) (C13-10) (C13-11) (C14-2) (C15-5) (C16-6) (C16-17) (C17-5) (C18-13) (C18-18) (C19-3) (C19-4) (C19-12) (C23-18) (C24-6) (C25-2) (C25-4) (C26-3) (C26-12) (C26-13)*

- The key to define a good schedule is communication.

- Maintaining effective and quality communication among the stakeholders "upfront" in the project is a key to achieve a good schedule for the project.
- Effective communication with the client can lead to better engineering schedule performance.
- Good client-contractor communication may help overcome some inefficient internal process that may contribute to schedule delays.
- Construction priorities and sequencing should be input for engineering schedule.
- An Engineering Work Package (EWP) should be prepared based on the associated Construction Work Package (CWP). Essentially, the construction information covered in the CWP should be communicated in advance to develop the EWP.
- Engineering schedule and deliverables should match and align with construction strategies. For example, engineering deliverables are planned *discipline-wise*, whereas construction may be planned *area-wise.*
- Schedule sensibilities should be communicated among engineering disciplines. A systematic monitoring and follow-up system (including following up of drawings and documents, pre-requisite information, interdisciplinary supporting info and non-deliverables, etc.) should be in place to ensure sensible requirements of the schedule are met. Monitoring and follow-up should also include regular progress meetings with engineering disciplines.
- A large portion of engineering schedule problems lies in poor communication between engineering disciplines:
    - Poor interdisciplinary communication causes engineering delay.

    - Disciplines should talk to each other. They should communicate their schedule requirements to other disciplines and make sure their needs are understood and acknowledged by other disciplines. Project engineers can play an important role in this regard, to help engineering disciplines have adequate coordination during planning. Note that input from other disciplines for planning purposes should be as complete as possible, leaving no room for assumptions.
    - Project managers/engineering managers should provide processes that facilitate communication among engineering disciplines, as well as within each discipline. This may include short daily meetings among interacting disciplines (in addition to common weekly meetings)
    - Any change of design within each discipline, no matter how small it may seem, should be communicated with all disciplines, or at least with all impacted disciplines. It is highly recommended that disciplines do not solely rely on formal channels of communication or change management procedures to do this, and keep informing other disciplines in informal ways as well, such as verbal discussion in casual meetings, or sending informal reminder emails and the like. Requesting feedback to ensure the change has been understood by all disciplines is also important.
- Interdisciplinary communication becomes very important in cases where engineering disciplines are located in different operating centers, remote areas, or even overseas.
    - Split of work among remote disciplines should be clearly communicated.
    - Expectations and level of completeness of deliverables should be clarified, to avoid unexpected rejection of the deliverables and corresponding delays.

    - Project local codes, standards, regulations, and other constraints should be clearly communicated to engineering offices overseas. Regular communication and follow-ups should be performed, and feedback should be obtained to ensure that local requirements are acknowledged by remote disciplines. Appropriate training should be in place to address this issue.
    - Advanced ICT tools should be employed to facilitate face-to-face communication and participation of remote disciplines in regular project meetings.
    - Remote disciplines should also be included in the circulation of any communication such as emails, MOMs, and the like.
    - The remote engineering team should be physically present in major events such as 3D model reviews and HAZOP reviews.
- Good-quality communication regarding asking the right question, providing the right information, and obtaining feedback should be emphasised:
    - For example, using experienced engineers in a vendor's technical bid evaluation (TBE) can assure the right information is exchanged between the vendor and the relevant engineering discipline.
    - Quality communication can prevent assumptions later in the project and provide reliable information for scheduling purposes.
    - Communication tools such as checklists for different purposes can be employed to ensure the right information is being exchanged during the communication.
- Communication can be emphasised to mitigate incomplete/insufficient information.
    - Establish informal discipline interface to get information in time.
    - Client may have historic data that can be used for the current project.

- Information from previous projects should be communicated to the current project
- NOTE: Careless use of information from a previous project may have adverse effects. A piece of information from the previous project may only be valid for the conditions of that particular project and not for the current project

6.7 Module 3: Communication and reducing Changes after IFC

In this module the recommendations and guidelines regarding reducing changes after IFC, which were derived from the analysis of data obtained during the interviews, are presented and grouped based on different applications.

6.7.1 Dealing with Inadequate Experience

In this section the recommendations regarding inadequate experience in teams are presented, with the focus on reducing changes after IFC.

Dealing with Inadequate Experience	*Related Subcategories:* *(C6-17) (C10-7) (C10-8) (C24-19)*

- Engineering normally does not have enough skills to add value to operations, and clients should involve operations as well, to review the design. Therefore, just like construction, operations should be in communication during major design decisions. Operational knowledge should be present in the design.
- Inadequate field experience in engineering disciplines may cause constructability problems, or costly and inefficient design solutions which can adversely impact the construction performance. In lieu of systematic involvement of construction in design activities, those individuals with little or no field experience should be in continuous communication with senior engineers throughout the development of the design.

- Early design decision (in the absence of engineering team) may be solely based on the knowledge of the project manager and/or project engineer. This situation should be avoided because it may cause severe changes in the design and many other problems down the road. Effective communication with existing resources in the project/organization is highly recommended in cases like this.

6.7.2 Dealing with Vendor Data and Involvement

In this section the recommendations regarding vendor data availability and vendor involvement are presented, with the focus on reducing changes after IFC.

Dealing with Vendor Data /Vendor Involvement	*Related Subcategories:* *(C1-5) (C5-19) (C8-22) (C11-15)(C11-16) (C12-6) (C14-4) (C14-5) (C14-11) (C18-23) (C23-14) (C24-14)*

- Ideally design should be based on final, approved vendor documents. Systematic communication between the engineering team and vendor (a link between vendor and engineering) should be established to maintain continuous and effective communication throughout the vendor design process. Communication with the vendor during the vendor design process will help ensure timely access to the vendor's information, which will become available as vendor design is being evolved.
- The vendor's catalogue information should not be used for design purposes, since it makes the design more vulnerable to change.
- It is recommended that vendor documents be available in the 60% model review. The communication strategy mentioned above can also be adopted to facilitate availability of those data.

- One major reason for IFC-with-hold revision is the unavailability of vendor documents during the preparation of IFC revision of certain deliverables. The communication strategy mentioned early in this section can help ensure the availability of such data.
- One of the main reasons for changes in engineering design is the vendor's changing their design in the late stages of engineering, where the majority of engineering deliverables are issued with IFC revision. In addition to ensuring the accuracy of data which are input to the vendor's design, maintaining systematic communication with the vendor during its design process can prevent late changes in vendor design, as well as discrepancies between the earlier vendor data and final vendor data.
- In order to avoid assumption-based design and facilitate timely availability of vendor data, care should be taken that business communication with vendor be initiated early enough in the procurement process.
- Involving vendors in earlier stages of the project can lead to a more mature definition of the scope and less possibility of design change during the detailed design phase. Communication with vendor during the EDS can help achieving more reliable process design, making it less vulnerable for change. As also discussed in section 6.6, the availability of the vendor in early stages of project can be obtained through:
    - Buying vendor's data through an engineering contract with vendor in EDS (by client)
    - Master agreement or alliance-supplier relationship (by client)
    - Forming a joint venture between vendor and contractor in FEED

6.7.3 Stakeholder Involvement

In this section the recommendations regarding stakeholder involvement are presented, with the focus on reducing changes after IFC.

Stakeholder Involvement	*Related Subcategories:* *(C3-16) (C5-10) (C5-18) (C6-18) (C6-20) (C6-21) (C8-25) (C9-2) (C10-9) (C10-10) (C11-22) (C11-23) (C11-29) (C11-30) (C11-31) (C13-13) (C14-10) (C22-9) (C23-15) (C24-4) (C26-6)*

- As a general recommendation, stakeholders should be communicated with and involved in every related design decision so as to minimize the possibility of design change and changes after IFC.
- Design decisions may not be adequately communicated, due to people's tendency to work in isolation, only caring about their own work (lack of interdisciplinary communication).
- It is highly recommended that contractors communicate the design decisions with the clients before finalizing those decisions, and involve the client in the design during the design process, and not just deliver the final design.
- The client should facilitate involvement of stakeholders during early phases of project, such as DBM or EDS.
- Unfortunately, most of the operation/maintenance comments come only during construction, which may lead to issues such as construction rework and changes in the IFC documents. The client should facilitate communication between engineering and operations/maintenance during the design phase with the appropriate interface, and involve them in design reviews to ensure the design has considered their needs.
- Communication with construction experts in order to bring construction knowledge into the design is a key to delivering reliable design. Systematic and formal constructability reviews with experienced people should be considered.

- 3D model reviews are common tools for reviewing the design, which, if conducted properly, can prevent many design changes and changes after IFC. The client has an important role to facilitate participation and full involvement of expert people from maintenance and operations, and even members of the asset integrity teams. Ultimately, the actual client is the operational users of the design. Involving operations in the design and design review is as important as involving construction.
- *Plot Plan* is a key engineering deliverable which should be finalized and frozen as early as possible during the design phase. Changes in the plot plan can impact almost every engineering discipline and may impose huge schedule delays and engineering rework to the project. Care should be taken that the operation and maintenance teams be onboard and consulted with, to freeze the plot plan.

6.7.4 Change in Design

In this section the recommendations regarding change in design are presented, with the focus on reducing changes after IFC.

Change in Design	*Related Subcategories:* *(C1-13) (C9-11) (C12-8) (C12-9) (C12-10) (C13-12) (C16-13) (C16-14) (C17-9) (C18-21) (C18-22) (C19-14) (C21-13) (C24-1) (C26-15)*

- A "No Change" philosophy should be cultivated throughout the project team, especially in engineering disciplines. Before implementing any requested change in the design, the necessity of change must be evaluated. It should be investigated whether the change is required due to safety issues, code violations, or constructability issues. Cost saving may be a reason for change. In these cases, there is normally a defined threshold for cost saving below which no change will be considered.

    - Clear communication of the necessity of any change should accompany the change request. This can include the technical justification, safety issue, constructability, or potential cost saving. In light of such communication, a better decision over accepting/rejection the change request can be made.

- Even major changes, if communicated in time, can be handled better. Communication of the design change between engineering disciplines needs to be systematically defined in management-of-change procedures. Major IFC changes have been caused because some other changes had not been communicated with all disciplines.
- Communication-related reasons for changes after IFC include:
    - Lack of interdisciplinary communication (also discussed in section 6.6)
    - Inadequate communication with construction
    - Inadequate constructability reviews (some constructability problems cannot be captured in 3D model reviews)
    - Poorly communicating the scope (not telling everything at the beginning)
    - Unavailability of information, which can be handled through maintaining systematic communication with the source of information (vendor, other disciplines, etc.), similar to what was discussed in sections 6.6.3 and 6.7.2. for vendor data
- Project execution strategy in terms of being *cost-driven* or *schedule-driven* should clearly communicated in a timely manner with the design team. Switching between those strategies later during the design phase can lead to significant design changes, including changes after IFC.

6.7.5 Scope Definition Issues

In this section the recommendations regarding scope definition are presented, with the focus on reducing changes after IFC.

Scope Definition Issues	*Related Subcategories:* *(C2-9) (C7-5) (C7-7) (C9-3) (C9-4) (C9-5) (C10-4) (C10-5) (C13-14) (C13-17) (C16-8) (C18-12) (C8-13) (C21-5) (C23-13) (C24-7)*

- Scope items should be clearly defined and communicated. Scope review meetings can be held to ensure the scope is understood by all stakeholders.
- Scope should not be subject to interpretation. Phrases like “fit to purpose”, or “as required” should be avoided in scope-related documents and communication.
- Part of understanding the scope is to understand what it takes to achieve the scope. This is sometimes taken for granted by clients. They may know what is desired but not have a clear understanding of what is required to achieve this (i.e. time, cost, resources, availability, risks, etc.). Therefore, a client may have different expectations than what the contractor understands. A contractor should emphasize the clear communication of those requirements and make sure the client understands all that is needed for the scope. Quality communication, in terms of asking the right question when exchanging proper information, plays an important role in this regard.
- Client may not know what they want until after seeing it realized (expressed as “I didn’t know what I was getting!”).
- Freezing the scope for key disciplines (such as process engineering) is highly recommended. To achieve this, more emphasis must be placed upon understanding and discussing the scope in further detail as early as possible, and involving all relevant

stakeholders, including third parties such as vendors in scope-related decisions and resolutions. Again, a systematic communication procedure can be used to obtain as much information required for scope definition as is possible.

- Information from some external stakeholders such as regulatory bodies my cause change in the scope. Care should be taken that enough communication is in place to receive all required information in time for defining the design scope. Unavailability of information from third parties such as the vendor, fabricator, etc. can also lead to scope change in later stages of the design. Establishing systematic communication can facilitate timely acquisition of information from those parties.
- Interdisciplinary communication can make disciplines understand each other's expectations and needs and thus allow them to intertwine those needs into the expected scope of work.
- Vendor scope of design should be clarified even before the detailed design phase. What is going to be procured from vendor should be finalized and completely known in the FEED.
- A clear scope and split of work at project battery limits are crucial, especially if the job is done by different stakeholders. For example, line testing at the battery limit tie-in point, when one contractor has finished the job while the other contractor has not, can create a chaotic situation and impose unexpected cost and delay upon the project. Another example is general services, such as geotechnical investigation, across the battery limit that may be subjected to significant coordination issues. Effective communication plays an important role in these types of situations.

6.7.6 Other communication issues

In this section the general recommendations regarding communication are presented, with the focus on reducing changes after IFC.

Other Communication Issues	*Related Subcategories:* *(C2-13) (C3-17) (C5-9) (C5-17) (C5-20) (C5-23) (C6-11) (C6-12) (C6-13) (C6-15) (C6-21) (C7-4) (C7-6) (C7-18) (C8-10) (C8-19) (C8-26) (C9-9) (C9-10) (C9-12) (C11-5) (C11-18) (C11-32) (C11-33) (C11-34) (C13-15) (C13-16) (C19-3) (C23-9) (C24-11) (C24-12) (C26-12) (C26-13) (C26-16)*

- Changes can be avoided if there is adequate communication in place.
- Adequate communication before final agreement on any scope-related resolution should be in place to ensure all parties have the same understanding of the agreement.
- Feedback needs to be requested and obtained to guarantee the same understanding of any scope-related agreement.
- Maintaining effective and quality communication among the stakeholders "upfront" in the project is key to achieving reliable scope and reduced possibility of design change during the project execution.
- Design changes should be communicated in 3D model to make sure all its potential impacts are captured, and thus preventing possible changes later after IFC.
- The client and contractor should have alignment over the key documents to minimize the possibility of change in those documents, and therefore mitigate changes in the downstream design documents.
- Vendor package information should be communicated with all stakeholders in order to obtain integration between vendor information and the rest of the project.

- Most valuable operations/maintenance comments come only during construction. This can be prevented by establishing defined lines of communication and linkage between operations/maintenance and engineering, so as to capture their knowledge into the design.
- Communication can be emphasised to mitigate incomplete/insufficient information situations, as described in section 6.6.6.
- Engineering disciplines should be encouraged to talk to each other.
    - Proper interface among disciplines should be established. Project engineers can best facilitate proper discipline interface management.
    - Inputs of design should be adequately communicated among the disciplines.
    - Regular interface meeting to exchange data should be held all through the project.
    - Misalignments and discrepancies should not be kept silent, and should be brought up as early as possible.
    - Disciplines should not work in silos, focusing just on technical aspects without communication with other disciplines. Design should not be performed "with closed eyes", nor ignoring others.
- Communication becomes even more critical if the engineering disciplines are located in remote areas, multiple offices, or even overseas. This issue has been discussed in detail in section 6.6.6.
- Systematic follow-up on hold items helps remove the hold before issuing IFC revisions, and thus prevents changes after IFC. Enough information should be obtained through systematic communication, to avoid hold items in key deliverables. Also, a deficiency list should be prepared in live format to capture all deliverables that have been issued IFC with hold items, so that the hold items can later be followed up and removed systematically.

- Information such as lessons learned from previous projects should be actively reviewed with the participation of relevant stakeholders to prevent potential design changes that otherwise would reoccur due to the same mistakes.

6.8 Validation of the Framework

As discussed in Chapter 3, the validity of the framework was examined through the following methods:

- **Internal Validation:** In order to internally validate qualitative research, the findings are sent back to the participants to determine if the participants are in agreement with the findings and conclusions.
- **External Validation:** For external validation, the findings are shared with individuals in the population target who did not participate in the interviews, to examine whether they agree or disagree with the findings of the study.

The framework was sent to the participants as well as other project experts along with the following questions, to examine the validity of the research:

1. To what extent do you agree that the recommendations provided in Part A can improve engineering design?
2. To what extent do you agree that the recommendations provided in Part B can improve engineering schedule performance?
3. To what extent do you agree that the recommendations provided in Part C can reduce changes after IFC?
4. To what extent do you agree that these recommendations can be generalized to all projects in the oil and gas industry?
5. To what extent do you agree that the results of this research are logically sound?

Note that Parts A, B, and C mentioned in the questions 1 to 3 are organized based on the three modules of the framework. The respondents were asked to respond to the questions by choosing one of the following answers:

- Strongly agree,
- Agree,
- Undecided,
- Disagree, or
- Strongly disagree

A total of 14 responses were received. The breakdown of the results for each question are shown in Table 6.1

Table 6.1: Results for Validation Questions

	Strongly Agree	Agree	Undecided	Disagree	Strongly Disagree
Question 1	71%	29%	0%	0%	0%
Question 2	57%	43%	0%	0%	0%
Question 3	43%	50%	7%	0%	0%
Question 4	43%	57%	0%	0%	0%
Question 5	64%	36%	0%	0%	0%

6.9 Summary

This chapter presented the framework to enhance engineering deliverables to improve construction performance. The framework was developed based on the findings of the Grounded Theory approach in data analysis that lead to the core category of *Communication: The One Thing to Enhance,* and tailoring it to the three major engineering deliverables issues that were identified in this research, which are Engineering Design Issues, Engineering Schedule Issues, and Changes after IFC. The framework is presented in three modules. Each module is devoted to enhancing one of the engineering deliverable issues mentioned above. In each module, certain dimensions of communication—*what* to communicate, *who* to communicate with, and *when* to communicate—were highlighted based on the results of the interviews and corresponding analytical memos.

Chapter Seven: **Conclusion**

Construction projects in oil and gas industry have been facing considerable amount of cost overruns and schedule delays over the past few decades, and there is no single reason accounting for poor construction cost and schedule performances. One source of the causes contributing to poor construction performance is the problems in engineering deliverables. Construction is the end user of the deliverables that are produced in the engineering phase, and therefore, any shortcoming in the engineering deliverables may have direct or indirect impact on the construction cost and schedule. With this picture in mind, the current research was aimed at enhancing engineering deliverables to improve construction performance. A comprehensive review of existing literature was conducted, which revealed a significant lack of scientific studies to investigate actual engineering process at lower level details within oil and gas projects, and to provide practical considerations to mitigate engineering problems, and issues in the engineering deliverables.

7.1 Summary of Research Process and Findings

The first step to enhance engineering deliverables is to understand what major issues related to those deliverables exist that adversely impact construction. Hence Phase I of this research was defined to identify factors affecting construction performance. This phase of the research aimed at identifying and ranking major factors related to engineering deliverables that may have negative impact on construction performance. A quantitative approach was adopted, and a questionnaire survey was employed as the data gathering instrument for this phase of the research.

In order to design the questionnaire, a preliminary list of 12 factors related to engineering deliverables that have negative impact on construction performance was prepared, based on the literature review and the results of discussions in focus groups. In order to evaluate the level of the impact of each of those factors on construction cost and schedule, a 5-point Likert measuring scale was adopted separately for impact on construction cost, and impact on construction schedule. Similarly, the same method was used to evaluate the commonality of each of the identified 12 factors in oil and gas industry. A sum of 60 responses were obtained, and the *Factor Ranking Method* including calculation of the relative importance index (RII) was used to rank the engineering deliverables factors separately based on their impact on cost, impact on schedule, and commonality. The adjusted RII was calculated to incorporate the commonality of the factors in the ranking based on their significance of impact on construction cost and schedule. The results showed three groups of issues in engineering deliverables have major impact in construction performance:

- **Engineering Design Issues:** refers to different dimensions of design problems including design errors, lack of constructability, and inadequacy of design.
- **Engineering Schedule Issues:** refers to schedule delays as well as untimeliness of engineering deliverables.
- **Changes after IFC:** refers to changes in the engineering deliverables after their IFC revision.

Based on the findings on Phase I, Phase II of the research was defined, seeking to eliminate or mitigate the problems identified in Phase I. The purpose of Phase II of the research is to understand how to enhance engineering deliverables by eliminating or mitigating the above-mentioned issues identified in Phase I. A total of 26 semi-structured interviews were conducted with oil and gas project experts. The main concepts from the Grounded Theory data analysis method was employed to inductively analyze the interviews. A sum of 480 concepts, which unfolded the participants' opinions regarding various dimensions of engineering deliverables issues and how to improve them, were identified during open coding. Through axial coding, in addition to identifying the categories and subcategories, another segregation of subcategories was performed within each category, through which the subcategories were grouped based on the engineering deliverables issue or issues they address. This further categorization of data did not interfere with the Grounded Theory data analysis method and had no effect on identifying the core category.

A total of 550 subcategories (including recurrences) were categorized under 11 major categories and simultaneously grouped based on the addressing engineering deliverables issue. The result of the axial coding with the segregation of the subcategories is presented in Table 5.6 in Chapter 5.

Towards the last interviews, it could be noticed that communication problems in different stages of projects (front-end loading and detailed engineering) formed the majority of the concepts mentioned by the participants. Standard techniques were used for category integration (selective coding), leading to conceptualizing the core category as *Communication: The One Thing to Enhance*. The wording used in the core category indicates not only that communication needs to be improved, but also it is the most crucial of all the categories to be attended to. Having derived the core category, the framework was then developed for framing research findings. Grouping the subcategories, based on the engineering deliverables issue(s) they address, facilitated developing the theoretical framework. The framework addresses how to improve different dimensions of communication in order to mitigate the three engineering deliverables issues highlighted earlier in this section. In order to correlate the core category with those issues, the framework is developed in three different modules:

- **Module 1:** Communication and Enhancing Engineering Design Issues
- **Module 2:** Communication and Enhancing Engineering Schedule Issues

- **Module 3:** Communication and Enhancing Engineering Scope Issues

Each of the modules addresses the communication problems that contribute to the related issue in engineering deliverables. For each module, all the subcategories under the corresponding engineering deliverables issues (presented in Table 5.6), together with memos prepared during the axial coding (Appendix A), were reviewed again to find out what dimension of communication could be improved and how, in order to improve the corresponding issue in the engineering deliverables.

7.2 Research Contributions

It can clearly be shown that this research has valuable contributions to both theory in academia, and project management practice in oil and gas construction projects. The research has managed to employ pure scientific methods to identify one of the root causes of construction poor performance in the engineering phase of projects, and to introduce a framework to mitigate the issue. This was achieved through introducing first-hand project knowledge of oil and gas project experts, and using academic instruments to obtain valid findings that can be used to further both the theory and practice.

7.2.1 Contribution to Theory

- This research has provided a formal academic theoretical basis for identifying communication problems as one of the fundamental issues in oil and gas projects, which previously was acknowledged only through the individual perceptions of project experts based on their personal experiences. The research did not start with communication; it ended with communication, and it did so by the application of well-established scientific methods which took the researcher on a journey from raw data — from the project execution practices in the industry—to an academic theory.

- The research helped fill the gap that was identified, through comprehensive review of the literature, in studies pertaining to engineering-related contributors to poor construction performance:
    - Little or no research has been conducted in the oil and gas industry to tackle engineering issues at the level of deliverables.
    - Similarly, few research works identified and ranked the issues of engineering deliverables with a focus on their impact on construction performance.
    - While some previous studies either sought to improve engineering, or investigated factors affecting construction, this research adopted a unique approach to, first, identify the engineering-related issues that adversely impacts construction, and then aimed at mitigating those problems to improve construction performance.
    - Almost no research has addressed enhancing communication in oil and gas projects at the project execution team activity level, and in detail as to what needs to be communicated, when, and to whom.
- Through category integration by using standard analytical tools, leading to conceptualizing the core category, it was academically concluded that communication problems are actually the common basis for a number of other engineering-related issues, such as coordination and alignment issues, stakeholder involvement issues, scope definition issues, constructability issues, and even lack of adequate knowledge in teams. This finding, for the first time, opens up a totally new vantage point towards understanding the importance of communication within projects.

- This research introduced unique features in the adopted research method as complementary to the standard research methodology. These unique and creative techniques can be used by other researchers to conduct similar qualitative research in the future.
    - In addition to the systematic Grounded Theory research method, a creative and unique coding system that used *code numbers* (as opposed to code names in the standard method), was adopted to facilitate handling large number of concepts (in this case 480 concepts), without which the recording, categorizing, grouping and referencing of those concepts would be next to impossible.
    - During the axial coding which was performed to identify major categories and their subcategories, an additional segregation of subcategories was carried out within each category, based on the engineering issue that each subcategory would address. This additional segregation would later facilitate the formation of the framework.

7.2.2 Contribution to Industry

- The current research provides tangible, practical, straightforward, and yet academically-supported solutions to improve communication as a major industry challenge, in the form of more than 200 recommendations and guidelines (Chapter 6), which can be practically implemented in the day-to-day activities of project people including lead engineers, project engineers, engineering managers, project managers, etc., within oil and gas projects.
- The three modules in the framework (also presented in section 7.1 above) can be independently used to address the corresponding engineering issue. This provides adequate flexibility and usability to the proposed framework so that companies or projects can use each module separately depending on their immediate area of need.

- Within each module of the framework, guidelines are further grouped based on different applications. This arrangement facilitates referencing and applying the guidelines in an efficient manner.
- The recommendations and guidelines, pertaining to certain cases of communication enhancement, provide one or more of the following to be considered in the improvement of that case:
    - What needs to be communicated
    - When it needs to be communicated
    - Whom it should be communicated to
- A number of practical mechanisms have been proposed in this research that can facilitate communication among different project stakeholders, or the increase the availability of relevant information as needed, in different contexts. Some of the important ones are as follows:
    - Vendor involvement mechanisms
        - Engineering contract with vendors
        - Master agreement with vendors
        - Joint-venture between vendor and contractor in EDS and EPC
    - Interdisciplinary communication mechanisms
        - Engineering daily toolbox meetings
        - Unofficial model review meetings on a weekly basis
        - Efficient office space arrangement to facilitate interdisciplinary engagement
    - Constructability enhancement mechanisms

- Mobilizing construction people in engineering offices
- Recruiting construction experts as part of engineering teams
- Including operations and construction in document distribution master list

7.3 Research Limitations

The results of this research may be vulnerable to some limitations as with any study employing qualitative and quantitative methods. The research limitations are summarized as follows:

- The researcher, being the primary instrument for the research, may be vulnerable to personal bias in situations such as obtaining and analysing information from people with a different level of experience or organizational role. This personal bias may be a potential limitation on the study.
- The data gathered in this research was primarily people's opinions and views and may be subjected to biases and lack of transparency, beyond the researcher's control. However, through the *constant comparison* technique in the process of qualitative data analysis, some biases of this type were eliminated.
- Since the interviews were conducted in Phase II of the research by which time the subject, concept, and design of the research was known to a great extent, it was decided not to conduct pilot interviews. Not implementing pilot interviews may pose some limitations to the study in that some problems with wording of questions, interview techniques, coding, etc., may not be captured and remedied. However, the researcher's experience in oil industry projects leading to the employment of a common language with the interviewee, as well as the semi-structured format of the interview which allowed open discussion

around a known subject, could alleviate some of the potential issues related to the lack of pilot interviews.

7.4 Recommendations

Improving communication should be considered as integral to the enhancement of engineering deliverables and should be promoted in project teams across the entire project lifecycle.

Communication in the early stages of the project needs to be emphasized. Client organizations play an important role in maintaining effective communication among various stakeholders at the beginning of the project.

In the FEL 2 (DBM) phase, where involvement of contractors and vendors is very limited, clients should not solely rely on in-house knowledge and experience in making major decisions regarding project scope and expectations. Adequate communication with outside resources such as potential vendor should be maintained through using appropriate mechanisms as mentioned earlier.

During the EDS phase, the best knowledge available to both client and contractor organizations should be employed through allocating the most experienced people possible in EDS teams. Involving, through effective communication, all relevant stakeholders including construction, operations, and even vendors in key decisions such as basic design, plot plans, project schedule, construction sequencing, and so forth, is crucial to delivering a successful EDS that facilitates smoother EPC execution. Care should be taken that the knowledge accumulated in the EDS phase should be clearly and completely communicated to the EPC phase. This becomes a major challenge in cases where the EDS and EPC are undertaken by different contractors.

In the EPC phase of the project, with more stakeholders involved, communication becomes even more important. Interdisciplinary communication in engineering teams is key to minimizing engineering design and schedule issues. The client should also be involved in major detailed design decisions. Therefore, effective communication between the engineering house and the client should be maintained. On the other hand, vendors should be continuously linked with engineering teams to ensure integration of the design and availability of information. Construction should participate in design review activities, even document reviews, and should comment before each revision. In addition to design reviews, there should be systematic communication between engineering teams and corresponding construction teams to exchange ideas, problems, and expert opinions, over the course of the design. Ideally, the client should facilitate the review of contractor’s design by operation experts as well—however, this is normally a challenge due to physical distance and busy schedule of key operation personnel.

Finally, the availability of engineering teams involved in the design during the construction after the detailed design phase is finished is crucial to construction performance. This needs to be considered by the project management team when dismissing or relocating key engineering personnel after engineering is completed.

7.5 Thoughts for Future Research

The current research presented a framework for enhancing engineering deliverables to improve construction performance. The findings of the research include identifying the engineering deliverables issues that are the major contributors to poor construction performance, and that communication is the one thing to improve in order to mitigate those issues.

The following research areas can be suggested to be conducted by other researchers in order to further the findings of the current research, or address certain aspects or applications that were not covered by this research.

7.5.1 Research Areas Related to Phase I:

- Case study research to investigate real-life construction projects in order to identify the engineering deliverables factors impacting construction performance based on the empirical data, representing the level of impact in terms of causing delays or imposing additional cost in construction operations.
- Focusing on identifying the root causes for design scope change both in client and in contractor organizations in FEL phases of the projects. As shown in Phase I of the current research, the changes after IFC during the design scope change was, by far, the first rank in engineering deliverables issues to impact both construction cost and schedule performance.
- Compare and contrast engineering perspective versus construction viewpoint, regarding the engineering problems affecting construction performance, in order to promote better understanding and coordination between engineering and construction.
- Conducting similar research in other industries such as utilities and power generation, and non-industrial projects.

7.5.2 Research Areas Related to Phase II

- Case study research to evaluate the capability of existing communication mechanisms in real-life projects in addressing communication requirements as presented in this research.
- Focusing on developing more practical mechanisms (e.g. contractual arrangements, partnerships, etc.) in order to facilitate vendors' presence and involvement during DBM and EDS phases.

- Research on enhancing communication methods, procedures, and protocols, in different project phases of oil industry projects. This can include defining proper interfaces to established clear lines of communications, and developing proposed communication procedures for different phases of projects.
- Research on applying communication tools to reduce human factors in engineering design issues.

7.6 Final Words

In an attempt to improve oil and gas construction project performance, this research focused on the problems in engineering deliverables that contribute to poor cost and schedule performances in construction. At the beginning, the researcher had no idea where it would end. Would it end up in a magic formula that would solve all problems? Or would it result in a one-fits-for-all flawless engineering procedure that could prevent all engineering-related issues? Later, the process of qualitative research, and employing the major concepts of the powerful Grounded Theory method, which developed the theory grounded on the sheer data obtained through face-to-face interviews, gradually showed the faint light at the end of the tunnel. Every single interview, when coded and analysed through listening to the recorded interview several times, thinking, and writing analytical memos, unfolded a piece of the solution. And finally there was the *aha* moment; the magic word showed itself: *Communication*! This research introduces a new vantage point for project execution teams to look at the importance of communication in oil industry projects, and provides a theoretically solid base for future research works aiming at improving oil and gas construction projects.

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Appendix A: Detailed Analysis of the Research Interviews

A.1 Interview # 1

Interview #1			
Participant Code: **KH**	*Position:* **Project Controls Manager**	*Years of Experience:* **18**	*Org. type:* **EPC**

Table A.1a: Identifying and Numbering Concepts for Interview #1 *(open coding)*

Code No.	Concepts
C1-1	*Appropriate stakeholder involved in FEL*
C1-2	*Value engineering for the design*
C1-3	*Good logic in Schedule (in vivo)*
C1-4	*Insufficient design information before IFC (e.g. vendor drawings)*
C1-5	*Missing link between vendor and in-house design (in vivo)*
C1-6	*Upstream vs downstream deliverables (in vivo)*
C1-7	*Imposing unrealistic schedule to team (in vivo)*
C1-8	*Override/skip design procedures*
C1-9	*Compress and compress… (in vivo)*
C1-10	*Compromising will bite the schedule later on*
C1-11	*Shortening everything up front (in vivo)*
C1-12	*Appropriate communication of changes*
C1-13	*Evaluate the necessity of change*
C1-14	*Minimizing project changes*
C1-15	*Cultivate the culture of "no change" in the whole team*
C1-16	*FELL and EPC performed by same contractors*
C1-17	*Planning sessions should include all stakeholders*

Table A.1b: Grouping concepts for interview #1

Discussion	Concept	
Insufficient information	*C1-5*	*Missing link between vendor and in-house design*
	C1-6	*Upstream vs downstream deliverables*
	C1-1	*Appropriate stakeholder be involved in FEL*
Schedule Issues	*C1-1*	*Appropriate stakeholder be involved in FEL*
	C1-3	*Good logic in schedule reduce lots of changes and rework in project*
	C1-8	*Override/skip design procedures*
	C1-9	*Compress and compress…*
	C1-10	*Compromising will bite the schedule later on*
	C1-11	*Shortening everything up front*
	C1-17	*Planning sessions should include all stakeholders*
Minimizing change in design	*C1-3*	*Good logic in schedule reduce lots of changes and rework in project*
	C1-12	*Appropriate communication of changes*
	C1-13	*Evaluate the necessity of change*
	C1-15	*Cultivate the culture of "no change" in the whole team*
	C1-16	*FEL and EPC performed by same contractors*
	C1-2	*Value engineering for the design*

Memo 1-1

One of the biggest problem during the detailed design phase is the lack of design information to perform the design before the IFC documents are to be issued (Insufficient design information before IFC). Inadequate information in the design phase causes schedule delays as well as changes after IFC which is considered scope change for construction. The impact of the lack of design information is greater in upstream vs downstream deliverables. Vendor data is an example. Often timed there is missing link between vendor and in-house design, meaning that design entity performs the design without update vendor data, normally relying on data from similar or previous projects, or hoping to incorporate accurate data in later revisions of project. This can be avoided by involving appropriate stakeholders including vendors and even operators in the early project phases. The mechanism for the involvement of those entities in FEL stage are not clearly and practically defined in most of the client organizations

Memo 1-2

Not involving appropriate stakeholders in FEL including contractor, fixed schedule milestones imposed by the client, and lack of good logic in the schedule will result in imposing an unrealistic schedule to design team. As a consequence, project management team would have to shorten everything up front, leaving not enough time for engineering. To accommodate this, design activity durations are compressed and compressed… systematic design approaches which are normally considered in company's design procedures are overridden/skipped to compensate for shortage of time. Meanwhile some design aspect such as quality, correctness, constructability, etc. are compromised to catch up with the schedule but this compromising will bite the schedule later on in the form of changes, construction delays, rework etc. The participants emphasizes that to include project stakeholders including contractors in project schedule decisions is a key factor to avoid unrealistic schedule (Planning sessions should include all stakeholders)

Mem 1-3

Three questions needs to be asked to evaluate the necessity of change in the design: a) is the current design safe? b) does the current design meet the standards? and c) is the current design constructible and operable? If the answer to all of these questions in yes then no change in the design should be made during the detailed design phase. The culture of "no change" should be cultivated in the whole team including owners and contractors to make the scope freeze possible in the projects. Often times, during parallel engineering, or when FEL and EPC are not performed by same contractor, some less expensive solutions are detected, for which case clients request for design changes. These types of changes can also be avoided by performing value engineering for design in DBM or EDS phases of the project. In any case, lines of communication should be established to facilitate appropriate communication of change, to make sure if the change is agreed upon by all stakeholders and all the potential impacts are considered. This provision by itself can prevent issues such as lack of design consistency and integrity.

Axial Coding for Interview #1:

Table A.1c: Categories and subcategories for Interview #1 *(axial coding)*

Category *(Relating Concept)*	Subcategory		
	Eng. Design Issues	**Eng. Schedule Issues**	**Changes after IFC**
Insufficient Time	*(C1-8) (C1-9) (C1-11)*	*(C1-9)*	
Knowledge and Experience		*(C1-3)*	
Stakeholder Engagement	*(C1-5)*	*(C1-1) (C1-5) (C1-17)*	*(C1-5)*
Design Strategies			*(C1-2)*
Communication	*(C1-12) (C1-16)*	*(C1-16)*	*(C1-13) (C1-15)*

A.2 Interview #2

Interview #2			
Participant Code: **TC**	*Position:* **Corporate Engineering Manager**	*Years of Experience:* **31**	*Org. type:* **EPC**

Table A.2a: Identifying and Numbering Concepts for Interview #2 *(open coding)*

Category No.	Category Name
C2-1	*How client executes the job*
C2-2	*Unrealistic schedule (in vivo)*
C2-3	*Exclusion of contractor*
C2-4	*Pre-determined dates*
C2-5	*Insufficient experience*
C2-6	*Contextual pressure for bidding*
C2-7	*Parallel design (in vivo)*
C2-8	*Reverse scheduling (in vivo)*
C2-9	*Unclear scope*
C2-10	*Incomplete information*
C2-11	*Give-me-what-you-got approach (in vivo)*
C2-12	*Insufficient Time to Do Proper Engineering*
C2-13	*Catalogue information (in vivo)*
C2-14	*Maturity of design (in vivo)*
C2-15	*Engineering innovation*
C2-16	*Uncertainty in design data" (in vivo)*
C2-17	*Standardization, modularization, packaging of design (in vivo)*
C2-18	*Buy some flexibility for construction schedule*

Table A.2b: Grouping concepts for interview #2

Discussion	Category/Concept	
Unrealistic Schedule	*C2-1*	*There is a big problem in how client execute the job*
	C2-3	*Clients tend to exclusion of contractor in early stages*
	C2-4:	*Pre-determined dates are the cause of unrealistic schedule*
	C2-5	*Insufficient experience to determine what is the proper schedule*
	C2-6	*There is a contextual pressure for bidding*
Insufficient Time to Do Proper Engineering	*C2-4*	*Pre-determined dates are the cause of unrealistic schedule*
	C2-7	*Parallel design in detailed design phase cause problems*
	C2-8	*Reverse scheduling*
	C2-9	*Scope is not clearly defined by the client*
	C2-10	*Incomplete information for proper scheduling at FEL*
	C2-11	*Give-me-what-you-got approach when design is not complete*
	C2-13	*Catalogue information*
	C2-14	*Maturity of design is not ache dived in squeezed schedule*
Uncertainty in design data	*C2-15*	*Engineering innovation*
	C2-17	*Standardization, modularization, packaging of design*
	C2-18	*Buy some flexibility for construction schedule*
	C2-19	*No deadline for commissioning*
	C2-20	*Partial IFC and hold clouds*
	C2-12	*Insufficient Time to Do Proper Engineering*

Memo 2-1

This participant being with a contractor company, sees a big problem in the client side and how clients execute the job, which includes commitment to a pre-determined dates in the projects and exclusion of contractors in preparation of project schedule. This situation is combined with what the participant believes is insufficient experience in the client organization, and results in using up a big chunk of the project time before execution phase, and leaves the EPC contractor with not enough time. It is quite obvious that the participant believes that had they, as a contractor company, had more input in the clients scheduling, most of their project issues would have been prevented. There is also a contextual pressure for bidding in which, although the contractors are aware of unrealistic schedule, they still agree with it and enter the bid, because otherwise they cannot get the job.

Memo 2-2

Because of the pre-determined dates such as construction dates, procurement dates, and fabrication dates in project schedule, a phenomenon called reverse scheduling occurs in which engineering activities are squeezed between those dates. This approach will normally lead to insufficient time to do proper engineering.

Parallel design in detailed design phase happens when client has not made up its mind on what they want (unclear scope), which ends up in inevitable scope changes even after IFC. In such situation activities are performed in parallel (instead of Finish to Start relationship), e.g. starting to purchase equipment while process design is still ongoing, or mechanical committing the equipment on the purchase order while process may keep changing. The design is done on a basis of incomplete information, e.g. vendor's catalogue information, not the actual process needs. For example, each engineering discipline, having commitment to meet its own schedule, would seek for information on a give-me-what-you-got basis, which in turn can cause vendors to design based on preliminary data sheet and preliminary process design, a start of a chain reaction. This condition will not allow maturity of design before

Memo 2-3

One important source of engineering deliverables issues, such as schedule delays and design change after IFC or partial IFC and hold clouds, is performing the detailed design with the existence of uncertainty in design data. (This in turn is one possible result of insufficient time to do proper engineering). Measures can be taken to face this inevitable problem, most effective of which is engineering innovations. One example would be careful and legitimate *over design* strategy that can cover a big portion of uncertain design data. Another strategy is standardization, modularization, and packaging of design, which to some extent deals with uncertain data and directs towards pre-determined design solutions, but its direct benefit is to buy some flexibility for construction schedule. This flexibility in construction schedule will in turn accommodate some risks due to uncertain data. In general, the only definite solution for uncertainty is allocating enough time to get to the final data. An ideal situation to accommodate this is that the client considers no deadline for commissioning, meaning that an optimum schedule is implemented after the start point until the end of construction.

Memo 2-4

In this section of the interview, directed the discussion was directed towards finding the causes for all theses. In tackling design issues (even with perfect schedule), the participant indicated that the key elements are resources that can maintain team communication and leadership. People problem is 85% of the issues, and technical competency, although necessary, is not enough. They need to be able to maintain a good discipline interface, communicate project problem very well at the discipline level. If language is a barrier, then they should extensively use emails to make sure issues are communicated. Situations like "Why didn't you tell me that before?" should be avoided (issues not buried under the carpet). Apparently, what cause this lack of effective communication at the project discipline level is what the participant referred to as silo effect where people's only concern their own discipline and they don't pay attention to the impact of their decision/ design/ etc., on the work of other project disciplines. In the matter of scope change and change in the drawings after IFC, or incomplete IFC documents (with "hold" clouds), again the importance of communication (although indirectly) can be tracked in the what the participant said: "No one follows up once the incomplete IFC is issued because there is normally no post-IFC action list in place" (otherwise it would be followed up through document controls).

Client –Contractor relationship:

Lack of effective communication between the client and contractor can also be tracked in this interview. The unrealistic schedule should be communicated by contractors prior to bidding, without the fear of losing the job. Clients, on the other hand should not exclude the contractor in FEED or FEL phases for developing the schedule. Another pattern seen in non-constructive client-contractor relationship is what I (the researcher) call political interaction. For example the schedule rebase line as mentioned by the participant, could be of no value without client accepting the change of end date. It is just a means to clear the project delays to that point and setting up a new wrong schedule (they are kidding themselves).

One avenue where improving communication can benefit the project is timely and systematic communication with vendors. The problem of insufficient information for vendor design, that leads to using catalogue information at detailed design phase rather than process needs, can also be addressed by establishing defined lines of communication between vendor and client (pre-FID stage) and vendor and contractor (EPC stage). The participant supported this idea but could not contribute a practical suggestion.

Axial Coding for Interview #2:

Table A.2c: Categories and subcategories for interview #2 *(axial coding)*

Category *(Relating Concept)*	Subcategory		
	Eng. Design Issues	**Eng. Schedule Issues**	**Changes after IFC**
Scope Definition/Understanding		*(C2-1) (C2-7) (C2-9)*	(C2-9)
Insufficient Time	*(C2-4) (C2-12)*	*(C2-4)(C2-8) (C2-9)*	
Knowledge and Experience		*(C2-5)*	
Stakeholder Engagement		*(C2-2)*	
Design Strategies			*(C2-15) (C2-17) (C2-18)*
Unavailable/Incomplete Information	*(C2-10) (C2-11)*		*(C2-13) (C2-11) (C2-14)*
Client-Contractor Collaboration		*(C2-6)*	

A3. Interview #3 and #4

Interview #3 and 4			
Participant Code: **JR&LR**	*Position:* **Corporate Senior Planner**	*Years of Experience:* **22 and 25**	*Org. type:* **Owner**

Table A.3a: Identifying and numbering concepts for interview #3&4 *(open coding)*

Code No.	Concept
C3-1	*Priority of construction not communicated into engineering*
C3-2	*No follow up on drawing in certain period in time*
C3-3	*Scope properly defined and communicated among the team*
C3-4	*People side- having right expertise in project (in vivo)*
C3-5	*A process that facilitates the communication among the stakeholders in early scheduling*
C3-6	*Schedule sensitivity of deliverables not communicated to engineering team*
C3-7	*Communication tools in place (in vivo)*
C3-8	*Interdisciplinary communication (e.g. short daily meeting) (in vivo)*
C3-9	*Develop the schedule in scheduling workshop*
C3-10	*Schedule is not unrealistic (in vivo)*
C3-11	*It is just a matter of resources*
C3-12	*Get the job and deal with it later (in vivo)*
C3-13	*Communication between the client and contractor over logical schedule*
C3-14	*Client-contractor collaboration (in vivo)*
C3-15	*Flexible design to accommodate changes*
C3-16	*More expertise in model review sessions (in vivo)*
C3-17	*Tools like feedback system, or lessons learnt*
C3-18	*IFC is not always the latest revision (change after IFC)*
C3-19	*Change after IFC is always there. Contingencies should take care of that*

Table A.3b: Grouping concepts for interview #3&4

Discussion	Category/Concept	
Reducing Scheduling Delay	*C3-1*	*Construction priorities communicated into engineering*
	C3-4	*Having right expertise during scheduling (in vivo)*
	C3-3	*Scope properly communicated among the team*
	C3-2	*Follow up on deliverables in certain period of time*
	C3-6	*Schedule sensitivity of deliverables not communicated to engineering*
	C3-8	*Interdisciplinary communication (e.g. short daily meeting) (in vivo)*
	C3-7	*Communication tools in place*
	C3-9	*Develop the schedule in scheduling workshop*
Unrealistic Schedule	*C3-10*	*Schedule is NOT unrealistic (in vivo)*
	C3-11	*It is just the matter of resources*
	C3-12	*Get the job and deal with it later (in vivo)*
	C3-13	*Communication between the client and contractor over logical schedule*
	C3-14	*Client-contractor collaboration (in vivo)*
	C3-5	*Process that facilitates communication stakeholders in early scheduling*
Minimizing Changes in Design	*C3-16*	*More expertise in model review sessions (even operation and fabrication)*
	C3-17	*Tools like feedback system, or lessons learnt*
	C3-18	*IFC is not always the latest revision (change after IFC)*
	C3-15	*Flexible design to accommodate changes*
	C3-19	*Change after IFC is always there*

Memo 3-1

The interview started with discussion over engineering deliverables schedule problems. One contributor to schedule problems, as mentioned by the participants, is that the engineers, especially at lead and project engineer level, fail to communicate key concept such as project scope, schedule sensitivities, or construction priorities with their team. This shortcoming may be because of lack of or insufficiency of commination tools, or lack of knowledge about *what needs to be communicated.* The former was highlighted by the participants in necessitating more frequent informal meetings among disciplines, in addition to regular weekly meetings. For the latter, lack of experience in engineering team may be considered as a contributing factor.

Enhancing communication of project sensitivities for scheduling can be achieved for example by developing he schedule through scheduling workshops with participants from relevant stakeholder, or simply following up required deliverables in a certain period of time.

Memo 3-2

Participation of all stakeholders in developing project schedule was emphasized in this interview as well as the previous one, but with more emphasis on engineering discipline, to achieve more reasonable and smoother schedule. The participants responded to the comment from previous interview regarding unrealistic schedule, indicating that normally the clients have experience doing similar projects enough to have a valid idea about the durations, and not produce an unrealistic schedule. Additionally, unlike interview #2, they believed that clients are normally open to contractor’s educated comments about the schedule, because clients, they thought, are aware that contractors have better understanding about the details. So a collaboration between client and contractor over project schedule *is* achievable. The also acknowledge that committing to shorter time is similar to committing to lower price. Those are not always the influencing factor for clients during the bid.

So far, based on the data form this interview, we have contradicting opinions from contractor and owner perspective, about unrealistic project schedule, and that the contractors cannot argue the schedule in the fear of losing the job. This topic would be brought forward in future interviews.

Memo 3-3

Design 3D model review is normally used in almost all oil and gas projects to reduce design issues such as constructability and operability in advance so less problems are faced during construction. Proper 3D model reviews can help maturity of design in that it facilitates detecting certain types of errors in time before issuing IFC drawings, make the drawings less vulnerable to changes after

IFC. However, in spite of using state-of-the-art technology available in generating the 3d model, still those engineering issues are encountered during construction. The question is why. Apparently not involving the qualified people, in terms of expertise and related disciplines is a common problem in projects. This was also brought up in previous interviews, and would also be discussed in next interviews.

Axial Coding for Interview #3&4:

Table A.3c: Categories and subcategories for interview #3&4 *(axial coding)*

Category *(Relating Concept)*	Subcategory		
	Eng. Design Issues	**Eng. Schedule Issues**	**Changes after IFC**
Insufficient Time		*(C3-10)*	
Knowledge and Experience		*(C3-4)*	*(C3-16)*
Stakeholder Engagement		*(C3-5)*	
Communication		*(C3-1) (C3-3) (C3-2) (C3-6) (C3-7) (C3-8) (C3-9)*	*(C3-17)*
Design Strategies			*(C3-15)*
Client-Contractor Collaboration		*(C3-12) (C3-13) (C3-14)*	
Resource Planning		*(C3-11)*	
Unavailable/Incomplete Information			*(C3-18) (C3-19)*

A4. Interview #5

Interview #5			
Participant Code: **JA**	*Position:* **Project Engineering Manager**	*Years of Experience:* **30**	*Org. type:* **Owner**

Table A.4a: Identifying and numbering concepts for interview #5 *(open coding)*

Code No.	Concepts
C5-1	*Assumptions in developing schedule should be realistic*
C5-2	*Assumptions should be agreed upon by both client and EPC contractor*
C5-3	*Owner putting end date (in vivo)*
C5-4	*Owners are normally open for contractor argues over schedule*
C5-5	*Maybe contractor just needs more resources*
C5-6	*Vendor data availability is big contributor for schedule delays*
C5-7	*Bring vendor input to the schedule*
C5-8	*Assigning enough people in disciplines*
C5-9	*Missing deliverables or missing information in deliverables (in vivo)*
C5-10	*Detail constructability review with experienced construction people*
C5-11	*Taking lessons learned from previous project very seriously (in vivo)*
C5-12	*Scope clarification between vendor and in-house engineering*
C5-13	*Not enough time (for client and EPC) to review vendor drawings properly*
C5-14	*More time in detailed design and 3d model review (to minimize change)*
C5-15	*Field visit by engineering*
C5-16	*Issue IFC just because you have to issue (in-vivo)*
C5-17	*Somebody should follow and watch the "hold" items (in vivo)*
C5-18	*Bringing operation and maintenance people to 3d model review*
C5-19	*Vendor documents should be available in 60%model review*
C5-20	*Design changes may not be communicated to 3d model*
C5-21	*Difficult to put right people in the same room at the same time*
C5-22	*Client contractor alignment over key documents*
C5-23	*Big problem is integration between vendor package and the rest of the project*
C5-24	*Understand the project and assign proper resource (quantity and quality wise)*

Table A.4b: Grouping concepts for interview #5

Discussion	Category/Concept	
Unrealistic Schedule	*C5-1*	*Assumptions in developing schedule should be realistic*
	C5-2	*Assumptions should be agreed upon by both client and EPC contractor*
	C5-4	*Owners are normally open for contractor argues over schedule*
	C5-5	*Maybe contractor just needs more resources*
	C5-7	*Bring vendor input to the schedule*
	C5-8	*Assigning enough people in disciplines*
	C5-3	*Owner putting end date (in vivo)*
Design Issues	*C5-9*	*Missing deliverables or missing information in deliverables (in vivo)*
	C5-10	*Detail constructability review with experienced construction people*
	C5-11	*Taking lessons learned from previous project very seriously (in vivo)*
	C5-12	*Scope clarification between vendor and in-house engineering*
	C5-15	*Field visit by engineering*
	C5-18	*Bringing operation and maintenance people to 3d model review*
	C5-19	*Vendor documents should be available in 60%model review*
Minimizing Design Change	*C5-13*	*Not enough time (for client and EPC) to review vendor drawings properly*
	C5-14	*More time in detailed design and 3d model review (to minimize change)*
	C5-16	*Issue IFC just because you have to issue (in-vivo)*
	C5-17	*Somebody should follow and watch the "hold" items (in vivo)*
	C5-18	*Bringing operation and maintenance people to 3d model review*
	C5-19	*Vendor documents should be available in 60%model review*
	C5-20	*Design changes may not be communicated to 3d model*
	C5-21	*Difficult to put right people in the same room at the same time*
	C5-22	*Client contractor alignment over key documents*
Reducing Scheduling Delay	*C5-23*	*Big problem is integration between vendor package and the rest of the project*
	C5-24	*Understand the project and assign proper resource (quantity and quality wise)*
	C5-22	*Client contractor alignment over key documents*
	C5-6	*Vendor data availability is big contributor for schedule delays*
	C5-19	*Vendor documents should be available in 60%model review*

Memo 5-1

As discussed in the previous analytical memos, there was no uniformity in the responses of the participants from owner and EPC companies over the issue of unrealistic engineering schedule. This issue was hence discussed in the current interview, due to its importance in engineering schedule performance. It is quite common that the data available at the early stages of the project, particularly EDS phase, are insufficient to develop a mature schedule. Therefore some schedule decisions are made based on assumptions. Whether or not those assumption are realistic and agreed upon by *all relevant stakeholders*, plays a crucial role in developing a sound realistic schedule. Note the term "*all relevant stakeholders*" which include not only the EPC contractor (indicating owner's openness for contractors concern), but also ideally the potential vendors of major equipment, a concept which is missed most of the time, majorly due to administrative difficulties. The concept of client contractor collaboration was also depicted in the previous interview.

This participant (owner) believes that contractors can manage what they call "unrealistic" schedule by allocating adequate resources; a concept that the previous interviewee (owner) raised too.

Memo 5-2

Inadequate understanding what is needed by construction (scope) will lead to missing deliverables, or missing information in the deliverables. This issue can generate interruptions in construction process which will hurt the performance. Scope clarification especially between vendors and in-house engineering is a key consideration in this regards. Design review tools should be utilized by expert and, as importantly, related people, and of course with adequate information available (performing 3D model review involving experienced individuals from engineering, construction, operation and maintenance, with finalized vendor data). The participant strongly believed that this kind of problems in encountered in almost every project. So the lessons-learned from previous project should be properly communicated and emphasized in the projects.

Memo 5-3

Compromising or skipping proper design review procedures when rushing the project, also mentioned in interview #1, was brought up here as well by the participant. Signs acknowledging the fact that more time needs to be allocated for engineering activates, both in FEL for client, and in EPC for contractor, can be tracked both in owner and client organizations based on the interviews so far. Other than adequate time, a proper quality control procedure for design also requires involving relevant people (engineering construction, operation, etc.), adequate information available (vendor drawings in 60% model review), and following up the findings of the design review (e.g. for removing “hold items” from IFC drawings). Among challenges are administrative challenges to involve all stakeholders and gaining owner-contractor alignment over key documents.

Memo 5-4

Availability of information (vendor data was mentioned here again) is a key contributor for engineering schedule performance. This is an important risk in every project that usually is not properly managed. Certain client-contractor alignment over key document on a case-by-case basis can be used as a mitigation strategy. The result may include earlier access to information, more educated assumptions, or even customizing based on what information is available at the time.

Axial Coding for Interview #5:

Table A.4c: Categories and subcategories for interview #5 *(axial coding)*

Category *(Relating Concept)*	Subcategory		
	Eng. Design Issues	**Eng. Schedule Issues**	**Changes after IFC**
Scope Definition/Understanding	*(C5-12)*	*(C5-24)*	
Insufficient Time		*(C5-3)*	*(C5-13)(C5-14)*
Knowledge and Experience	*(C5-10) (C5-15)*		*(C5-10)*
Stakeholder Engagement	*(C5-18)*	*(C5-7)*	*(C5-18) (C5-21)*
Communication	*(C5-11)*		*(C5-17)*
Design Strategies			
Client-Contractor Collaboration		*(C5-4) (C5-22)*	*(C5-16) (C5-22)*
Resource Planning		*(C5-5) (C5-8) (C5-24)*	
Unavailable/Incomplete Information	*(C5-19)*	*(C5-1) (C5-6) (C5-19)*	*(C5-9) (C5-19) (C5-20)*
Alignment/Coordination		*(C5-2)*	*(C5-23)*

A5. Interview #6

Interview #6			
Participant Code: **SR**	*Position:* **Senior Project Engineering**	*Years of Experience:* **23**	*Org. type:* **Owner**

Table A.5a: Identifying and numbering concepts for interview #6 *(open coding)*

Code No.	Concepts
C6-1	*One major cause of schedule delay is process design modification*
C6-2	*More changes in schedule driven vs non-schedule driven projects*
C6-3	*Design change delays the schedule*
C6-4	*Pre-determined date for start of construction*
C6-5	*Lack of vendor data are not considered in schedule (floats are not realistic)*
C6-6	*We are "theoretical" when developing baseline schedule*
C6-7	*Capture timing information from major equip. vendors at the end of EDS*
C6-8	*This does not happen in 90% of the cases*
C6-9	*Engineering contract with the vendors in EDS*
C6-10	*Majority of design is driven by vendor information*
C6-11	*E&I contracts normally have more delay than others in construction*
C6-12	*We should bring E&I contracts more earlier to the project*
C6-13	*I am using the word "Neglect" (in vivo)*
C6-14	*Maximum change happens in Electrical and Instrumentation sections and happens in the field*
C6-15	*Design is done with closed eye (in vivo)*
C6-16	*Only considering their portion of responsibility in Engineering*
C6-17	*Eng. Companies don't have skill set to add value for operation,…*
C6-18	*Construction and operation knowledge should be present in engineering*
C6-19	*More responsibility of owners side to get these roles embedded into the team*
C6-20	*Owner maintain sufficient communication between operation and maintenance with engineering*
C6-21	*Most of their valuable comments come only during construction*
C6-22	*Schedules are driven by end date. It is a matter of resource planning*
C6-23	*Yet, owners are still open to contractors rational to modify schedule*
C6-24	*Different contractors doing EDS and detailed design*
C6-25	*Success of the project is not depending only on one side*
C6-26	*More collaboration between owner and contractor to deliver better schedule in the early phases*
C6-27	*(reducing revisions)- schedule pressure, just to issue on time*
C6-28	*Insufficient time to do the proper engineering*
C6-29	*Nobody cares about engineering (in vivo)*
C6-30	*(improving design schedule performance)- effective communication with owner as well as interdisciplinary to save time on revisions*

Table A.5b: Grouping concepts for interview #6

Discussion	Category/Concept	
Unrealistic Schedule	*C6-5*	*Lack of vendor data are not considered in schedule (floats are not realistic)*
	C6-6	*We are "theoretical" when developing baseline schedule*
	C6-7	*Capture timing information from major equip. vendors at the end of EDS*
	C6-8	*This does not happen in 90% of the cases*
	C6-9	*Engineering contract with the vendors in EDS*
	C6-22	*Schedules are driven by end date. Sometimes it is a matter of resource planning*
	C6-23	*Yet, owners are still open to contractors rational to modify schedule*
	C6-24	*Different contractors doing EDS and detailed design*
	C6-25	*Success of the project is not depending only on one side*
	C6-26	*More collaboration between owner and contractor to deliver better schedule in the early phases*
Design Issues	*C6-10*	*Majority of design is driven by vendor information*
	C6-27	*Schedule pressure, just to issue on time*
	C6-28	*Insufficient time to do the proper engineering*
	C6-29	*Nobody cares about engineering (in vivo)*
Minimizing Design Change	*C6-14*	*Maximum change happens in Electrical and Instrumentation sections and happens in the field*
	C6-11	*E&I contracts normally have more delay than others in construction*
	C6-12	*We should bring E&I contracts more earlier to the project*
	C6-13	*I am using the word "Neglect" (in vivo)*
	C6-15	*Design is done with closed eye (in vivo)*
	C6-16	*Only considering their portion of responsibility in Engineering*
	C6-17	*Engineering companies don't have skill set to add value for operation and maintenance*
	C6-18	*Construction and operation knowledge should be present in engineering*
	C6-19	*More responsibility of owners side to get these roles embedded into the team*
	C6-20	*Owner maintain sufficient communication between operation and maintenance with engineering*
	C6-21	*Most of their valuable comments come only during construction*
Reducing Scheduling Delay	*C6-1*	*One major cause of schedule delay is process design modification*
	C6-2	*More changes in schedule driven vs non-schedule driven projects*
	C6-3	*Design change delays the schedule*
	C6-4	*Pre-determined date for start of construction*
	C6-30	*Effective communication with owner as well as interdisciplinary to save time on revisions*

Memo 6-1

The project schedule developed in early phases of the project do not consider the risk of unavailability of vendor data, and therefore the floats considered in the schedule are not realistic. Assumptions are made that are sometimes not practical, because the information are assumed, not obtained from the related stakeholder (again, vendor data availability was mentioned here). Also, the processing of data, between different stakeholders engaged in project for a certain period in different time (e.g. separate contractors doing the EDS and EPC) can be a cause for a schedule that is not agreed upon at the beginning of EPC phase. Exchanging knowledge and experience in a constructive way between the client and the contractor can deliver a more realistic schedule.

Memo 6-2

Insufficient time allocated for engineering was mentioned here again as a root cause of schedule problems as well as design issues. The importance of the engineering activities are often compromised by other project priorities including pre-determined milestone dates. The schedule pressure lead to the urge of issuing the deliverable on the assigned date just to meet the schedule, without following proper design and review procedure (also mentioned in Interviews 1, 2, 4 and 5).

Memo 6-3

Engaging the right stakeholder in right time can prevent a majority of design changes happening after IFC. Apparently, there are some factors that prevent the project management team to involve the right participants in different stages of the project, both in client side and in contractor side. The interviewee mentioned just another example of this issue for electrical and instrumentation (E&I) contracts which, the interview believed, should be finalized earlier in detailed design phase.

Involving the stakeholders is an issue within engineering disciplines as well. The problem is that the disciplines are not aware of other relevant stakeholders needs, and are just focusing on finishing their own activities. Here, the major stakeholders are downstream (and sometimes even upstream) engineering disciplines, construction, fabrication yard, and even the client itself. This "negligence" is sometimes because of the lack of knowledge in engineering to add value to (or understand what is value for) construction, operation and maintenance. Therefore, once again, the importance of the presence of construction and operation knowledge in engineering (in other words, involving experts from construction and operation in the design) is highlighted. The client has more control to foster this engagement than the contractor. Most of the valuable comments from operation and maintenance come only during the construction (and not during the engineering), which burden huge impact on construction performance.

Memo 6-4

It goes without saying that engineering deliverables issues highlighted in this research are interrelated. Design issues in engineering deliverables, for example, (which are possible results of poor scheduling) can cause design changes after IFC. The design changes, on the other hand, may contribute schedule delays. This interrelation is acknowledged in in this study as well. The participant mentioned that process design changed have to most impact on schedule delays, because process discipline in oil and gas project is the source of the flow of information through all other disciplines. It was also mentioned that, due to higher schedule pressure in schedule-driven projects, there are more design changes occurring in this type of projects compared to non-schedule driven projects. This opinion also reinforces the concept of interrelated engineering issues. Effective communication between stakeholders e.g. client-contractor communication, as well as interdisciplinary communication can alleviate the compound effect of those issues. For example, during changes after IFC, a good line of communication between the discipline issuing the change and its counterpart in client office, can dramatically reduce the formal review and approval time needed by the client, and therefore, reduce the impact on schedule.

Axial Coding for Interview #6:

Table A.5c: Categories and subcategories for interview #6 *(axial coding)*

Category *(Relating Concept)*	Subcategory		
	Eng. Design Issues	**Eng. Schedule Issues**	**Changes after IFC**
Scope Definition/Understanding		*(C6-1) (C6-3)*	
Insufficient Time	*(C6-27)(C6-28) (C6-29)*	*(C6-22) (C6-2) (C6-4)*	
Knowledge and Experience			*(C6-17) (C6-18)*
Stakeholder Engagement		*(C6-9) (C6-18) (C6-19)*	*(C6-12) (C6-21)*
Communication		*(C6-24) (C6-30)*	*(C6-13) (C6-15) (C6-20) (C6-21)*
Design Strategies			*(C6-14)*
Client-Contractor Collaboration		*(C6-23) (C6-25) (C6-26)*	
Resource Planning		*(C6-22)*	
Unavailable/Incomplete Information	*(C6-10)*	*(C6-5) (C6-6) (C6-7) (C6-8)*	*(C6-11)*
Alignment/Coordination	*(C6-29)*		

A6. Interview #7

Interview #7			
Participant Code: **MY**	*Position:* **Senior Mechanical Engineer**	*Years of Experience:* **15**	*Org. type:* **EPC**

Table A.6a: Identifying and numbering concepts for interview #7 *(open coding)*

Code No.	Concepts
C7-1	*Schedule is an unrealistic thing (in vivo)*
C7-2	*The key to define a good schedule is communication (in vivo)*
C7-3	*Quality of communication*
C7-4	*Disciplines do not care of anything other than technical aspects without communicating with other disciples*
C7-5	*Expectations and needs of other disciplines are not clear for each other*
C7-6	*Interface management is not perform properly*
C7-7	*Quality of communication causes poor definition of scope (e.g. codes are provided for vendors but not client specs)*
C7-8	*Design changes performed at lower levels are not communicated to PM therefore not captured in MOC*
C7-9	*Playing different role other than your own role in the project causes delay*
C7-10	*Design problems because people are shy and don’t go ask a knowledgeable persons in the engineering team.*
C7-11	*Lack of knowledgeable people in the engineering team*
C7-12	*QA systems may reduce design issues (checklist)*
C7-13	*If a comment does not address an error, code, safety, and this type of issues, then don’t implement the comment*
C7-14	*Engineering should ask the right questions during TBE of the vendor*
C7-15	*Vendors often entertain with their participation to build relationship to get the job*
C7-16	*Master agreement with vendor to have vendor information earlier*
C7-17	*Poor design (constructability) may result in change after IFC*
C7-18	*At least avoid hold in key documents such as P&ID*
C7-19	*Issue IFC to make someone happy for few minutes (in vivo)*
C7-20	*Owner should not accept those documents as IFC*

Table A.6b: Grouping concepts for interview #7

Discussion	Category/Concept	
Unrealistic Schedule	*C7-1*	*Schedule is an unrealistic thing (in vivo)*
	C7-2	*The key to define a good schedule is communication (in vivo)*
	C7-3	*Quality of communication*
	C7-14	*Engineering should ask the right questions during TBE of the vendor*
	C7-15	*Vendors often entertain their participation to build relationship to get the job*
	C7-16	*Master agreement with vendor to have vendor information earlier*
Design Issues	*C7-8*	*Design changes performed at lower levels are not communicated to PM therefore not captured in MOC*
	C7-18	*Design problems because people are shy and don't go ask a knowledgeable persons in the engineering team.*
	C7-10	*Design problems because people are shy and don't go ask a knowledgeable persons in the engineering team.*
	C7-11	*Lack of knowledgeable people in the engineering team*
	C7-12	*QA systems may reduce design issues (checklist)*
Minimizing Design Change	*C7-4*	*Disciplines do not care of anything other than technical aspects without communicating with other disciples*
	C7-5	*Expectations and needs of other disciplines are not clear for each other*
	C7-6	*Interface management is not perform properly*
	C7-13	*If a comment does not address an error, code, safety, and this type of issues, then don't implement the comment*
	C7-17	*Poor design (constructability) may result in change after IFC*
	C7-18	*At least avoid hold in key documents such as P&ID*
	C7-19	*Issue IFC to make someone happy for few minutes*
	C7-20	*Owner should not accept those documents as IFC*
Reducing Scheduling Delay	*C7-7*	*Poor quality of communication causes poor definition of scope (e.g. codes are provided for vendors but not client specs)*
	C7-9	*Playing different role other than your own role in the project causes delay*
	C7-14	*Engineering should ask the right questions during TBE of the vendor*
	C7-15	*Vendors often entertain with their participation to build relationship to get the job*

Memo 7-1

Unavailability of information during the preparation of schedule makes it less reliable and practical for the detailed design phase. To bring those information you need to communicate with stakeholders who possess those information. So engaging the right stakeholder is a key to develop a reliable schedule. Once they are engaged, care should be taken to maintain effective and quality communication in terms of exchanging relevant and necessary information (asking right questions) that could add value to the project schedule. Quality of communication also can refer to providing accurate information such as durations and lead times.

Bringing in vendors during the FEL or at least EDS has some contractual/administrative challenges, but most of the time they are willing to entertain the client to build up relationship for potential future contracts. They only need to be approached and communicated with. Nevertheless, there are still methods to engage vendors earlier in the project. Master agreements with vendors, or alliance suppliers (mostly for clients) are among them.

Memo 7-2

As also mentioned in the memos of the previous interview, engineering issues are interrelated. Here the participant reinforced the idea in a different perspective. Some design issues are indirectly caused by changes in design. The changes occurred in one discipline is not communicated to the project management, nor to other relevant discipline, and those other disciplines do not implement the changes in their own design, which immediately make their deliverables faulty.

One factor that contributes to design problems is certainly the lack of or insufficient technical or project knowledge of the individuals within the engineering design teams. Companies normally rely on mentorship of the senior engineers to overcome this problem. However, one common problem is that sometimes the individuals are shy to ask what the y need to know. This lack of communication may have a variety of reasons including language barriers, cultural differences, or soft skills problems.

Memo 7-3

Schedule pressure will result in issuing engineering deliverables that are not complete, miss information, are not constructible, or have other design issues, which is a recipe for changes after IFC. It also fosters less collaboration (or even not caring) among disciplines and generate a silo effect through which disciplines work in their own silo and caring only for their own interest. In this non-constructive atmosphere, the disciplines will not talk to each other to clarify their needs, and deliverables are issued only to make managers happy (for few minutes)!

Axial Coding for Interview #7:

Table A.6c: Categories and subcategories for interview #7 *(axial coding)*

Category *(Relating Concept)*	Subcategory		
	Eng. Design Issues	**Eng. Schedule Issues**	**Changes after IFC**
Insufficient Time		*(C7-1)*	
Knowledge and Experience	*(C7-10)(C7-11)*		*(C7-17)*
Stakeholder Engagement		*(C7-15) (C7-16)*	
Communication	*(C7-3) (C7-8) (C7-18)*	*(C7-2) (C7-3) (C7-14) (C7-9)*	*(C7-3) (C7-6) (C7-7)*
Design Strategies	*(C7-12)*		*(C7-13)*
Client-Contractor Collaboration			*(C7-19) (C7-20)*
Unavailable/Incomplete Information			*(C7-18)*
Alignment/Coordination			*(C7-4) (C7-5)*

A7. Interview #8

Interview #8			
Participant Code: **MT**	*Position:* **Project Controls Manager**	*Years of Experience:* **19**	*Org. type:* **EPC**

Table A.7a: Identifying and numbering concepts for interview #8 *(open coding)*

Code No.	Concepts
C8-1	*Schedule being unrealistic is not a good excuse (can be negotiated with the owner parallel with crushing and fast tracking strategies (e.g. separate 30% model review for pipe racks, and not waiting for process units 30% model review)*
C8-2	*Lack of coordination between disciplines during the planning stage*
C8-3	*Not enough planners in the project*
C8-4	*Not proper resource planning*
C8-5	*Incorrect/ unrealistic duration input from disciplines*
C8-6	*Also it is possible that disciplines input more-than-necessary duration time to be on safe side*
C8-7	*A win-win strategy should be adopted to plan the project schedule*
C8-8	*Vendor information is curtail input for scheduling*
C8-9	*Planning for engineering, procurement, and construction should be all integrated*
C8-10	*Interfaces between engineering and vendors are not functioning well to support PO activities*
C8-11	*Engineering delay because of delay in placement of the order (major equipment)*
C8-12	*Procurement post order activities are also important*
C8-13	*With partnership, or master agreement, vendor data can be available earlier*
C8-14	*Care should be taken that main engineering documents (e.g. P&ID, PFD, Plot plans are not delayed*
C8-15	*Construction sequencing information should be input for design schedule*
C8-16	*EWP should be defined based on CWP*
C8-17	*Construction goes area-wise, engineering goes discipline-wise*
C8-18	*Construction should be involved in defining EWP*
C8-19	*Turnaround of people and lack of documentation*
C8-20	*Lack of knowledgeable engineers (especially in hot market)*
C8-21	*Poor monitoring and follow-up system*
C8-22	*A major reason for IFC-with-hold documents is lack of vendor document in time for engineering IFC*
C8-23	*The "hold" items in the IFC are not followed up after the IFC is issued*
C8-24	*Contractor issues IFC for many reasons including generating cash flow to the project*
C8-25	*Constructability review should formally be conducted. (sometimes done without construction people)*
C8-26	*Local standards are not communicated with overseas subsidiaries/contractors*

Table A.7b: Grouping concepts for interview #8

Discussion	Category/Concept	
Unrealistic Schedule	*C8-1*	*Schedule being unrealistic is not a good excuse*
	C8-13	*With partnership, or master agreement, vendor data can be available earlier*
	C8-15	*Construction sequencing information should be input for design schedule*
	C8-20	*Lack of knowledgeable engineers (especially in hot market)*
Design Issues	*C8-10*	*Interfaces between engineering and vendors are not functioning well to support PO activities*
	C8-20	*Lack of knowledgeable engineers (especially in hot market)*
	C8-23	*The "hold" items in the IFC are not followed up after the IFC is issued*
	C8-26	*Local standards are not communicated with overseas subsidiaries /contractors*
Minimizing Design Change	*C8-9*	*Planning for engineering, procurement, and construction should be all integrated*
	C8-14	*Care should be taken that main engineering documents (e.g. P&ID, PFD, Plot plans are not delayed*
	C8-19	*Turnaround of people and lack of documentation*
	C8-22	*A major reason for IFC-with-hold documents is lack of vendor document in time for engineering IFC*
	C8-23	*The "hold" items in the IFC are not followed up after the IFC is issued*
	C8-24	*Contractor issues IFC for many reasons including generating cash flow to the project*
	C8-25	*Constructability review should formally be conducted. (sometimes done without construction people)*
	C8-26	*Local standards are not communicated with overseas subsidiaries/contractors*
Reducing Scheduling Delay	*C8-2*	*Lack of coordination between disciplines during the planning stage*
	C8-3	*Not enough planners in the project*
	C8-4	*Not proper resource planning*
	C8-5	*Incorrect/ unrealistic duration input from disciplines*
	C8-6	*Disciplines input more-than-necessary duration time to be on safe side*
	C8-7	*A win-win strategy should be adopted to plan the project schedule*
	C8-8	*Vendor information is curtail input for scheduling*
	C8-11	*Engineering delay because of delay in placement of the order (major equipment)*
	C8-12	*Procurement post order activities are also important*
	C8-14	*Care should be taken that main engineering documents (e.g. P&ID, PFD, Plot plans are not delayed*
	C8-16	*EWP should be defined based on CWP*
	C8-18	*Construction should be involved in defining EWP*
	C8-17	*Construction goes area-wise, engineering goes discipline-wise*
	C8-19	*Turnaround of people and lack of documentation*
	C8-21	*Poor monitoring and follow-up system*

Memo 8-1

Construction sequencing is also type of information that is necessary for developing project schedule by the clients but may not be available during the early stage of the project. Normally clients at the earlier phases of projects don't have access to construction expertise. The FELL is done in-house, the FEED may be awarded to an engineering company, or it may be awarded to the EPC Company who will be doing the EPC phase. The latter case is the best scenario in terms of availability of construction information, which if managed properly will benefit the project the most. But for other possibilities, establishing a clear line of communication with some source of construction expertise (e.g. through direct hire or assigning from other ongoing projects) should be considered. The last line of defence in terms of bringing construction knowledge into the game is relying on experienced and knowledgeable engineering teams within client and the engineering company doing the FEL or EDS.

Memo 8-2

Problems in design can be due to the fact that the interface between the vendor and engineering house is not functioning properly (similar to C5-23 in Interview #5). What it means is that the flow, adequacy, accuracy, and timeliness of the information exchange between vendor and engineering house is not effective. In other words the quality of communication (C7-3 in Interview #7) is missing (see also Memo 7-1).

Memo 8-3

Alignment of engineering with other stakeholders (mentioned here are vendors, procurement and construction) can maximize the maturity of design and making it less vulnerable to change. This should go hand in hand with the availability of information from required for design as mentioned by other interviewees as well. The main reason why the IFC deliverables are issued with "hold" item is lack of required information (mostly vendor data) at the time if issuing that deliverable. A deteriorating factor is that the proceeding follow-up to remove the “hold” items, are not done systematically. Alignment, obtaining information, and following –up are instances of different aspects of effective communication.

The accuracy of the exchanged information between disciplines can generate changes after IFC. One contributor to the lack of accuracy of information at the time of IFC can be the “turnover of the people” in the project. People leave the project without documenting their project-specific knowledge, lessons learned, history of decisions and events, etc.

Memo 8-4

“A win-win strategy” during project planning is what the participant mentioned as a measure to take in order to prevent engineering schedule delays. The win-win concept can be considered between client and contractor, engineering and vendor, and between engineering disciplines, all of which have positive impact in developing project schedule at different levels. A win-win situation between two entities is achieved when each side is aware of the interests of the other side and tries to align those interests with its own. This awareness requires proper communication between the two entities which include asking the right questions, providing the right information etc.

Inaccurate information such as unrealistic (optimistic or pessimistic) durations of activities or lead times, underestimating the need for resource, alignment between construction and engineering lack of systematic follow-up system can be considered as the background concepts of the participants opinion about reducing the schedule delays.

Axial Coding for Interview #8:

Table A.7c: Categories and subcategories for interview #8 *(axial coding)*

Category *(Relating Concept)*	Subcategory		
	Eng. Design Issues	**Eng. Schedule Issues**	**Changes after IFC**
Insufficient Time		*(C8-1)*	
Knowledge and Experience	*(C8-20)*	*(C8-20) (C8-19)*	*(C8-19)*
Stakeholder Engagement		*(C8-13) (C8-16) (C8-18)*	*(C8-25)*
Communication	*(C8-10) (C8-23) (C8-26)*	*(C8-21)*	*(C8-23)(C8-26) (C8-12)*
Design Strategies		*(C8-14) (C8-16)*	*(C8-14)*
Client-Contractor Collaboration		*(C8-7)*	*(C8-24)*
Resource Planning		*(C8-3) (C8-4)*	
Unavailable/Incomplete Information		*(C8-15)(C8-5)(C8-6) (C8-8) (C8-11)*	*(C8-22)*
Alignment/Coordination		*(C8-2) (C8-16) (C8-17)*	*(C8-9)*

A8. Interview #9

Interview #9			
Participant Code: **FK**	*Position:* **Business Development Manager**	*Years of Experience:* **14**	*Org. type:* **EPC**

Table A.8a: Identifying and numbering concepts for interview #9 *(open coding)*

Code No.	Concepts
C9-1	*Client doing proper VE at DBM to avoid design scope change during EPC*
C9-2	*Stakeholders engagement by client in DBM*
C9-3	*Regulatory or permitting requirements that were not detected earlier*
C9-4	*Scope change because of unavailability of data/material down the road*
C9-5	*Unavailable third party (vendor) information*
C9-6	*Lack of good planner understanding EPC relationship*
C9-7	*Refer to lessons learned to produce better plan*
C9-8	*Human factor*
C9-9	*Proper interfaces among disciplines*
C9-10	*Disciplines don't talk to each other*
C9-11	*Even major changes, if communicated in time can be handled better*
C9-12	*The one thing to improve is communication between disciplines*
C9-13	*Apply over design as a strategy*
C9-14	*Standardization of design. Modular design*

Table A.8b: Grouping concepts for interview #9

Discussion	Category/Concept	
Minimizing Scope Change	*C9-1*	*Client doing proper VE at DBM to avoid design scope change during EPC*
	C9-2	*Stakeholders engagement by client in DBM*
	C9-3	*Regulatory or permitting requirements that were not detected earlier*
	C9-11	*Even major changes, if communicated in time can be handled better*
	C9-4	*Scope change because of unavailability of data/material down the road*
	C9-5	*Unavailable third party (vendor) information*
	C9-9	*Proper interfaces among disciplines*
	C9-10	*Disciplines don't talk to each other*
	C9-12	*The one thing to improve is communication between disciplines*
	C9-13	*Apply over design as a strategy*
	C9-14	*Standardization of design. Modular design*
Design Issues	*C9-9*	*Proper interfaces among disciplines*
	C9-10	*Disciplines don't talk to each other*
	C9-12	*The one thing to improve is communication between disciplines*
	C9-14	*Standardization of design. Modular design*
Reducing Scheduling Delay	*C9-6*	*Lack of good planner understanding EPC relationship*
	C9-7	*Refer to lessons learned to produce better plan*
	C9-8	*Human factor*
	C9-9	*Proper interfaces among disciplines*
	C9-10	*Disciplines don't talk to each other*
	C9-12	*The one thing to improve is communication between disciplines*

Memo 9-1

Majority of the opinions of the participant of this interview addressed factors such as engagement of the stakeholders in early stages, alignment and coordination of planners and engineering disciplines, as well is engineering disciplines with each other, timely communication of key elements like scope changes, and unavailability of information at the right time, which was also mentioned in previous interviews. One new concept, however, was discussed which is the possibility of not detecting required regulatory permits that may delay almost every aspect of the project down the road. Obtaining regulatory permit is a very time-consuming process performed during FEL/FEED phase which involves dealing with governmental, non-governmental, or environmental organizations, who normally have no interest or ties with the project goals. A good relationship (e.g. membership and other participations within those organizations) as well as effective line of communication with systematic follow-up mechanism in place will reduce the lead time for getting those types of permits.

Axial Coding for Interview #9:

Table A.8c: Categories and subcategories for interview #9 *(axial coding)*

Category *(Relating Concept)*	Subcategory		
	Eng. Design Issues	**Eng. Schedule Issues**	**Changes after IFC**
Scope Definition/Understanding			*(C9-1)*
Knowledge and Experience		*(C9-6) (C9-8)*	
Stakeholder Engagement			*(C9-2)*
Communication	*(C9-9)(C9-10) (C9-12) (C9-9)*	*(C9-7) (C9-8) (C9-10) (C9-12)*	*(C9-11) (C9-9) (C9-10) (C9-12)*
Design Strategies			*(C9-13) (C9-14)*
Unavailable/Incomplete Information			*(C9-2)(C9-3) (C9-4) (C9-5)*

A.9 Interview #10

Interview #10			
Participant Code: **ET**	*Position:* **Senior Project Manager**	*Years of Experience:* **30**	*Org. type:* **EPC**

Table A.9a: Identifying and numbering concepts for interview #10 *(open coding)*

Code No.	Concepts
C10-1	*In reimbursable projects clients do not define scope clearly (in vivo)*
C10-2	*Unclear scopes delays procurement especially ling lead items*
C10-3	*Some of the FEED being done in the design phase (in vivo)*
C10-4	*What we are buying from vendor should be known in FEED not in detailed design phase*
C10-5	*Client does not know what it wants until after seeing the result (in vivo)*
C10-6	*Operation normally don't understand the drawings (sometimes not even the 3d model)*
C10-7	*Lack of (construction) experience in engineering contractor*
C10-8	*Knowledge of the operation is also needed in the design phase*
C10-9	*Client should involve operation in the design review*
C10-10	*Involve the client as much as possible in the design phase for decision making, design review and the like.*
C10-11	*Schedule delay may be due to improper planning in the engineering side*
C10-12	*To deal with short schedules you have to have very experienced people (in vivo)*
C10-13	*"Overdesign" and "flexible design" strategy to cover uncertainty*
C10-14	*Resource planning is another major cause of engineering delay*
C10-15	*Good planer –which is difficult to find- is essential for a good plan (in vivo)*
C10-16	*Input from other disciplines should be complete at the time of planning*
C10-17	*Send engineering to field for a couple of years*

Table A.9b: Grouping concepts for interview #10

Discussion	Category/Concept	
Scope Change	*C10-1*	*In reimbursable projects clients do not define scope clearly (in vivo)*
	C10-3	*Some of the FEED being done in the design phase (in vivo)*
	C10-4	*What we are buying from vendor should be known in FEED not in detailed design phase*
Design Issues	*C10-17*	*Send engineering to field for a couple of years*
Minimizing Design Change	*C10-5*	*Client does not know what it wants until after seeing the result (in vivo)*
	C10-6	*Operation normally don't understand the drawings (sometimes not even the 3d model)*
	C10-7	*Lack of (construction) experience in engineering contractor*
	C10-8	*Knowledge of the operation is also needed in the design phase*
	C10-9	*Client should involve operation in the design review*
	C10-10	*Involve the client as much as possible in the design phase for decision making, design review and the like.*
	C10-13	*"Overdesign" and "flexible design" strategy to cover uncertainty*
Reducing Scheduling Delay	*C10-2*	*Unclear scopes delays procurement especially ling lead items*
	C10-11	*Schedule delay may be due to improper planning in the engineering side*
	C10-12	*To deal with short schedules you have to have very experienced people (in vivo)*
	C10-14	*Resource planning is another major cause of engineering delay*
	C10-15	*Good planer –which is difficult to find- is essential for a good plan (in vivo)*
	C10-16	*Input from other disciplines should be complete at the time of planning*

Memo 10-1

One observation over the course of this research is that the contractors are complaining that the clients do not define the scope clearly, and the clients, on the other, hand are saying that the contractors do not understand the scope clearly. Depending on the certain project context, e.g. contractual arrangement, those statements may be valid to some extent. For example, as per the participant, in cost-reimbursable projects, the owners don't find it necessary to invest time and money to define the scope as clear as possible, because they already acknowledge that the lack of precise scope definitions would not be a risk for potential bidders, and the client would clarify the scope as the project goes on. So we can see in those types of contract that sometimes the FEED is not completed until after EPC has long been started. This approach, although may get the detailed design phase to the start point very quickly, it may contribute to faulty planning, numerous design changes down the road and schedule delays for engineering deliverables. For example, if what that is going to be purchased from vendors are not known in FEED, it will be source of huge rework and changes during the detailed design phase.

Memo 10-2

The scope definition approach taken by clients in reimbursable contracts, discussed in Memo 10-1, can be so extreme (again, considering other project context) that the client may not be able to make decision (define the scope) until after seeing the result. An effective strategy in this case (and also in any other situations where the risk of unclear scope exists) would be to involve the client in design decisions before design finalization and contribution to IFC deliverables. The involvement of client would also mean having more interactive role in the design review and control as well

As mentioned, this strategy can generally benefit the projects irrespective of what level of scope detail has been provided by client in different types of pricing arrangement. Involvement of client in the design decisions will improve engineering schedule, reduce the risk of major scope changes as well as changes after IFC, and improved design maturity.

This memo stands out in that it highlights the importance of the presence of stakeholders upstream to the engineering during the design phase.

Memo 10-3

The level of completeness of scope was discussed in the previous memo. One impact of unclear scope is delaying the procurement of long-lead items within equipment. Procurement of long lead items burden huge risks on project schedule and normally is a major project bottleneck. Other than clear scope, clear input from other engineering disciplines is another key factor for a robust schedule that reduce the potentials for delays in engineering deliverables.

Even with adequate planning information in place, improper planning in the engineering side due to lack of experienced planner can eventually result in schedule delays in engineering. A good planner have better understanding of the engineering process, can foresee possible risks and bottlenecks, knows the relationship of engineering activates, has better judgment of the quoted durations and lead times, and can make more realistic assumption in case of inadequacy of the information at hand. In the absence of experienced planner, the responsibility of engineering management, as well as engineering disciplines in ensuring that accurate and adequate information is communicated to the planer, is more highlighted.

In general, lack of relevant experience in project team can deteriorate all issues in engineering deliverables. The problem may detected in variety of disciplines including inexperienced planners as discussed above, engineering team without construction experience, and operation/maintenance team without capabilities to understand engineering. An effective strategy to mitigate the impact of insufficient experience among the team is to first identify the week points i.e. the disciplines which suffer from this deficiency, and then focus on enhancing or emphasizing communication lines to that discipline to compensate the corresponding shortcoming. For example, in case the construction experience is missing in engineering teams, one strategic long-term solution for organizations would be sending engineers to site for few years and then mobilizing them back in the engineering offices. However, at project level, the strategy should be improving communication with sources of construction knowledge one way or another. Similar strategy can be applied for lack of experience in commissioning, operation, and maintenance.

Axial Coding for Interview #10:

Table A.9c: Categories and subcategories for interview #10 *(axial coding)*

Category *(Relating Concept)*	Subcategory		
	Eng. Design Issues	**Eng. Schedule Issues**	**Changes after IFC**
Scope Definition/Understanding		*(C10-2)*	*(C10-1) (C10-4) (C10-5)*
Unavailable/Incomplete Information		*(C10-16)*	*(C10-3)*
Knowledge and Experience	*(C10-17)*	*(C10-11) (C10-12) (C10-15)*	*(C10-6) (C10-7) (C10-8)*
Stakeholder Engagement			*(C10-9) (C10-10)*
Design Strategies			*(C10-13)*
Resource Planning		*(C10-14)*	

A10. Interview #11

Interview #11			
Participant Code: **JL**	*Position:* **Senior Project Engineer**	*Years of Experience:* **29**	*Org. type:* **Owner**

Table A.10a: Identifying and numbering concepts for interview #11 *(open coding)*

Code No.	Concepts
C11-1	*Price arrangement has impact on schedule delays*
C11-2	*Poor planning in contractor side, inexperienced planners*
C11-3	*Not adequate staffing for planning department*
C11-4	*Delays because scope not well defined or not well understood*
C11-5	*Company standards are subjected to interpretation*
C11-6	*Suggest meetings to see if everybody understands the scope of work*
C11-7	*We don't give the contractor a lot of time for engineering (in vivo)*
C11-8	*Engineering, most of the time, is squeezed a lot (in vivo)*
C11-9	*Contractor would have to rush issuing deliverables because they are running against time (in vivo)*
C11-10	*Contractor needs to resource properly*
C11-11	*Lump-sum contract comes in the way of adequate resourcing*
C11-12	*Owners are open to contractors criticism about the schedule in the bidding phase*
C11-13	*Schedule delays due to inefficient internal processes (client and contractor) e.g. review and squad check process, QA process, etc.*
C11-14	*Schedule delay due to lack of control over vendor work (dependence on vendor timing) (in vivo)*
C11-15	*It is unlikely to be able to engage vendor in FEED unless you pay them*
C11-16	*IFCs are changed because of omission of vendor information*
C11-17	*IFCs are changed mostly at construction site not during the design*
C11-18	*The problem with 3d model review is that at the time the model is not complete. Not everything is modeled (including vendor package)*
C11-19	*The level of detail in the drawings is more in reimbursable contracts compared to lump-sum, and they are more reliable (in vivo)*
C11-20	*In lump-sum contracts, they issue the drawing and transfer the problem to construction (in vivo)*
C11-21	*More omissions and errors in engineering drawings in lump-sum contracts*
C11-22	*Operation and maintenance people should be involved in 3D model review*
C11-23	*The real client is the operation section*
C11-24	*The first thing to improve (for design issues) is communication (in vivo)*
C11-25	*Disciplines don't communicate changes with impacted disciplines*
C11-26	*RACI charts and document review matrix are not functional (in vivo)*
C11-27	*It takes lot of time for new hires to get to know the system, which causes some issues (Rotation of people)*
C11-28	*Minimum expectation for IFA content should be defined*
C11-29	*Owners should also communicate design decisions with operation*
C11-30	*You need to bring operation and maintenance onboard to freeze the plot plan (in vivo)*
C11-31	*Even bringing people form Asset Integrity can benefit the project*
C11-32	*It is both owner side, and contractor side. They should be one solid team*
C11-33	*Projects that have disciplines in remote or different locations*
C11-34	*Drawings should leave no room for inquiry of clarification to the end user*

Table A.10b: Grouping concepts for interview #11

Discussion	Category/Concept	
Insufficient Information	*C11-15*	*It is unlikely to be able to engage vendor in FEED unless you pay them*
Unrealistic Schedule	*C11-12*	*Owners are open to contractors criticism about the schedule in the bidding phase*
	C11-15	*It is unlikely to be able to engage vendor in FEED unless you pay them*
Design Issues	*C11-5*	*Company standards are subjected to interpretation*
	C11-8	*Engineering, most of the time, is squeezed a lot (in vivo)*
	C11-9	*Contractor would have to rush issuing deliverables because they are running against time (in vivo)*
	C11-18	*The problem with 3D model review is that at the time the model is not complete. Not everything is modeled (including vendor package)*
	C11-20	*In lump-sum contracts, they issue the drawing and transfer the problem to construction (in vivo)*
	C11-21	*More omissions and errors in engineering drawings in lump-sum contracts*
	C11-24	*The first thing to improve (for design issues) is communication*
	C11-25	*Disciplines don't communicate changes with impacted disciplines*
	C11-26	*RACI charts and document review matrix are not functional (in vivo)*
	C11-33	*Projects that have disciplines in remote or different locations*
	C11-34	*Drawings should leave no room for inquiry of clarification to the end user*
Minimizing Design Change	*C11-5*	*Company standards are subjected to interpretation*
	C11-15	*It is unlikely to be able to engage vendor in FEED unless you pay them*
	C11-16	*IFCs are changed because of omission of vendor information*
	C11-17	*IFCs are changed mostly at construction site not during the design*
	C11-18	*The problem with 3d model review is that at the time the model is not complete. Not everything is modeled (including vendor package)*
	C11-19	*The level of detail in the drawings is more in reimbursable contracts compared to lump-sum, and they are more reliable*
	C11-20	*In lump-sum contracts, they issue the drawing and transfer the problem to construction (in vivo)*
	C11-22	*Operation and maintenance people should be involved in 3D model review*
	C11-23	*The real client is the operation section*
	C11-28	*Minimum expectation for IFA content should be defined*
	C11-29	*Owners should also communicate design decisions with operation*
	C11-30	*You need to bring operation and maintenance onboard to freeze the plot plan*
	C11-31	*Even bringing people form Asset Integrity can benefit the project*
	C11-32	*It is both owner side, and contractor side. They should be one solid team*
	C11-33	*Projects that have disciplines in remote or different locations*

	C11-34	*Drawings should leave no room for inquiry of clarification to the end user*
Reasons of Scheduling Delay	*C11-1*	*Price arrangement has impact on schedule delays*
	C11-2	*Poor planning in contractor side, inexperienced planners*
	C11-3	*Not adequate staffing for planning department*
	C11-4	*Delays because scope not well defined or not well understood*
	C11-5	*Company standards are subjected to interpretation*
	C11-6	*Suggest meetings to see if everybody understands the scope of work*
	C11-7	*We don't give the contractor a lot of time for engineering (in vivo)*
	C11-8	*Engineering, most of the time, is squeezed a lot (in vivo)*
	C11-9	*Contractor would have to rush issuing deliverables because they are running against time (in vivo)*
	C11-10	*Contractor needs to resource properly*
	C11-11	*Lump-sum contract comes in the way of adequate resourcing*
	C11-13	*Schedule delays due to inefficient internal processes (client and contractor)*
	C11-14	*Schedule delay due to lack of control over vendor work (dependence on vendor timing) (in vivo)*
	C11-25	*Disciplines don't communicate changes with impacted disciplines*
	C11-27	*It takes lot of time for new hires to get to know the system, which causes some issues (Rotation of people)*
	C11-32	*It is both owner side, and contractor side. They should be one solid team*
	C11-33	*Projects that have disciplines in remote or different locations*

Memo 11-1

Engaging stakeholders in early stages of the project where client is doing most of the job (e.g. FELL phases) has it is own challenges. This is the time where hardly any contractual relationship exists between the client and any other project entity. Some sort of contract e.g. a master agreement, or alliance supplier relationship may be beneficial in this kind of situations. In any case, availability of such information (e.g. vendor data) was again emphasised in order to have a realistic schedule. Lack of control over vendor work and timing is a major contributor to schedule delays for engineering deliverables (similar concerns discussed in interviews 5 and 8; categories C5-23 and C8-10). Therefore proper risk management should be in place at the time of finalizing the details with the selected vendor. One mitigation strategy, though, can be establishing more effective communication all through the time during vendors' design and fabrication stage, to obtain regular updates and implement those updates into risk response plan.

Memo 11-2

A not-well-defined scope is also a source of schedule delays as well as design issues. Understanding the scope by the contractor may be compromised when the client design specifications is subjected to interpretation. This is a classic example of not understanding the scope by the contractor due to inadequate quality of communication. This issue was also addressed in previous interviews.

Memo 11-3

Insufficient time allocated for engineering, which may result in rushing design activities has adverse impact on the design. As discussed in the previous interviews, a good resource planning can alleviate the impact of squeezed schedule. However, some project context, pricing arrangement for example, might come in the way of proper resource planning. With lump-sum contracts, issues with resource planning are more than in reimbursable contracts. Therefore, eventually more design issues such as errors and omissions can be detected in lump-sum contacts. Additionally, the level of detail in the drawings are lower (more detailed) in reimbursable contracts compared to lump-sum contracts. Poor staffing in combination of squeezed schedule can result in incomplete vital deliverables such as 3D models. Which do not contain key elements such as vendor package, secondary steel for cable racks, heat tracing panels, and the like.

Enhancing communication within engineering discipline has been said to have great impact in achieving mature design deliverables. This can be more highlighted in cases where design disciplines are located in different or remote locations. Multi-operating centre project are subjected to big risks of misunderstanding the divisions of responsibilities, misinterpreting the design specs, and other similar issues due to poor quality communication. The ultimate goal in enhancing design issues is that the final drawing does not have any room for inquiry at the time of construction.

Memo 11-4

Clarity of expectation is another term to describe understanding the scope. One major reason for document changes after IFC is that the completeness of the information and thoroughness of review process in earlier revisions are taken for granted. For example the IFA revisions are carelessly issued and reviewed, assuming that at the time of IFC it would be more complete and worth of more attention at that time! A good strategy to tackle this issue is that the minimum expectation in terms of levels of details, reliability of design input, and degree of completeness should be defined by clients to prevent earlier issuance of document without adding value to contribute to the progress.

A point worth noticing mentioned here was addressing the operation team as the real owner (i.e. customer /end-user) of the project, which emphasises the necessity of engagement of operation team in various stages of the design.

Axial Coding for Interview #11:

Table A.10c: Categories and subcategories for interview #*11 (axial coding)*

Category *(Relating Concept)*	Subcategory		
	Eng. Design Issues	**Eng. Schedule Issues**	**Changes after IFC**
Scope Definition/Understanding	*(C11-5)*	*(C11-4) (C11-5)*	*(C11-5)*
Insufficient Time	*(C11-7) (C11-8) (C11-9) (C11-26)*	*(C11-7) (C11-8) (C11-9)*	*(C11-17)*
Knowledge and Experience		*(C11-2) (C11-13) (C11-27)*	
Stakeholder Engagement		*(C11-15)*	*(C11-15) (C11-22) (C11-23) (C11-29) (C11-30) (C11-31)*
Communication	*(C11-24) (C11-25) (C11-33)*	*(C11-6) (C11-25) (C11-33)*	*(C11-33)*
Design Strategies	*(C11-20)*		*(C11-28)*
Client-Contractor Collaboration		*(C11-12) (C11-32)*	*(C11-32)*
Resource Planning		*(C11-3) (C11-10)*	
Unavailable/Incomplete Information	*(C11-18) (C11-34)*	*(C11-14)*	*(C11-16) (C11-18) (C11-34)*
Alignment/Coordination			
Project Context	*(C11-20) (C11-21)*	*(C11-1) (C11-11) (C11-13)*	*(C11-19) (C11-20)*
Other			

A11. Interview #12

Interview #12			
Participant Code: **AF**	*Position:* **Project Engineer**	*Years of Experience:* **15**	*Org. type:* **Owner**

Table A.11a: Identifying and numbering concepts for interview #12 *(open coding)*

Code No.	Concepts
C12-1	*Contracting strategy has impact on engineering schedule performance*
C12-2	*Integration between vendor information availability and engineering at the early stages of the project*
C12-3	*Issuing "IFC at Risk" (in vivo)*
C12-4	*The schedule is done by planners from EP contractor and C is not involved*
C12-5	*Even construction advisor (used in these cases) are not involved early*
C12-6	*"Buying vendor information" (in vivo)*
C12-7	*Weekly informal model reviews (in vivo) to improve communication among disciplines*
C12-8	*A threshold for cost saving, below which no change is acceptable*
C12-9	*Changes for cost savings happen when there is not enough information at FEL1 and FEL2 phases*
C12-10	*Lack of communication between disciplines is a major for IFC changes*
C12-11	*Clients consider a bit of contingency for the schedule that is assigned to contractor*
C12-12	*"We know they are not going to make it" (in vivo)*
C12-13	*Involving of construction and operation in model reviews*

Table A.11b: Grouping concepts for interview #12

Discussion	Category/Concept	
Design Issues	*C12-13*	*Involving of construction and operation in model reviews*
	C12-7	*Weekly informal model reviews (in vivo) to improve communication among disciplines*
Mini**mizing Design Change**	*C12-8*	*A threshold for cost saving, below which no change is acceptable*
	C12-9	*Changes for cost savings happen when there is not enough information at FEL1 and FEL2 phases*
	C12-10	*Lack of communication between disciplines is a major for IFC changes*
	C12-6	*"Buying vendor information" (in vivo)*
	C12-3	*Issuing "IFC at Risk" (in vivo)*
Unrealistic Schedule	*C12-11*	*Clients consider a bit of contingency for the schedule that is assigned to contractor*
	C12-12	*"We know they are not going to make it" (in vivo)*
	C12-4	*The schedule is done by planners from EP contractor and C is not involved*
	C12-5	*Even construction advisor (used in these cases) are not involved early*

Reducing Scheduling Delay	*C12-1*	*Contracting strategy has impact on engineering schedule performance*
	C12-2	*Integration between vendor information availability and engineering at the early stages of the project*
	C12-6	*"Buying vendor information" (in vivo)*

Memo 12-1

Insufficient information, especially vendor data was highlighted in this interview. It was also acknowledge that there should be some sort of contractual binding to be able to "buy" vendor data. What was highlighted in this interview in terms of unavailable vendor data is that the engineering should be integrated with procurement considering the fact of unavailability of vendor data. This means that the engineering and the procurement should work closely to follow up on the engineering needs and interactively get status updates from vendor and implement in engineering workflow. **Memo 12-2**

The impact of contracting strategy on different aspect of engineering deliverable issues has already been discussed. However, what can be deduced from this interview is the strategy to take to compensate the shortcoming of a given contracting strategy. The Interviewee's company of interest uses more EP &C rather than EPC types of contracts, where the construction is performed by a separate entity and comes in the paly later in the project. However, acknowledging the necessity of the engagement of stakeholders, this company has adopted strategies and official procedures to benefit from additional communication to the missing parties. For example the concept of issuing "IFC at Risk" to get the drawings to construction earlier as needed, or consultation with a construction company at early stages where only the EP company is officially involved. Therefore we can conclude that if some aspect of the project, context has is unfavorable in terms of having negative impact on engineering deliverables issues, we can improve the situation by enhancing communication around/within those weaker aspects of project context.

Another example discussed earlier in the Interview #10 (see Memo 10-3) was the impact of lack of enough experience within project team.

Memo 12-3

The participant indicated that most of the times clients would know that the schedule is not practical and the contractors are not going to meet the schedule, and hence they consider a contingency without revealing it to the contractor. This approach does not appear to be of a healthy client-contractor relationship. More collaboration will yield better results.

Axial Coding for Interview #12:

Table A.11c: Categories and subcategories for interview #12 *(axial coding)*

Category	Subcategory		
(Relating Concept)	**Eng. Design Issues**	**Eng. Schedule Issues**	**Changes after IFC**
Scope Definition/Understanding	*(C12-13)*		*(C12-9)*
Insufficient Time		*(C12-11)*	
Knowledge and Experience			
Stakeholder Engagement		*(C12-4) (C12-5) (C12-6)*	*(C12-6)*
Communication	*(C12-7)*		*(C12-10)*
Design Strategies			*(C12-3) (C12-8)*
Client-Contractor Collaboration		*(C12-12)*	
Resource Planning			
Unavailable/Incomplete Information			
Alignment/Coordination		*(C12-2)*	
Project Context		*(C12-1)*	

A12. Interview #13

Interview #13			
Participant Code: **GL**	*Position:* **Senior Civil Engineer**	*Years of Experience:* **36**	*Org. type:* **EPC**

Table A.12a: Identifying and numbering concepts for interview #13 *(open coding)*

Code No.	Concepts
C13-1	*Poor scope definition at the beginning cause engineering delays*
C13-2	*Schedule should be based on a clearly understood scope*
C13-3	*Not enough man-power*
C13-4	*Experience level of the engineering team. Not field experience*
C13-5	*Mentoring and site tours for less experienced engineers*
C13-6	*We use information from previous projects when vendor data is not available*
C13-7	*The client won't change the deadlines for engineering even if the start is delayed for any reason (e.g. permitting)*
C13-8	*Some clients take risks to allow some money to start engineering without official approval of the phase gate*
C13-9	*Integrated master schedule by all disciplines*
C13-10	*Regular progress meetings*
C13-11	*Someone should take care of interdisciplinary supporting information*
C13-12	*Improving constructability greatly impacts the number of changes after IFC*
C13-13	*Complete perspective of construction and operation needs to be there*
C13-14	*IFC based on incomplete information – e.g. working with a third party*
C13-15	*Deficiency list to manage IFC-with-hold (in vivo)*
C13-16	*Good interface meetings to exchange data*
C13-17	*Battery limit information clearly defined (in vivo)*
C13-18	*Cold eyes review before IFC (in vivo)*
C13-19	*Sometimes people don't want to go and consult with someone else*

Table A.12b: Grouping concepts for interview #13

Discussion	Category/Concept	
Design Issues	*C13-4*	*Experience level of the engineering team. Not field experience*
	C13-5	*Mentoring and site tours for less experienced engineers*
	C13-11	*Someone should take care of interdisciplinary supporting information*
	C13-18	*Cold eyes review before IFC (in vivo)*
	C13-19	*Sometimes people don't want to go and consult with someone else*
Mini**mizing Design Change**	*C13-12*	*Improving constructability greatly impacts the number of changes after IFC*
	C13-13	*Complete perspective of construction and operation needs to be there*
	C13-14	*IFC based on incomplete information – e.g. working with a third party*
	C13-15	*Deficiency list to manage IFC-with-hold (in vivo)*
	C13-16	*Good interface meetings to exchange data*
	C13-17	*Battery limit information clearly defined (in vivo)*
Unrealistic Schedule	*C13-7*	*The client won't change the deadlines for engineering even if the start is delayed for any reason (e.g. permitting)*
	C13-8	*Some clients take risks to allow some money to start engineering without official approval of the phase gate*
Reducing Scheduling Delay	*C13-1*	*Poor scope definition at the beginning cause engineering delays*
	C13-2	*Schedule should be based on a clearly understood scope*
	C13-3	*Not enough man-power*
	C13-4	*Experience level of the engineering team. Not field experience*
	C13-6	*We use information from previous projects when vendor data is not available*
	C13-9	*Integrated master schedule by all disciplines*
	C13-10	*Regular progress meetings*
	C13-11	*Someone should take care of interdisciplinary supporting information*

Memo 13-1

Insufficient experience combined with individual's reluctance to consult with more knowledgeable members of the team was also mentioned by the participants in the Interview#7 (C7-18) and Interview#10 (C10-7). As discussed in Memo 12-2 focusing on enhancing communication in and around week points can be considered. Lack of construction experience in engineering team, for example, will require better communication with construction team, involving them in engineering design and design reviews, and the like.

Memo 13-2

Following up of actions in different engineering activities seems to have impact on reducing engineering deliverables issues. A "deficiency list" is document generated to manage and follow up those deliverables that are issued IFC with "hold" items. IFC documents that have "hold" items on them are major source of engineering errors inconsistency, and constructability issues, as well as schedule delay for engineering and construction. Here, the deficiency list is a documents that communicates missing information to the rest of the team in a systematic and manageable fashion. Another common problem that needs more attention in terms of systematic follow-up is the interdisciplinary supporting information. Those information are in the form of (sometime unofficial) documents that are not considered as project documents and hence don't have official deadline in the project schedule. A systematic method should be in place to ensure those information are timely provided among the disciplines.

Axial Coding for Interview #13:

Table A.12c: Categories and subcategories for interview #13 *(axial coding)*

Category *(Relating Concept)*	Subcategory		
	Eng. Design Issues	**Eng. Schedule Issues**	**Changes after IFC**
Scope Definition/Understanding		*(C13-1) (C13-2)*	*(C13-17)*
Insufficient Time		*(C13-7)*	
Knowledge and Experience	*(C13-4) (C13-5)*	*(C13-4)*	
Stakeholder Engagement	*(C13-5)*		*(C13-12) (C13-13)*
Communication	*(C13-11) (C13-18) (C13-19)*	*(C13-10) (C13-11)*	*(C13-15) (C13-16)*
Design Strategies			
Client-Contractor Collaboration			
Resource Planning		*(C13-3)*	
Unavailable/Incomplete Information		*(C13-6)*	*(C13-14)*
Alignment/Coordination		*(C13-9)*	
Project Context		*(C13-8)*	

A13. Interview #14

Interview #14			
Participant Code: **GO**	*Position:* **Project Engineering Manager**	*Years of Experience:* **35**	*Org. type:* **Owner**

Table A.13a: Identifying and numbering concepts for interview #14 *(open coding)*

Code No.	Concepts
C14-1	*Delay in vendor information is the biggest issues in engineering schedule*
C14-2	*Rush and emergency in schedule, guesses, estimates, …*
C14-3	*Big discrepancies when you receive information*
C14-4	*Vendor changing their design at the very late stages*
C14-5	*Design should be based on final approved vendor information*
C14-6	*No contractor is forced to sign the contract! (in vivo)*
C14-7	*They (contractors) should voice it if the schedule doesn't look realistic*
C14-8	*Pay for vendor's engineering in the EDS*
C14-9	*Process design is almost 80% complete by the time of EDS*
C14-10	*Full involvement of construction, operation, and maintenance in 3D model reviews*
C14-11	*Latest vendor information might contradict with what is there in the model*
C14-12	*Overdesign as a strategy to tackle uncertainty*
C14-13	*Client-contractor collaboration another way to deal with uncertainty*
C14-14	*Hand-pick engineering team as much as possible*
C14-15	*Leadership skills, communication skills, ownership (in vivo)*
C14-16	*Working as team is major component to success –client, contractor, …*
C14-17	*Email is the worst type of communication. Talk to each other*

Table A.13b: Grouping concepts for interview #14

Discussion	Category/Concept	
Design Issues	*C14-3*	*Big discrepancies when you receive information*
	C14-5	*Design should be based on final approved vendor information*
	C14-8	*Pay for vendor's engineering in the EDS*
	C14-9	*Process design is almost 80% complete by the time of EDS*
	C14-10	*Full involvement of construction, operation, and maintenance in 3D model reviews*
	C14-14	*Hand-pick engineering team as much as possible*
	C14-15	*Leadership skills, communication skills, ownership (in vivo)*
	C14-17	*Email is the worst type of communication. Talk to each other*
	C14-16	*Working as team is major component to success –client, contractor, …*
Mini**mizing Design Change**	*C14-4*	*Vendor changing their design at the very late stages*
	C14-5	*Design should be based on final approved vendor information*
	C14-10	*Full involvement of construction, operation, and maintenance in 3D model reviews*
	C14-11	*Latest vendor information might contradict with what is there in the model*
Unrealistic Schedule	*C14-6*	*No contractor is forced to sign the contract! (in vivo)*
	C14-7	*They (contractors) should voice it if the schedule doesn't look realistic*
Reducing Scheduling Delay	*C14-1*	*Delay in vendor information is the biggest issues in engineering schedule*
	C14-2	*Rush and emergency in schedule, guesses, estimates, …*
	C14-3	*Big discrepancies when you receive information*
	C14-4	*Vendor changing their design at the very late stages*
	C14-8	*Pay for vendor's engineering in the EDS*
	C14-9	*Process design is almost 80% complete by the time of EDS*
	C14-16	*Working as team is major component to success –client, contractor, …*
Insufficient Information	*C14-12*	*Overdesign as a strategy to tackle uncertainty*
	C14-13	*Client-contractor collaboration another way to deal with uncertainty*

Memo 14-1

Unavailable vendor information for engineering designs has been discussed in almost every interview so far. In lieu of adequate information, the design is performed based on assumptions, catalogue information, information from previous projects, and the like. However, there is the risk of discrepancy of the final vendor data and what was assumed and used in the design, which needs to be addressed properly, because those discrepancies being revealed at later stages of the design, might burden considerable amount of design changes (even after IFC), and consequently schedule delays for engineering deliverable. Therefore, efforts should be made to be involved in the vendor design process, and not just waiting for the final vendor data and possible surprizes at upon receiving final vendor design. The new concept here is that not only vendor's involvement in different stages of the project is necessary (as discussed many times earlier), now we can deduce that the project engineering also needs to be involved in vendors design process from the beginning to the end.

Axial Coding for Interview #14:

Table A.13c: Categories and subcategories for interview #14 *(axial coding)*

Category *(Relating Concept)*	Subcategory		
	Eng. Design Issues	**Eng. Schedule Issues**	**Changes after IFC**
Scope Definition/Understanding			
Insufficient Time		*(C14-2)*	
Knowledge and Experience	*(C14-14)*		*(C14-10)*
Stakeholder Engagement	*(C14-10)*		
Communication	*(C14-15) (C14-17)*		
Design Strategies			*(C14-12)*
Client-Contractor Collaboration	*(C14-16)*	*(C14-6) (C14-7) (C14-16)*	*(C14-13)*
Resource Planning			
Unavailable/Incomplete Information	*(C14-5) (C14-8) (C14-9)*	*(C14-1) (C14-4) (C14-8) (C14-9)*	*(C14-4) (C14-5) (C14-11)*
Alignment/Coordination	*(C14-3)*	*(C14-3)*	
Project Context			

A14. Interview #15

Interview #15			
Participant Code: **ST**	*Position:* **Senior Project Engineer**	*Years of Experience:* **25**	*Org. type:* **Owner**

Table A.14a: Identifying and numbering concepts for interview #15 *(open coding)*

Code No.	Concept
C15-1	*We cannot avoid engineering delays but we can minimize that*
C15-2	*All the project stakeholders impact the schedule*
C15-3	*Sometime client delay in disclosing the information (delays the start)*
C15-4	*Then the vendor information maybe late*
C15-5	*Internal disciplines poor coordination delays the engineering*
C15-6	*Invite vendor inside the (contractor) organization to get involved*
C15-7	*You have to work with "budgetary price" level of information (in vivo)*
C15-8	*Discipline coordination is very important in output of design*
C15-9	*PM is responsible for integrity of the engineering is aligned within itself*
C15-10	*If you want to wait for complete information, you will impact schedule*
C15-11	*With lack of information you have to undergo some changes after IFC*
C15-12	*You can't hold an IFC drawing for say 5% incompleteness*

Table A.14b: Grouping concepts for interview #15

Discussion	Category/Concept	
Reducing Scheduling Delay	*C15-1*	*We cannot avoid engineering delays but we can minimize that*
	C15-2	*All the project stakeholders impact the schedule*
	C15-3	*Sometime clients delay in disclosing the information (delays the start)*
	C15-4	*Then the vendor information maybe late*
	C15-5	*Internal disciplines poor coordination delays the engineering*
Mini**mizing Design Change**	*C15-11*	*With lack of information you have to undergo some changes after IFC*
	C15-12	*You can't hold an IFC drawing for say 5% incompleteness*
Design Issues	*C15-8*	*Discipline coordination is very important in output of design*
	C15-9	*PM is responsible for integrity of the engineering and that it is aligned within itself*
Insufficient Information	*C15-6*	*Invite vendor inside (the contractor) organization to get involved*
	C15-7	*You have to work with "budgetary price" level of information (in vivo)*
	C15-10	*If you want to wait for complete information, you will impact schedule*

Memo 15-1

One approach for managing the project from contractor's point of view is to assume some aspect of engineering deliverables problems to be not only an accepted inevitable fact, but also even necessary. For example, IFC with "holds" may look inevitable due to lack of information at the time of IFC, but it also may be considered as a *planned* strategy to get construction going. For example contractors may argue that "you cannot hold an IFC for say 5% of incompleteness" However the goal is not to hold the document until that 5% is also complete. The ultimate goal in this case is to be able to take care of that 5% incompleteness in advance, and timely enough, so that at the time of IFC the design is complete.

Axial Coding for Interview #15:

Table A.14c: Categories and subcategories for interview #15 *(axial coding)*

Category *(Relating Concept)*	Subcategory		
	Eng. Design Issues	**Eng. Schedule Issues**	**Changes after IFC**
Scope Definition/Understanding			
Insufficient Time			
Knowledge and Experience			
Stakeholder Engagement	*(C15-6)*	*(C15-2)*	
Communication			
Design Strategies			
Client-Contractor Collaboration		*(C15-3)*	
Resource Planning			
Unavailable/Incomplete Information		*(C15-4) (C15-10) (C15-7)*	*(C15-11) (C15-12)*
Alignment/Coordination	*(C15-8) (C15-9)*	*(C15-5)*	
Project Context			
Other		*(C15-1)*	

A15. Interview #16

Interview #16			
Participant Code: **SD**	*Position:* **Project Manager**	*Years of Experience:* **20**	*Org. type:* **EPC**

Table A.15a: Identifying and numbering concepts for interview #16 *(open coding)*

Code No.	Concepts
C16-1	*Not enough money spend in FEED to select the best option*
C16-2	*Technology/vendor is not finalized in FEED and it is transferred to detailed design phase*
C16-3	*The FEED is so long that technology changes during the FEED*
C16-4	*New technology in one discipline not communicated with other disciplines*
C16-5	*"You are as good as your client" (in vivo)*
C16-6	*Client needs to understand what they want and how they are going to get it*
C16-7	*Lack of knowledge in client will be transferred to the engineering*
C16-8	*External stakeholders such as vendor*
C16-9	*In EDS, you have to put the best people you know on the project*
C16-10	*Use lessons-learned at the beginning of the project even before KOM*
C16-11	*Get together and talk about what may go wrong*
C16-12	*You need best knowledge in EDS and best transfer that knowledge to EPC*
C16-13	*Some constructability issues cannot be captured easily in model reviews* *e.g. the clearance required by piling machine to install piles*
C16-14	*Operation and maintenance people involve in model review*
C16-15	*Project management 101: Who are the stakeholders in every stage gate? (in vivo)*
C16-16	*Involve, communicate, and follow up*
C16-17	*Good leads and good PMs always have good communication*
C16-18	*Communication is critical when you are in conflict*
C16-19	*Lots of good leads but they are not good communicators*
C16-20	*Team building is great means to improve communication among team*

Table A.15b: Grouping concepts for interview #16

Discussion	Category/Concept	
Reducing Schedule Delays	*C16-2*	*Technology/vendor is not finalized in FEED and it is transferred to detailed design phase*
	C16-3	*The FEED is so long that technology changes during the FEED*
	C16-4	*New technology in one discipline not communicated with other disciplines*
	C16-5	*"You are as good as your client" (in vivo)*
	C16-6	*Client needs to understand what they want and how they are going to get it*
	C16-8	*External stakeholders such as vendor*
	C16-9	*In EDS, you have to put the best people you know on the project*
	C16-16	*Involve, communicate, and follow up*
	C16-17	*Good leads and good PMs always have good communication*
Minimizing Design Change	*C16-1*	*Not enough money spend in FEED to select the best option*
	C16-4	*New technology in one discipline not communicated with other disciplines*
	C16-8	*External stakeholders such as vendor*
	C16-13	*Some constructability issues cannot be captured easily in model reviews*
	C16-14	*Operation and maintenance people involve in model review*
	C16-15	*Project management 101: Who are the stakeholders in every stage gate? (in vivo)*
	C16-16	*Involve, communicate, and follow up*
Design Issues	*C16-5*	*"You are as good as your client" (in vivo)*
	C16-10	*Use lessons-learned at the beginning of the project even before KOM*
	C16-11	*Get together and talk about what may go wrong*
	C16-12	*You need best knowledge in EDS and best transfer that knowledge to EPC*
	C16-15	*Project management 101: Who are the stakeholders in every stage gate? (in vivo)*
	C16-16	*Involve, communicate, and follow up*
	C16-17	*Good leads and good PMs always have good communication*
	C16-18	*Communication is critical when you are in conflict*
	C16-19	*Lots of good leads but they are not good communicators*
	C16-20	*Team building is great means to improve communication among team*
Insufficient Information	*C16-6*	*Client needs to understand what they want and how they are going to get it*
	C16-7	*Lack of knowledge in client will be transferred to the engineering*
	C16-9	*In EDS, you have to put the best people you know on the project*
	C16-12	*You need best knowledge in EDS and best transfer that knowledge to EPC*

Memo 16-1

Adequacy of knowledge and experience among project team is more emphasized in FEED and especially EDS phase. This is where you would need experienced people at senior level with outstanding knowledge including project, technical, construction, and operation knowledge. Although it is often very difficult for organization to gather a pool of brains for one project at FEL, it should be considered that the higher the level of knowledge existing in project team, the less the problems and issues will be encountered during the next phases of the project including, of course, engineering and design phase.

An important point highlighted by the participant indicated that the best knowledge needed to deliver a successful l EDS phase, will have to be best transferred to next phase i.e. EDS. This is a curtail concept, especially in case where the contractor involved in EDS is not the same as in EPC, which is a common practice in oil industry projects. This knowledge transfer is possible through effective communication and smart involvement of the stakeholders during the transition between the two contractors. The transfer of knowledge lies mostly on the shoulders of clients. “You are as good as your client!”

Memo 16-2

Clarity of scope and its impact on engineering issues was discussed from a new perspective, and that is the new technologies introduced to the project during different phases of the project. New technologies may not be understood and finalized during FEED and it is transferred to detailed design phase. This lack of understanding when transferred to EPC may foster parallel engineering (also discussed in Interview #2) which is one major cause for scope changes and engineering delays. Care should be taken to allocate enough budget and time at FEEL to evaluate alternatives and finalize the technology by the end of EDS. On a different note, new technologies introduced to one discipline during detailed design phase may not be communicated properly with other disciplines as well, resulting in inconstancy in design and discrepancies in the engineering deliverables.

Memo 16-3

The participants emphasized the impact of communication in almost every topic that was discussed in this interview. One key skill required to be a good project manager, good project engineer, and good discipline lead was said to be maintaining good communication. The phrase "involve, communicate, and follow up" was remedy that the participant would prescribe for a wide range of engineering issues discussed in the interview. This included "*what to communicate*" (e.g. lessons learned, what can go wrong, new technologies, and scope), "*when to communicate*" (e.g. in FEED, at EDS transfer, during EPC), "how to communicate" (e.g. meetings, face to face, get together, etc.) and similar dimensions of communication.

Axial Coding for Interview #16:

Table A.15c: Categories and subcategories for interview #*16 (axial coding)*

Category *(Relating Concept)*	Subcategory		
	Eng. Design Issues	**Eng. Schedule Issues**	**Changes after IFC**
Scope Definition/Understanding		*(C16-1) (C16-2) (C16-3) (C16-6)*	
Insufficient Time			
Knowledge and Experience	*(C16-7)*	*(C16-9)*	
Stakeholder Engagement	*(C16-15)*	*(C16-8)*	*(C16-8) (C16-14) (C16-15)*
Communication	*(C16-10) (C16-11) (C16-12) (C16-16) (C16-17) (C16-18) (C16-19) (C16-20)*	*(C16-4) (C16-16) (C16-17)*	*(C16-4) (C16-16)*
Design Strategies			
Client-Contractor Collaboration	*(C16-5)*	*(C16-5)*	
Resource Planning			
Unavailable/Incomplete Information			*(C16-13)*
Alignment/Coordination			
Project Context			

A16. Interview #17

Interview #17			
Participant Code: **BS**	*Position:* **Project Controls Manager**	*Years of Experience:* **17**	*Org. type:* **Owner**

Table A.16a: Identifying and numbering concepts for interview #17 *(open coding)*

Code No.	Concepts
C17-1	*General: not enough emphasis on FEL activities*
C17-2	*Value engineering should be in earlier FEL not in EDS or even EPC*
C17-3	*Client set dates based on ununderstood scope (unrealistic schedule)*
C17-4	*Within engineering, communication problems between disciplines is major cause of engineering issues*
C17-5	*Engineering done overseas; delay, quality, etc. will suffer*
C17-6	*Training people overseas to get aligned with company*
C17-7	*Lack of alignment between project team in FEED phase*
C17-8	*At some point engineering should be frozen*
C17-9	*No changes except if the design is not safe, constructible, and to the code*
C17-10	*Mobilize people from commissioning and construction in engineering office*
C17-11	*IFC-with-hold should not be deemed as 100%*
C17-12	*Non-deliverables should also be included in engineering schedule*

Table A.16b: Grouping concepts for interview #17

Discussion	Category/Concept	
Reducing Scheduling Delay	*C17-1*	*General: not enough emphasis on FEL activities*
	C17-5	*Engineering done overseas; schedule, quality, etc. will suffer*
	C17-7	*Lack of alignment between project team in FEED phase*
	C17-12	*Non-deliverables should also be included in engineering schedule*
Minimizing Design Change	*C17-1*	*General: not enough emphasis on FEL activities*
	C17-2	*Value engineering should be in earlier FEL not in EDS or even EPC*
	C17-4	*Within engineering, communication problems between disciplines is major cause of engineering issues*
	C17-6	*Training people overseas to get aligned with company*
	C17-8	*At some point engineering should be frozen*
	C17-9	*No changes except if the design is not safe, constructible, and to the code*
	C17-10	*Mobilize people from commissioning and construction in engineering office*
	C17-11	*IFC-with-hold should not be deemed as 100%*
Design Issues	*C17-1*	*General: not enough emphasis on FEL activities*
	C17-5	*Engineering done overseas; schedule, quality, etc. will suffer*
	C17-6	*Training people overseas to get aligned with company*
	C17-7	*Lack of alignment between project team in FEED phase*
	C17-10	*Mobilize people from commissioning and construction in engineering office*
Unrealistic Schedule	*C17-3*	*Client set dates based on ununderstood scope (unrealistic schedule)*

Memo 17-1

Emphasis on FEL activities (which include FEED phase) was highlighted again by this participant. The importance of delivering a successful FEL phase lies on the fact that it leads to more clear scope definition, less uncertainties, and more reliability of project decisions. This in turn, will result in more reliable schedule, and fewer scope changes and design issues, and therefore has a positive impact on all the aspects of engineering deliverables issues under the current study. Additionally, performing a proper value engineering during FEL (also mentioned in the interview#1) to finalize the best alternative earlier in FEL rather than during EDS, mitigates the risk of drastic design scope changes down in the detailed design phase. On another note, lack of alignment between project team during the FEED can have impacts on detailed design phase in terms of causing more changes and design issues, as well as pour schedule definition leading to engineering delays.

Memo 17-2

One issue that was also mentioned in the interview #8 is performing the engineering work of an EPC project in overseas offices. It looks like that this strategy, which is mainly adopted for business reasons to reduce the cost of the projects performed in North America, is a major source of misalignment among the team, inconsistency of design, discrepancies in understanding scope, and other similar problems, that will have negative impact on design quality and engineering schedule performance. A high-level solution for that is to enhance and maintain high quality communication including clear line of communication and interface definition to correctly understand the division of responsibilities, list of deliverables, required quality of deliverables, applicable codes and standards, engineering input data required for design, project deadlines and other needs, and the like.

Memo 17-3

As also mentioned in the interview #17, understanding the scope by the client, in terms of what is the scope and what it takes to achieve the scope, is curtail for developing a realistic schedule. Otherwise, the schedule, which is based on ununderstood and unclear project scope, would be destined to fail.

Axial Coding for Interview #17:

Table A.16c: Categories and subcategories for interview #17 *(axial coding)*

Category *(Relating Concept)*	Subcategory		
	Eng. Design Issues	**Eng. Schedule Issues**	**Changes after IFC**
Scope Definition/Understanding		*(C17-3)*	*(C17-2) (C17-8)*
Insufficient Time			
Knowledge and Experience	*(C17-6)*		*(C17-6)*
Stakeholder Engagement	*(C17-10)*		*(C17-10)*
Communication	*(C17-4)(C17-5)*	*(C17-5)*	
Design Strategies			*(C17-9)*
Client-Contractor Collaboration			
Resource Planning			
Unavailable/Incomplete Information		*(C17-12)*	
Alignment/Coordination	*(C17-7)*	*(C17-7)*	
Project Context	*(C17-1)*	*(C17-1)*	*(C17-1) (C17-11)*
Other			

A17. Interview #18

Interview #18			
Participant Code: **MZ**	*Position:* **Senior Mechanical Engineer**	*Years of Experience:* **37**	*Org. type:* **EPC**

Table A.17a: Identifying and numbering concepts for interview #18 *(open coding)*

Code No.	Concepts
C18-1	*Major cause for design issue is rushing things*
C18-2	*Getting to construction fast is why not enough time allocated to engineering*
C18-3	*Not using highly qualified people in engineering to save on cost*
C18-4	*The whole process of engineering is communication (in vivo)*
C18-5	*Client communicating the scope to engineering*
C18-6	*Disciplines communicate on what the deliverables, tools, needs are. (in vivo)*
C18-7	*Final deliverable in engineering is communication (in vivo)*
C18-8	*You have to understand what client is looking for (in vivo)*
C18-9	*Specs in north America are the same around the world? (in vivo)*
C18-10	*Is the quality of material the same around the world? (in vivo)*
C18-11	*How much does the third party know about what goes in my test procedure (in vivo)*
C18-12	*I am designing a Toyota but you wanted a Cadillac (in vivo)*
C18-13	*90% of the problems we have in big projects is communication (in vivo)*
C18-14	*What do you mean by "fit for Purpose'?*
C18-15	*Blockers: You have a client and you have to make him satisfied*
C18-16	*Everybody (disciplines) should buy in the schedule*
C18-17	*Those who don't buy in will later say "I told you so"-human nature*
C18-18	*Communication again shows itself (in vivo)*
C18-19	*With sufficient time, most of the engineering issues will be removed*
C18-20	*Unrealistic schedule may or may not be fixed by more staffing*
C18-21	*IFC revisions: You are not telling me everything at the beginning*
C18-22	*Unavailability of information is a source of changes after IFC*
C18-23	*Quotes from vendors: I am asking for something that the guy doesn't have information about (lack of communication)*

Table A.17b: Grouping concepts for interview #18

Discussion	Category/Concept	
Reducing Scheduling Delay	*C18-20*	*Unrealistic schedule may or may not be fixed by more staffing*
	C18-16	*Everybody (disciplines) should buy in the schedule*
	C18-17	*Those who don't buy in will later say "I told you so"-human nature*
	C18-18	*Communication again shows itself (in vivo)*
	C18-13	*90% of the problems we have in big projects is communication (in vivo)*
Mini**mizing Design Change**	*C18-21*	*IFC revisions: You are not telling me everything at the beginning*
	C18-22	*Unavailability of information is a source of changes after IFC*
	C18-23	*Quotes from vendors: I am asking for something that the guy doesn't have information about (lack of communication)*
	C18-14	*What do you mean by "fit for Purpose'?*
	C18-15	*Blockers: You have a client and you have to make him satisfied*
	C18-12	*I am designing a Toyota but you wanted a Cadillac (in vivo)*
Design Issues	*C18-13*	*90% of the problems we have in big projects is communication (in vivo)*
	C18-8	*You have to understand what client is looking for (in vivo)*
	C18-9	*Specs in north America are the same around the world? (in vivo)*
	C18-10	*Is the quality of material the same around the world? (in vivo)*
	C18-11	*How much does the third party know about what goes in my test procedure (in vivo)*
	C18-1	*Major cause for design issue is rushing things*
	C18-2	*Getting to construction fast is why not enough time allocated to engineering*
	C18-3	*Not using highly qualified people in engineering to save on cost*
	C18-4	*The whole process of engineering is communication (in vivo)*
	C18-5	*Client communicating the scope to engineering*
	C18-6	*Disciplines communicate on what the deliverables, tools, needs are. (in vivo)*
	C18-7	*Final deliverable in engineering is communication (in vivo)*
	C18-19	*With sufficient time, most of the engineering issues will be removed*

Memo 18-1

The participant in this interview put a tremendous emphasis on the role of communication in delivering faultless engineering services within the projects. Except in few cases, almost all of the codes identified in this interview discuss something directly or indirectly related to communication during the early or detailed engineering phase of the project. I draw the reader's attention, for example, to two in-vivo codes C18-4 (The whole process of engineering is communication) and C18-13 (90% of the problems we have in big projects is communication).

Memo 18-2

Alignment in understanding of project scope, especially when dealing with overseas equipment vendors is achieved with effective communication to ensure technical specifications are exactly those that are required by the project. Similarly the alignment among the engineering disciplines is required to develop a schedule which has everybody's "buy-in", and facilitates smooth delivery for the engineering disciplines. This alignment also is achievable through enhancing inter-disciplinary communication that can facilitate effective exchange of reliable data, leading to more reliable schedule for engineering that everybody agrees upon.

Developing the same understanding of the scope between the client and the contractor is another example of alignment among relevant stakeholders which again can be enhanced by improving communication (e.g. the in-vivo code C18-12: I am designing a Toyota but you wanted a Cadillac, or the in-vivo code C18-14: What do you mean by "fit for purpose"?).

Memo 18-3

Among the items that do not directly point to communication are lack of adequate knowledge among the team and insufficient time allocated for engineering design. These issues have also been discussed in several interviews before this one. Insufficient time is told to be a major cause for design problems, and the main reason for not allocating enough time to engineering is to get to construction as fast as possible. However, as also discussed in previous interviews, owners are willing to listen to contractors educated rational if the schedule allocated for engineering is unrealistic. Again, maintaining a good relationship, together with open and timely communication and follow-up can go a long way in developing a reasonable schedule that both parties agree upon.

Axial Coding for Interview #18:

Table A.17c: Categories and subcategories for interview #18 *(axial coding)*

Category *(Relating Concept)*	Subcategory		
	Eng. Design Issues	**Eng. Schedule Issues**	**Changes after IFC**
Scope Definition/Understanding	*(C18-8)*		*(C18-14) (C18-12)*
Insufficient Time	*(C18-1) (C18-2) (C18-19)*		
Knowledge and Experience	*(C18-3)*		
Stakeholder Engagement			
Communication	*(C18-13) (C18-4) (C18-5) (C18-6) (C18-7)*	*(C18-18) (C18-13)*	*(C18-21)*
Design Strategies			
Client-Contractor Collaboration			
Resource Planning		*(C18-20)*	
Unavailable/Incomplete Information			*(C18-22) (C18-23)*
Alignment/Coordination	*(C18-9) (C18-10) (C18-11)*	*(C18-16) (C18-17)*	
Project Context			*(C18-15)*
Other			

A18. Interview #19

Interview #19			
Participant Code: **NR**	*Position:* **Senior Project Manager**	*Years of Experience:* **27**	*Org. type:* **EPC**

Table A.18a: Identifying and numbering concepts for interview #19 *(open coding)*

Code No.	Concepts
C19-1	*Disconnection between field and the office, lack of interaction*
C19-2	*Similar information from previous projects e.g. As-built, can be used*
C19-3	*How can we deal with incomplete information: just more communication among the team (in vivo)*
C19-4	*Each discipline needs to understand other disciplines requirements*
C19-5	*The schedule should understand and acknowledge disciplines' requirement*
C19-6	*When you rush everything, design issues will occur*
C19-7	*The right people for squad check are too busy to do the check*
C19-8	*You cannot say it is unrealistic. It is somewhere in between*
C19-9	*Long lead items: Most of the time they just talk to themselves, not to the vendor of the long lead items to evaluate the amount of lead time*
C19-10	*During FEED you should at least go to three vendors*
C19-11	*Ask for budgetary quote which has acceptable level of information*
C19-12	*Make sure you ask the right question*
C19-13	*Errors is a major cause of IFC changes*
C19-14	*Alternatives proposed by engineering not in a timely manner*
C19-15	*IFC-with-hold is issued just to meet the deadline, to get paid*
C19-16	*Technical qualification of the team*

Table A.18b: Grouping concepts for interview #19

Discussion	Category/Concept	
Reducing Scheduling Delay	*C19-9*	*Long lead items: Most of the time they just talk to themselves, not to the vendor of the long lead items to evaluate the amount of lead time*
	C19-10	*During FEED you should at least go to three vendors*
	C19-11	*Ask for budgetary quote which has acceptable level of information*
	C19-12	*Make sure you ask the right question*
	C19-8	*You cannot say it is unrealistic. It is somewhere in between*
	C19-4	*Each discipline needs to understand other disciplines requirements*
	C19-5	*The schedule should understand and acknowledge disciplines' requirement*
Mini**mizing Design Change**	*C19-15*	*IFC-with-hold is issued just to meet the deadline, to get paid*
	C19-13	*Errors is a major cause of IFC changes*
	C19-14	*Alternatives proposed by engineering not in a timely manner*
Design Issues	*C19-16*	*Technical qualification of the team*
	C19-6	*When you rush everything, design issues will occur*
	C19-7	*The right people for squad check are too busy to do the check*
	C19-1	*Disconnection between field and the office, lack of interaction*
Insufficient Information	*C19-3*	*How can we deal with incomplete information: just more communication among the team (in vivo)*
	C19-2	*Similar information from previous projects e.g. As-built, can be used*

Memo 19-1

A big portion of seemingly unavailable information may exist in sources which is already accessible to the project. They just need to be discovered. They might be buried somewhere deep in archives, in personal folders, or even in the form of undocumented experience of a senior member of project tem. To unfold those valuable information, you need to get people to talk! As also mentioned in the interviews #3 and #17, running brainstorming workshops, for example in scheduling sessions is a good strategy. Systematic documentation and review of the lessons-learned from the current and previous projects (also emphasized in interview # 5), or referring to As-built documents of previous projects can provide information that can directly be used in current project, be it for the design, or the scheduling of the project. Promoting interpersonal communication to enhance team dynamic, or just to break the ice among team members, fosters further collaboration of more senior members with the rest of the team, and facilitates the circulation of accumulated knowledge and experience among project team. This concept is also emphasized here in codes C19-1 to C19-4 by the participant.

Memo 19-2

Quality of communication (here, asking the right question, as to “what to communicate”) is mentioned in codes C19-11 and C19-12. Sometimes, even when the relevant stakeholders are engaged, and the communication is in place in a timely manner, the right content of the communication may be missing.

Axial Coding for Interview #19:

Table A.18c: Categories and subcategories for interview #19 *(axial coding)*

Category *(Relating Concept)*	Subcategory		
	Eng. Design Issues	**Eng. Schedule Issues**	**Changes after IFC**
Scope Definition/Understanding			*(C19-14)*
Insufficient Time	*(C19-6)*	*(C19-8)*	
Knowledge and Experience	*(C19-16)*		
Stakeholder Engagement	*(C19-7)*	*(C19-9)*	
Communication	*(C19-1) (C19-3)*	*(C19-9)(C19-10) (C19-12) (C19-4) (C19-5) (C19-3)*	*(C19-3)*
Design Strategies			
Client-Contractor Collaboration			
Resource Planning			
Unavailable/Incomplete Information	*(C19-2)*	*(C19-11)*	
Alignment/Coordination			
Project Context		*(C19-15)*	
Other			*(C19-13)*

A19. Interview #20

Interview #20			
Participant Code: **NA**	*Position:* **Senior Reliability Engineer**	*Years of Experience:* **22**	*Org. type:* **Owner**

Table A.19a: Identifying and numbering concepts for interview #20 *(open coding)*

Code No.	Concepts
C20-1	*Engineering is not available at the time of construction*
C20-2	*3D updates (after engineering) are not ready when construction needs it*
C20-3	*At the end of engineering, construction is left with insufficient support from engineering*
C20-4	*Engineering done overseas, cannot provide support construction*
C20-5	*1 year experience at site is equivalent to say 5 years at office in terms of engineering information (in vivo)*
C20-6	*The engineer who is laid off after the engineering, will take away all the project specific knowledge with them*
C20-7	*Documenting, taking pictures, slides, etc. during the engineering evolution as well as construction (in vivo)*
C20-8	*Defining systems by engineering should consider construction needs, and even contracting strategies*
C20-9	*Engineering normally meets their schedule, but at the cost of low quality design, errors, lots of revisions, etc.*
C20-10	*I have seen tremendous amount of errors in drawings even from well-known EPC companies (in vivo)*
C20-11	*Replacing designed material with available material at the time of construction needs availability of engineering to verify new material*
C20-12	*Design basis and drawings being in metric system, and equipment vendors data being in imperial system, cause problem at the time of construction*

Table A.19b: Grouping concepts for interview #20

Discussion	Category/Concept	
Engineering and Construction Interaction	*C20-1*	*Engineering is not available at the time of construction*
	C20-2	*3D updates (after engineering) are not ready when construction needs it*
	C20-3	*At the end of engineering, construction is left with insufficient support from engineering*
	C20-4	*Engineering done overseas, cannot provide support construction*
	C20-6	*The engineer who is laid off after the engineering, will take away all the project specific knowledge with them*
	C20-7	*Documenting, taking pictures, slides, etc. during the engineering evolution as well as construction (in vivo)*
	C20-11	*Replacing designed material with available material at the time of construction needs availability of engineering to verify new material*
Design Issues	*C20-5*	*One year experience at site is equivalent to say 5 years at office in terms of engineering information (in vivo)*
	C20-8	*Defining systems by engineering should consider construction needs, and even contracting strategies*
	C20-9	*Engineering normally meets their schedule, but at the cost of low quality design, errors, lots of revisions, etc.*
	C20-10	*I have seen tremendous amount of errors in drawings even from well-known EPC companies (in vivo)*
	C20-12	*Design basis and drawings being in metric system, and equipment vendors data being in imperial system, cause problem at the time of construction*

Memo 20-1

The participant in this interview, with years of experience in project construction and commissioning, opened a new vantage point for this research, to look at enhancing engineering to improve construction performance.

Engaging stakeholders, especially involving people from construction, operation and maintenance in the engineering phase and major design decisions was emphasised and discussed in many interviews over the course of this research. However, the importance of the adequate presence of engineering during the construction was never mentioned. It is a valid concern to engage the engineering during construction. Although in majority large oil and gas construction projects, there is always a field engineering department which include field engineering manager, field project engineers, and discipline field engineers, it does not have enough capacity, in terms of number of people as well as engineering expertise, to deal with complicated engineering problems, and construction still suffers from inadequate engineering support to deal with engineering issues raised frequently during the construction. This is even worse when the construction continues long after the engineering phase is finished and most of the engineering teams are dismissed.

Tremendous amount of valuable knowledge and information remains with the engineering team who have actually done the design for the project. All, or at least a significant portion of it is gone by the dismissal of the engineering team. These types of knowledge and information include:

- Historic background of the design decisions
- Agreements /assumptions made at the time of design
- Particular experiences and expertise that were employed for certain designs

Memo 20-2

Enhancing communication among the team can have a positive impact on some aspect of the issues discussed in the previous memo. For example if the design decisions, assumptions, agreements, and resolutions are properly communicated through the engineering management down to all relevant stakeholders including construction, or if field engineering is effectively kept in the loop of communication during the key design decision process, there will be minimum dependency or reliance to the office engineering down the road in construction. This aspect becomes more curtail and critical when the engineering is done overseas.

Memo 20-3

It should be noted that involvement of engineering during construction is not limited to availability of engineers to be consulted when needed. Other services such as updating and completing the 3D model as the construction proceeds, may be required by construction as mentioned in code C20-2

Axial Coding for Interview #20:

Table A.19c: Categories and subcategories for interview #20 *(axial coding)*

Category *(Relating Concept)*	Subcategory		
	Eng. Design Issues	**Eng. Schedule Issues**	**Changes after IFC**
Scope Definition/Understanding			
Insufficient Time	(C20-9)		
Knowledge and Experience	(C20-5)		
Stakeholder Engagement	(C20-1) (C20-3) (C20-11)		
Communication	(C20-7) (C20-8) (C20-4)		
Design Strategies	(C20-10)		
Client-Contractor Collaboration			
Resource Planning			
Unavailable/Incomplete Information	(C20-2) (C20-6)		
Alignment/Coordination	(C20-12)		
Project Context	(C20-8)		
Other			

A20. Interview #21

Interview #21			
Participant Code: **PB**	*Position:* **Principal, Engineering**	*Years of Experience:* **23**	*Org. type:* **E&P**

Table A.20a: Identifying and numbering concepts for interview #21 *(open coding)*

Code No.	Concepts
C21-1	*Low hanging fruits are already taken care of*
C21-2	*Using technology algorithms provides more consistency in design process*
C21-3	*Integration of technology across multiple disciplines*
C21-4	*Convey the design to all stakeholder e.g. augmented reality*
C21-5	*Change during construction :"I didn't know that was what I was getting"*
C21-6	*Some of the changes is because of new desire for something different*
C21-7	*30 years ago the design was unchangeable*
C21-8	*In very high risk technology (aerospace) they don't accept change so easily*
C21-9	*Reduce the cost uncertainty by eliminating the processes of change*
C21-10	*Become less innovative (in vivo)*
C21-11	*End user expectation is societal; the ability to customize and change as they wish (in vivo)*
C21-12	*Flexibility to accept late changes is becoming a competitive advantage*
C21-13	*Vast majority of IFC changes occur because a normal changes are implemented in disciplines but one discipline misses it (in vivo)*
C21-14	*How engaged the people working on the project are has impact on improving design errors (e.g. people feel they are valued in the project)*
C21-15	*Dealing with insufficient design information is the cost you pay for a schedule-driven project*
C21-16	*You can teach technical skills but integrity is much harder to teach*
C21-17	*Integrated project delivery: a method to bring all project parties to the table much earlier, by providing incentives schemes such as sharing the profit*
C21-18	*Bringing vendors in model reviews (requires fundamental long term relationship between the parties)*
C21-19	*One strategy is to let client know that the schedule does not work that way, but it rarely works*
C21-20	*Put some caveat in agreements over schedule (in vivo)*
C21-21	*It is crucial to maintain regular and close dialog with all stakeholders (in vivo) –Identify areas that the need to pay attention*
C21-22	*Upper management scrutiny (Why? What is missing, …)*

Table A.20b: Grouping concepts for interview #21

Discussion	Category/Concept	
Unrealistic Scheduling	*C21-19*	*One strategy is to let client know that the schedule does not work that way, but this strategy rarely works*
	C21-20	*Put some caveat in agreements over schedule (in vivo)*
Reducing Scheduling Delay	*C21-21*	*It is crucial to maintain regular and close dialog with all stakeholders (in vivo) –Identify areas that the need to pay attention*
	C21-22	*Upper management scrutiny (Why? What is missing, …)*
Mini**mizing Design Change**	*C21-5*	*Change during construction :"I didn't know that was what I was getting"*
	C21-6	*Some of the changes is because of new desire for something different*
	C21-7	*30 years ago the design was unchangeable*
	C21-8	*In very high risk technology (aerospace) they don't accept change so easily*
	C21-9	*Reduce the cost uncertainty by eliminating the processes of change*
	C21-10	*Become less innovative (in vivo)*
	C21-11	*End user expectation is societal; the ability to customize and change as they wish (in vivo)*
	C21-12	*Flexibility to accept late changes is becoming a competitive advantage*
	C21-13	*Vast majority of IFC changes occur because a normal changes are implemented in disciplines but one discipline misses it (in vivo)*
Design Issues	*C21-1*	*Low hanging fruits are already taken care of*
	C21-2	*Using technology algorithms provides more consistency in design process*
	C21-3	*Integration of technology across multiple disciplines*
	C21-4	*Convey the design to all stakeholder e.g. augmented reality*
	C21-14	*How engaged the people working on the project are has impact on improving design errors (e.g. people feel they are valued in the project)*
	C21-16	*You can teach technical skills but integrity is much harder to teach*
	C21-17	*Integrated project delivery: a method to bring all project parties to the table much earlier, by providing incentives schemes such as sharing the profit*
	C21-18	*Bringing vendors in model reviews (requires fundamental long term relationship between the parties)*
Insufficient Information	*C21-15*	*Dealing with insufficient design information is the cost you pay for a schedule-driven project*

Memo 21-1

The participant of this interview had an executive role in the organization as Engineering Principal, and therefore his viewpoint towards the topics under discussion were coming from high-level strategic and business-oriented visions he had for the company, rather than from pure practical project experiences as with other interviewees. Concepts such as “flexibility to accept late changes becoming a competitive advantage” (code C21-12), or “End user’s ability to customize and change as they wish becoming a societal expectation” (code C21-11) are some examples that can represent his vantage point towards engineering issues which in those cases is scope change.

Yet, to a great extent, those ideas still supported major aspects that were discussed in previous interviews. For example “integrated project delivery” (code C21-17) which is a method that brings all project parties to the table much earlier in the project, is a response to the need for proper stakeholder engagement which was emphasised by many participants in various contexts over the course of this research. So are “maintaining regular and close dialog with stakeholders” (code C21-21), and “using augmented reality” (code C21-4) to convey the design to all stakeholders.

Memo 21-2

It was reinforced that unclear and ununderstood project scope will result in design changes later in the project. However, it was also acknowledged that the lack of clear definition of scope can be accounted for by the impact of technology advances that facilitate rapid introduction of newer technologies, sometimes for less cost, over the course of a project basic and detailed design phase. This new technology environment has altered owners’ expectations and approaches. Examples are parallel engineering to find better alternatives (discussed in interview #2), or not finalizing EDS phase and extending it into the detailed design phase (discussed in interview #17), or simply not freezing the scope by the end of FEL phases (interview #16)

Memo 21-3

The role of communication in enhancing engineering deliverables was mentioned here in a different context which is improving the integrity of design (codes C21-3,16,17), or conveying the design to all stakeholders (code C21-4), communicating changes across all disciplines (code C21-13, also discussed in interview#1), and maintaining regular dialog with all stakeholders (code C21-21).

Axial Coding for Interview #21:

Table A.20c: Categories and subcategories for interview #21 *(axial coding)*

Category *(Relating Concept)*	Subcategory		
	Eng. Design Issues	**Eng. Schedule Issues**	**Changes after IFC**
Scope Definition/Understanding			*(C21-5) (C21-6) (C21-7) (C21-8)*
Insufficient Time	*(C21-15)*	*(C21-15)*	*(C21-15)*
Knowledge and Experience			
Stakeholder Engagement	*(C21-14) (C21-17) (C21-18)*		
Communication	*(C21-4) (C21-16)*	*(C21-21)*	*(C21-13)*
Design Strategies	*(C21-2)*		*(C21-12)*
Client-Contractor Collaboration		*(C21-19) (C21-20)*	
Resource Planning			
Unavailable/Incomplete Information			
Alignment/Coordination	*(C21-3)*		
Project Context			
Other	*(C21-1)*	*(C21-22)*	*(C21-9) (C21-10) (C21-11)*

A21. Interview #22

Interview #22			
Participant Code: **MF**	*Position:* **Project Controls Manager**	*Years of Experience:* **19**	*Org. type:* **Owner**

Table A.21a: Identifying and numbering concepts for interview #22 *(open coding)*

Code No.	Concepts
C22-1	*Vendor data delays is the biggest cause of engineering delay*
C22-2	*If we could obligate vendor to follow their quoted timeline*
C22-3	*We do interactive planning in big board rooms only making assumptions regarding vendor data availability*
C22-4	*Disciplines making promises on someone else's (vendor) behalf*
C22-5	*Best would be involving vendors during the FEED*
C22-6	*Insufficient resourcing is another cause of engineering delays*
C22-7	*Each phase blames previous phase for unrealistic schedule, but it is inevitable because of human factor*
C22-8	*Project management should believe in the importance of experienced planners to empower project control function (in vivo)*
C22-9	*Involving operation is as important as involving construction in the engineering*

Table A.21b: Grouping concepts for interview #22

Discussion	Category/Concept	
Unrealistic Schedule	*C22-7*	*Each phase blames previous phase for unrealistic schedule, but it is inevitable because of human factor*
	C22-5	*Best would be involving vendors during the FEED*
Reducing Scheduling Delay	*C22-1*	*Vendor data delays is the biggest cause of engineering delay*
	C22-2	*If we could obligate vendor to follow their quoted timeline*
	C22-3	*We do interactive planning in big board rooms only making assumptions regarding vendor data availability*
	C22-4	*Disciplines making promises on someone else's (vendor) behalf*
	C22-6	*Insufficient resourcing is another cause of engineering delays*
	C22-8	*Project management should believe in the importance of experienced planners to empower project control function (in vivo)*
	C22-9	*Involving operation is as important as involving construction in the engineering*

Memo 22-1

Although the participant did not support the idea that the schedules are unrealistic, he emphasized that involving vendors during the FEED can result in more reliable and smoother schedule. There is one problem with that however, and that is the vendors sometimes do not follow their own quoted timeline. This is where the "integrated project delivery" method discussed in interview #21 (code C21-17) that provides incentives schemes such as sharing benefit and loss, can help to ensure timely delivery of vendor information. Overall, there is a great emphasis in this interview on the importance availability of vendor data in enhancing engineering schedule.

Axial Coding for Interview #22:

Table A.21c: Categories and subcategories for interview #22 *(axial coding)*

Category *(Relating Concept)*	Subcategory		
	Eng. Design Issues	**Eng. Schedule Issues**	**Changes after IFC**
Scope Definition/Understanding			
Insufficient Time			
Knowledge and Experience		*(C22-8)*	
Stakeholder Engagement		*(C22-5)(C22-2)* *(C22-3) (C22-9)*	
Communication			
Design Strategies			
Client-Contractor Collaboration			
Resource Planning		*(C22-6)*	
Unavailable/Incomplete Information		*(C22-1) (C22-3)*	
Alignment/Coordination		*(C22-4)*	
Project Context			
Other		*(C22-7)*	

A22. Interview #23

Interview #23			
Participant Code: **FT**	*Position:* **Senior Mechanical Engineer**	*Years of Experience:* **18**	*Org. type:* **E&P**

Table A.22a: Identifying and numbering concepts for interview #23 *(open coding)*

Code No.	Concepts
C23-1	*Lack of involvement of right people in the right time (in vivo)*
C23-2	*Design continues based on the decision of client project team not the relevant stakeholder*
C23-3	*When you do things in a rush you start to cut corners (in vivo)*
C23-4	*Normally there is not enough time for engineering to implement later-stage changes*
C23-5	*Construction strategies changes and cause engineering schedule shuffle*
C23-6	*Late changes is a source of engineering design issues*
C23-7	*Human errors can be reduced through proper review processes*
C23-8	*Human errors may be in the process itself (e.g. changing manually vs changing through software)*
C23-9	*Communication is very important. Inputs of design are not properly communicated among disciplines*
C23-10	*Vendors drawings sometimes not distributed to all relevant disciplines*
C23-11	*All of these can be improved by looking at communication protocols (in vivo)*
C23-12	*Project managers have important role in enforcing the bigger picture of communication*
C23-13	*Changes due to not finalizing agreements with third party (in vivo)*
C23-14	*Not initiating vendor POs in proper time. Deign based on assumptions*
C23-15	*Engaging stakeholders in every related decisions*
C23-16	*Highlighting to the client what information you need*
C23-17	*Challenge of getting right/sufficient resources to deliver on time*
C23-18	*Establish informal discipline interface to get information ahead of time*
C23-19	*Unrealistic schedules due to inadequate time for preparing the proposal to the client*
C23-20	*Sit with the client and come up with the mitigation plan*
C23-21	*Take a practical innovative approach to keep our milestones even if they is not so perfect (in vivo)*

Table A.22b: Grouping concepts for interview #23

Discussion	Concept	
Unrealistic Scheduling	*C23-19*	*Unrealistic schedules due to inadequate time for preparing the proposal to the client*
	C23-20	*Sit with the client and come up with the mitigation plan*
	C23-21	*Take a practical innovative approach to keep our milestones even if they is not so perfect (in vivo)*
Reducing Scheduling Delay	*C23-17*	*Challenge of getting right/sufficient resources to deliver on time*
	C23-18	*Establish informal discipline interface to get information ahead of time*
Mini**mizing Design Change**	*C23-9*	*Communication is very important. Inputs of design are not properly communicated among disciplines*
	C23-13	*Changes due to not finalizing agreements with third party (in vivo)*
	C23-14	*Not initiating vendor POs in proper time. Deign based on assumptions*
	C23-15	*Engaging stakeholders in every related decisions*
Design Issues	*C23-1*	*Lack of involvement of right people in the right time (in vivo)*
	C23-2	*Design continues based on the decision of client project team not the relevant stakeholder*
	C23-3	*When you do things in a rush you start to cut corners (in vivo)*
	C23-4	*Normally there is not enough time for engineering to implement later-stage changes*
	C23-5	*Construction strategies changes and cause engineering schedule shuffle*
	C23-6	*Late changes is a source of engineering design issues*
	C23-7	*Human errors can be reduced through proper review processes*
	C23-8	*Human errors may be in the process itself (e.g. changing manually vs changing through software)*
	C23-10	*Vendors drawings sometimes not distributed to all relevant disciplines*
	C23-11	*All of these can be improved by looking at communication protocols (in vivo)*
	C23-12	*Project managers have important role in enforcing the bigger picture of communication*
	C23-16	*Highlighting to the client what information you need*

Memo 23-1

One aspect of unclear / ununderstood scope that leads to engineering design problem as well as schedule delays is the change in construction strategy during the detailed design (code C23-5). The change in construction strategy may be partly because of what was mentioned in the interview #16, which is lack of clients understanding of what they want and how they are going to get it (code C16-6). Only after the detailed design has progressed to some degree, it becomes clear that certain construction method which was originally planned is not possible/feasible and need to be changed.

Memo 23-2

There are also a number of other possible reasons accounting for change in construction strategy during detailed design phase. Not involving experienced and knowledgeable people in the FEED (code C16-9 in interview#16) and making faulty assumptions, not involving construction people early in the project, and delay in delivery of major equipment especially long-lead items are some common examples. However, one can deduce that most of those causes are already discussed over the course of this research and can be prevented.

Memo 23-3

Insufficient time is not just a challenge for engineering phase. Sometimes clients do not consider insufficient time for contractors to spend on their pre-bid investigation to understand the job as clearly as possible prior to undergo a time and price commitment. This in turn may result in agreeing on a schedule which is already not reasonable, and would otherwise be challenged by the contractor. Just as with the case of unrealistic schedule discussed a number of time during this research, a good collaboration and healthy dialogue between the client and the contractor can alleviate this kind of situations as also was reinforced by the participant here (code C23-20)

Axial Coding for Interview #23:

Table A.22c: Categories and subcategories for interview #23 *(axial coding)*

Category *(Relating Concept)*	Subcategory		
	Eng. Design Issues	**Eng. Schedule Issues**	**Changes after IFC**
Scope Definition/Understanding	*(C23-5)*		*(C23-13)*
Insufficient Time	*(C23-3) (C23-4) (C23-6)*	*(C23-19)*	
Knowledge and Experience			
Stakeholder Engagement	*(C23-1) (C23-2)*		*(C23-15)*
Communication	*(C23-7)(C23-8) (C23-10)(C23-11) (C23-12) (C23-16)*	*(C23-18)*	*(C23-9)*
Design Strategies		*(C23-21)*	
Client-Contractor Collaboration		*(C23-20)*	
Resource Planning		*(C23-17)*	
Unavailable/Incomplete Information			*(C23-14)*
Alignment/Coordination			
Project Context			
Other			

A23. Interview #24

Interview #24			
Participant Code: **SY**	*Position:* **Corporate Geotechnical Lead**	*Years of Experience:* **25**	*Org. type:* **Owner**

Table A.23a: Identifying and numbering concepts for interview #24 *(open coding)*

Code No.	Concepts
C24-1	*It should be clear to everybody if the project is cost-driven or schedule-driven*
C24-2	*Switching between those strategies later in the project may generate lots of changes and rework*
C24-3	*Not understanding the scope accurately will result in inaccurate estimates*
C24-4	*Sometimes people work in isolation (in vivo) Stakeholders not engaged*
C24-5	*Off-line communication and alignment before official model reviews*
C24-6	*Experienced clients can compensate for lots of unavailable information during FEED*
C24-7	*Base disciplines e.g. process and geotechnical should fix the scope as early as possible*
C24-8	*Contractor should ask the client “What do you want?” (in vivo)*
C24-9	*Risk tolerances (technical, cost, schedule,…) needs to be clarified*
C24-10	*Operation can help a lot in making correct assumptions in FEED (e.g. will we need piles or gravel pad), based on their long time presence in the plant*
C24-11	*Miss-alignments kept silent until discovered later in model reviews*
C24-12	*Communicate in advance before getting final agreements*
C24-13	*Client specs may have certain application which may not be proper for all purposes (e.g. road spec used for refinery is too conservative for tailings)*
C24-14	*Cost estimator are not technically capable to differentiate quoted items (iv vivo)*
C24-15	*A less expensive alternative at FEED may be costlier in construction due to certain conditions (constructability at FEED)*
C24-16	*Engineering companies normally do not hire construction specialists*
C24-17	*Construction sequencing is sometimes missed in FEED because of not involving construction experts*
C24-18	*Activities that are common for different battery limits (e.g. geotechnical)*
C24-19	*Early decisions merely based on the technical knowledge of PMs and PEs which are not adequate most of the time*
C24-20	*Small deviations from the design, if not communicated properly, may generate big cost and schedule issue in construction.*
C24-21	*Client information may come from “experience-based design” which may not be proper solution for the project*

Table A.23b: Grouping concepts for interview #24

Discussion	Category/Concept	
Unrealistic Scheduling	*C24-4*	*Sometimes people work in isolation (in vivo) Stakeholders not engaged*
	C24-21	*Client information may come from "experience-based design" which may not be proper solution for the project*
Reducing Scheduling Delay	*C24-1*	*It should be clear to everybody if the project is cost-driven or schedule-driven*
Mini**mizing Design Change**	*C24-1*	*It should be clear to everybody if the project is cost-driven or schedule-driven*
	C24-2	*Switching between those strategies later in the project may generate lots of changes and rework*
	C24-3	*Not understanding the scope accurately will result in inaccurate estimates*
	C24-4	*Sometimes people work in isolation (in vivo) Stakeholders not engaged*
	C24-5	*Off-line communication and alignment before official model reviews*
	C24-6	*Experienced clients can compensate for lots of unavailable information during FEED*
	C24-7	*Base disciplines e.g. process and geotechnical should fix the scope as early as possible*
	C24-11	*Miss-alignments kept silent until discovered later in model reviews*
	C24-12	*Communicate in advance before getting final agreements*
	C24-14	*Cost estimator are not technically capable to differentiate quoted items (iv vivo)*
	C24-15	*A less expensive alternative at FEED may be costlier in construction due to certain conditions (constructability at FEED)*
	C24-18	*Activities that are common for different battery limits (e.g. geotechnical)*
	C24-19	*Early decisions merely based on the technical knowledge of PMs and PEs which are not adequate most of the time*
	C24-20	*Small deviations from the design, if not communicated properly, may generate big cost and schedule issue in construction.*
Design Issues	*C24-8*	*Contractor should ask the client "What do you want?" (in vivo)*
	C24-9	*Risk tolerances (technical, cost, schedule,…) needs to be clarified*
	C24-10	*Operation can help a lot in making correct assumptions in FEED (e.g. will we need piles or gravel pad), based on their long time presence in the plant*
	C24-13	*Client specs may have certain application which may not be proper for all purposes (e.g. road spec used for refinery is too conservative for tailings)*
	C24-16	*Engineering companies normally do not hire construction specialists*
	C24-17	*Construction sequencing is sometimes missed in FEED because of not involving construction experts*

Memo 24-1

Clear definition of project scope should also encompass clear execution strategy to achieve that scope. Depending on the context, the project may be cost-driven or schedule-driven, each of which involve different approaches towards execution of the project. The key point here is that those strategies should be decided by the client at the beginning of the project, and clearly communicated to and understood by the client. Switching those strategies in the middle of the project can lead to tremendous schedule delay and cost overrun, both during the engineering phase and in construction.

Memo 24-2

The necessity of the presence of adequate knowledge and specialized experts from different disciplines at the early stages of projects is sometimes taken for granted by the clients. As also discussed by the participant (code C24-21) clients may rely solely on they experiences from their similar project in the past and use those information directly for the project at hand. This approach works well most of the time, but other times may end up in catastrophic results in the project, due to the fact that certain conditions may have changed from previous project and the same solution as the previous project may work adversely in the current project. Again, the role of engaging the right people and bringing in the best experts within the organization during FEED or EDS phase was highlighted and emphasized.

Memo 24-3

Informal interpersonal communication among the team can enhance alignment between different disciplines and therefore predict many engineering deliverables issues. Open face-to-face communication about the matter of interest, e.g. a key design decision, or the 3D model review session next week, can deliver better results in terms of consistency and alignment.

Axial Coding for Interview #24:

Table A.23c: Categories and subcategories for interview #24 *(axial coding)*

Category *(Relating Concept)*	Subcategory		
	Eng. Design Issues	**Eng. Schedule Issues**	**Changes after IFC**
Scope Definition/Understanding	*(C24-8) (C24-9) (C24-13)(C24-18)*	*(C24-1)*	*(C24-1)(C24-2) (C24-3) (C24-7)*
Insufficient Time			
Knowledge and Experience	*(C24-6)*	*(C24-6)*	*(C24-19)*
Stakeholder Engagement	*(C24-10) (C24-16) (C24-17)*	*(C24-4)*	*(C24-4) (C24-15) (C24-19)*
Communication	*(C24-20)*	*(C24-4) (C24-5)*	*(C24-11) (C24-12)*
Design Strategies			
Client-Contractor Collaboration			
Resource Planning			
Unavailable/Incomplete Information	*(C24-6) (C24-21)*	*(C24-6) (C24-21)*	
Alignment/Coordination			
Project Context			
Other			

A24. Interview #25

Interview #25			
Participant Code: **MM**	*Position:* **Project Manager**	*Years of Experience:* **21**	*Org. type:* **EPC**

Table A.24a: Identifying and numbering concepts for interview #25 *(open coding)*

Code No.	Concepts
C25-1	*Inadequate discipline knowledge to provide input for planning*
C25-2	*Careless using information from previous projects*
C25-3	*Lack of a risk management to consider proper schedule contingency*
C25-4	*Poor interdisciplinary communication and work flow*
C25-5	*Ensure proper follow up is in place to get information*
C25-6	*Involving vendors early enough to facilitate timely vendor data availability*
C25-7	*Lack of understanding engineering sequence*
C25-8	*Inadequate time allocation for detailed design phase*
C25-9	*Rushing things prevents proper implementation of design check process*
C25-10	*Inadequate spent in FEL to be able to freeze design basis*
C25-11	*By the time of FID only 25% of engineering is completed*
C25-12	*Client's culture of collaboration with contractor*
C25-13	*Quality communication to obtain mutual agreement on schedule*
C25-14	*Ideally, design engineers should have 3 years of construction experience before starting their careers in engineering houses*

Table A.24b: Grouping concepts for interview #25

Discussion	Category/Concept	
Unrealistic Scheduling	*C25-2*	*Careless using information from previous projects*
	C25-3	*Lack of a risk management to consider proper schedule contingency*
	C25-12	*Client's culture of collaboration with contractor*
	C25-13	*Quality communication to obtain mutual agreement on schedule*
Reducing Scheduling Delay	*C25-1*	*Inadequate discipline knowledge to provide input for planning*
	C25-4	*Poor interdisciplinary communication and work flow*
	C25-6	*Involving vendors early enough to facilitate timely vendor data availability*
	C25-7	*Lack of understanding engineering sequence*
Mini**mizing Design Change**	*C25-10*	*Inadequate time spend in FEL to be able to freeze design basis*
	C25-11	*By the time of FID only 25% of engineering is completed*
Design Issues	*C25-8*	*Inadequate time allocation for detailed design phase*
	C25-9	*Rushing things prevents proper implementation of design check process*
	C25-14	*Ideally, design engineers should have 3 years of construction experience before starting their careers in engineering houses*
Insufficient Information	*C25-5*	*Ensure proper follow up is in place to get information*

Memo 25-1

Using information from previous project was discussed in detail in Memo 19-1. This strategy is encouraged in dealing with insufficient information during FEED or EDS phase, as also mentioned in interview #19 and interview #5. However, as similarly emphasised in the previous interview (Memo 24-2), careless using of the information coming from previous project can result in catastrophic results (code C25-2).

Memo 25-2

By reviewing the codes identified in this interview, it appears that nearly all the codes in this interview were already discussed one way or another in previous interviews. This interview encompasses almost same ideas regarding the causes for different issues of engineering deliverable, with almost same recommendation to mitigate them. This observation can be interpreted as a good sign for data saturation, which is a necessary criteria to indicate the adequacy of the research data collection.

Axial Coding for Interview #25:

Table A.24c: Categories and subcategories for interview #25 *(axial coding)*

Category *(Relating Concept)*	Subcategory		
	Eng. Design Issues	**Eng. Schedule Issues**	**Changes after IFC**
Scope Definition/Understanding			*(C25-10)*
Insufficient Time	*(C25-8) (C25-9)*		
Knowledge and Experience	*(C25-14)*	*(C25-1) (C25-7)*	
Stakeholder Engagement		*(C25-6)*	
Communication	*(C25-5)*	*(C25-13) (C25-4)*	
Design Strategies			
Client-Contractor Collaboration		*(C25-12)*	
Resource Planning			
Unavailable/Incomplete Information		*(C25-2)*	*(C25-11)*
Alignment/Coordination			
Project Context			
Other		*(C25-3)*	

A25. Interview #26

Interview #26			
Participant Code: **BM**	*Position:* **Senior Project Manager**	*Years of Experience:* **33**	*Org. type:* **EPC**

Table A.25a: Identifying and numbering concepts for interview #26 *(open coding)*

Code No.	Concepts
C26-1	*Client and contractors have different understanding of the scope*
C26-2	*We fail at the beginning when we don't sit down and compare things (in vivo)*
C26-3	*From the beginning, communication should be fluent enough to go all to the end (in-vivo)*
C26-4	*Clients expectancy about the project is different than the contractor*
C26-5	*Contractors make joint venture with the vendors at FEED phase*
C26-6	*Presence of the vendor in FEED can help process design be more reliable.*
C26-7	*Schedules fail very early on. They don't fail later (in vivo).*
C26-8	*Enough time needs to be spent on challenging every aspect of schedule before finalizing it.*
C26-9	*Clients need to evaluate contractors concern about the schedule.*
C26-10	*Part of engineering delays is because of what client wants in not clearly communicated to the contractor (bad communication) (in vivo)*
C26-11	*Interdisciplinary communication is a challenge but it is a key to success*
C26-12	*In every communication, there should be feedback to make sure it is understood*
C26-13	*Very upfront in project, communication is the key (in vivo)*
C26-14	*Even office arrangement of engineering team should facilitate more interaction and better communication among the teams.*
C26-15	*Say "No" to change requests (in vivo) except it is because of safety or inadequate design reasons*
C26-16	*Even those types of changes could have probably been avoided if there were adequate communication in place*
C26-17	*Inadequate use of procedures due to lack of enough time, may cause changes after IFC*

Table A.25b: Grouping concepts for interview #26

Discussion	Category/Concept	
Unrealistic Scheduling	*C26-1*	*Client and contractors have different understanding of the scope*
	C26-2	*We fail at the beginning when we don't sit down and compare things (in vivo)*
	C26-3	*From the beginning, communication should be fluent enough to go all to the end (in-vivo)*
	C26-4	*Clients expectancy about the project is different than the contractor*
	C26-5	*Contractors make joint venture with the vendors at FEED phase*
	C26-9	*Clients need to evaluate contractors concern about the schedule.*
	C26-13	*Very upfront in project, communication is the key (in vivo)*
Reducing Scheduling Delay	*C26-8*	*Enough time needs to be spent on challenging every aspect of schedule before finalizing it.*
	C26-7	*Schedules fail very early on. They don't fail later (in vivo).*
	C26-10	*Part of engineering delays is because of what client wants in not clearly communicated to the contractor (bad communication) (in vivo)*
Minimizing Design Change	*C26-6*	*Presence of the vendor in FEED can help process design be more reliable.*
	C26-13	*Very upfront in project, communication is the key (in vivo)*
	C26-15	*Say "No" to change requests (in vivo) except it is because of safety or inadequate design reasons*
	C26-16	*Even those types of changes could have probably been avoided if there were adequate communication in place*
Design Issues	*C26-11*	*Interdisciplinary communication is a challenge but it is a key to success*
	C26-12	*In every communication, there should be feedback to make sure it is understood*
	C26-14	*Even office arrangement of engineering team should facilitate more interaction and better communication among the teams.*
	C26-17	*Inadequate use of procedures due to lack of enough time, may cause changes after IFC*

Axial Coding for Interview #26:

Table A.25c: Categories and subcategories for interview #26 *(axial coding)*

Category *(Relating Concept)*	Subcategory		
	Eng. Design Issues	**Eng. Schedule Issues**	**Changes after IFC**
Scope Definition/Understanding		*(C26-1) (C26-2) (C26-4)*	
Insufficient Time		*(C26-8)*	*(C26-17)*
Knowledge and Experience		*(C26-7)*	
Stakeholder Engagement	*(C26-6)*		*(C26-6)*
Communication	*(C26-11)(C26-12) (C26-14)*	*(C26-3) (C26-10) (C26-13)*	*(C26-16)(C26-13)*
Design Strategies			
Client-Contractor Collaboration		*(C26-9)*	
Resource Planning			
Unavailable/Incomplete Information		*(C26-5)*	
Alignment/Coordination			
Project Context			
Other			*(C26-15)*

Appendix B: Research Participant Recruitment Documents

UNIVERSITY OF CALGARY

Name of Researcher, Faculty, Department, Telephone & Email:
Farshid Gholami Bavil Olyai,
PhD Candidate
Project Management Specialization
Department of Civil Engineering
Schulich School of Engineering
University of Calgary
Ph.: (403) 481 1970,
Email: fgholami@ucalgary.ca

Supervisor:

Dr. George F. Jergeas

Director and Professor
Project Management Specialization
Department of Civil Engineering
Schulich School of Engineering
University of Calgary

Title of Project:

A Framework for Enhancing Engineering Deliverables to Improve Construction Performance in Oil and Gas Projects

Sponsor:

Not Applicable

This consent form, a copy of which has been given to you, is only part of the process of informed consent. If you want more details about something mentioned here, or information not included here, you should feel free to ask. Please take the time to read this carefully and to understand any accompanying information.

The University of Calgary Conjoint Faculties Research Ethics Board has approved this research study. Participation is completely voluntary and confidential. You are free to discontinue participation at any time during the study.

Purpose of the Study

The purpose of this research is to enhance engineering deliverables through identifying engineering-related causes of poor construction performance and productivity loss in oil and gas industry, tracing them back to the engineering deliverables, and then eliminating or mitigating them by developing a framework, including tools, processes, or methods, that can be practiced during the engineering phases of oil and gas projects.
Since you have the relevant experience and knowledge, I would like to invite you to participate in this research and share your perspectives on this subject.

What Will I Be Asked To Do?

You will participate in this research by being interviewed and you will be asked for your professional experience in project based environment. Overall, there will be 2 interviews. Interviews will be conducted face to face or via telephone at the time which is appropriate and convenient for you. Each interview will take about 30 to 45 minutes and (upon your consent) will be recorded onto audiocassette/digital recorder for the purpose of accuracy, and then transcribed onto paper. The interviews will yield data on which the research results will be based.

Your participation is completely voluntary and it has no positive or negative effect on your current employment situation in your company. Moreover, if you reject to participate in this research, we will respect your privacy and keep your reply quite confidential. You are also free to decline to answer any or all questions, or discontinue participation at any time during the research.

What Type of Personal Information Will Be Collected?

No personal identifying information will be collected in this study, and all participants will be anonymized. Should you agree to participate, you will be ask to provide your job title /position, years of experience, and type of your organization (e.g. Client, EPC, Engineering, Construction, etc.).

For the purpose of accuracy, we highly prefer to audio-record the interviews. Please choose "Yes" or "No" for this option:

I grant permission to be audio-taped: *Yes: ___ No: ___*

Are there Risks or Benefits if I Participate?

This research brings no risks to you. No remuneration/compensation is offered and you will not incur any cost.

What Happens to the Information I Provide?

All data containing personal information from which you could be identified will be stored in a locked file cabinet in my office during the study. It will only be available to me and the supervisor. Electronic data will be password protected. Collected data will also be used to inform a PhD project. All published results of the study will contain only statistical or group data from which no individual participant can be identified. Raw data will be retained in a secure location until five years after completion of the research project and will then be destroyed.

You are being asked to make a voluntary decision as to whether you wish to participate in this study. If you decide not to participate, or if you later decide to discontinue your participation, your decision will not affect your present or future relations with the University of Calgary. Your decision to participate (or not) in the study will in no way affect your relations with/standing in your company by which you are employed, and that participation is not a condition of employment. Upon request, a copy of the final report will be provided to you. You will always be free to discontinue participation at any time during research, and data collected from withdrawals will be discarded. If you decide to participate, please provide your signature as indicated below.

Signatures

Your signature on this form indicates that 1) you understand to your satisfaction the information provided to you about your participation in this research project, and 2) you agree to participate in the research project.

In no way does this waive your legal rights nor release the investigators, sponsors, or involved institutions from their legal and professional responsibilities. You are free to withdraw from this research project at any time. You should feel free to ask for clarification or new information throughout your participation.

Participant’s Name: (please print) ____

Participant’s Signature: ____ Date: _______________

Researcher’s Name: (please print) ____

Researcher’s Signature: ____ Date: ________________

Questions/Concerns

If you have any further questions or want clarification regarding this research and/or your participation, please contact:

Farshid Gholami
PhD Candidate
Project Management Specialization
Department of Civil Engineering
Schulich School of Engineering
University of Calgary
Ph.: (403) 481 1970,
Email: fgholami@ucalgary.ca

If you have any concerns about the way you've been treated as a participant, please contact the Research Ethics Analyst, Research Services Office, University of Calgary at (403) 220-4283; email cfreb@ucalgary.ca. A copy of this consent form has been given to you to keep for your records and reference. The investigator has kept a copy of the consent form.

RECRUITMENT LETTER

Dear Sir / Madam

I, along with a PhD's student of Project Management Specialization in the Department of Civil Engineering at the University of Calgary am conducting an educational/professional research project on enhancing engineering deliverables for improving construction performance.

The purpose of this research is to enhance engineering deliverables through identifying engineering-related causes of poor construction performance and productivity loss in oil and gas industry, tracing them back to the engineering deliverables, and then eliminating or mitigating them by developing a framework, including tools, processes, or methods, that can be practiced during the engineering phases of oil and gas projects.

I, Dr. George F. Jergeas and my research students (Farshid Gholami) from University of Calgary would like to invite you to participate in this research and share your perspectives on this subject. You will be asked questions (in the form of interviews or questionnaire) related to your field of expertise and your kind co-operation is highly acknowledged. The information, gathered by me or my research student will remain with University of Calgary and will not be disclosed to anybody without your permission. This is to protect privacy and confidentiality of workers. Your decision to participate (or not) in the study will in no way affect your relations with/standing in your company by which you are employed, and that participation is not a condition of employment.

If you have any further questions, please contact me (Dr. George Jergeas; email: jergeas@ucalgary.ca) or my graduate student (Farshid Gholami email: fgholami@ucalgary.ca) at Project Management Specialization in Department of Civil Engineering, University of Calgary, Calgary, Alberta. In addition, if you have any concerns about the way you've been treated as a participant, please contact the Research Ethics Analyst, Research Services Office, University of Calgary, at (403) 220-4283; email cfreb@ucalgary.ca.

Thank you

Sincerely,

____

(**Dr. George F. Jergeas)**.