International Journal of Construction Engineering and Management 2014, 3(4): 117-133
DOI: 10.5923/j.ijcem.20140304.03

Factors Influencing Design Changes in Oil and Gas Projects

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Abstract Although many project time delays, cost overruns and quality defects—particularly in the oil sector—are attributed to design changes, the associated issues have not yet been thoroughly investigated. This study aims to provide a knowledge-based foundation for the evaluation and prediction of the impact of design changes on project performance, by identifying and analysing the main contributing factors. Using findings from a thorough literature survey, semi-structured interviews, and knowledge-mining from completed projects in the oil industry, a total of 28 factors were consolidated and grouped into four major categories. These factors were then ranked on their relative importance, based on data from a questionnaire survey distributed to a wide range of professions in the industry. An analysis of the results found that the most influential factors contributing to design changes are project scope definition, level of schedule overlapping, and project team's work experience, respectively. Ultimately, a predictive model has been proposed for determining the impact of design changes on project performance. The outcomes of this study form part of the authors' on-going research focusing on the analysis of the casual relationships between diverse factors to develop the predictive model.

Keywords Design changes, Impact of changes, Influencing factors, Project performance, Oil industry

1. Introduction

The term "Design Change" here refers to any addition, omission or adjustment to established project design requirements, documents, drawings or specifications. Design changes, whether voluntary or imposed, are common and inevitable in large industrial projects. Many project time delays, cost overruns and quality defects—especially in the oil sector—can be attributed to design changes, sometimes implemented in the belief that the changes will be beneficial for the project, but with unforeseen detrimental effects. A study performed by Jergeas [1], analyzing scope changes during the early stages of large oil sands projects in Alberta, showed few design milestones could be achieved on time, due to the stream of changes and trends.

Design changes and their antecedents and influences are known to depend on a variety of factors, including project characteristics, type and timing of changes, project team experience and project management effectiveness. Researchers and practitioners have long searched for ways to improve change evaluation and management practices in large projects. However, despite a considerable amount of recent research, very little is known about dealing with design changes and the contributing factors in oil and gas projects.

This study bridges the current knowledge gap by highlighting and analyzing the principal factors affecting design changes. It provides an increased understanding of crucial factors with predictive potential in assessing these sorts of changes, and also helps project participants determine the cost and schedule impact of changes on project performance more accurately.

The paper starts with a brief overview of the literature, followed by an explanation of the methodology used to identify, evaluate and rank the factors affecting design changes. The results of data analysis are discussed next, and to conclude, a conceptual model based on the most essential factors is proposed to recognize the pattern of the impact of design changes, and more accurately estimate the contingency and budget required to deal with these sorts of changes.

2. Background / Literature Review

Project changes, causes and impacts have been subject to a considerable amount of research and attention over the past years. An extensive review of literature reveals that studies on the general subject of project changes cover a

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Published online at http://journal.sapub.org/ijcem

broad spectrum of topics, including change causes and classification, change effects and change management system. In the early 1990s, the Construction Industry Institute (CII) set up a dedicated research team to carry out a series of studies on project changes, causes, and effects on project performance [2-5]. In addition to these efforts, academic researchers have also carried out some substantial research; the main findings of these studies have been summarized in the paragraphs.

2.1. Change Causes and Classification

Change causes are conditions or events that either directly trigger or contribute to a change in projects [6]. Owners and designers initiate changes as the project design is completed, to reflect basic changes in the project scope. Contractors often initiate changes to accommodate field conditions and to facilitate construction. Hsieh *et al.* (2004) analyzed change orders in metropolitan public projects in Taiwan [7]. They divided the causes of change orders into two main dimensions: "technical/construction needs" and "administrative needs". Sun and Meng (2009) proposed a taxonomy adopting a hierarchical structure: at the top level, change causes are divided into external causes, organizational causes and project internal causes [6].

Project changes have been classified in different ways by previous research studies. The main types of changes, adopted from the literature, are presented in Table 1.

2.2. Change Effects

Although project changes are sometimes beneficial or even essential (for example, in rectifying errors), the negative impacts associated with the implementation of changes should not be understated. They may lead to frustration, interruption in the flow of work, errors and rework, which, in turn, increase costs and delays, and decrease productivity. Figure 1 presents a list, derived through previous research, of the major effects of changes.

Table 1. Classification of Project Changes

Categories	Types	Description	References
Based on the scope of work	Project development change (PDC)	Changes that are required to execute the original scope of work or to obtain the original process basis	[8, 9]
	Scope change (SC)	Changes in the base scope of work or process basis	
Based on the view of different parties	Formal or directed change	A change that occurs when the owner or its agent directs a change, and all parties agree that the change is actually a change.	[2, 10-13]
	Constructive change	A change that occurs when the contractor is ordered to perform work that it views as an increase in its scope, whereas the owner or owner's agent feels that the work is included in the contractor's original scope.	
	Cardinal change	A change that qualifies as a breach of contract by the owner	
Based on the effect of change	Additive change	Changes that involve addition of work	[2]
	Deductive change	Changes that involve deletion of work	
	Demolition and Rework	Changes that involve rework	

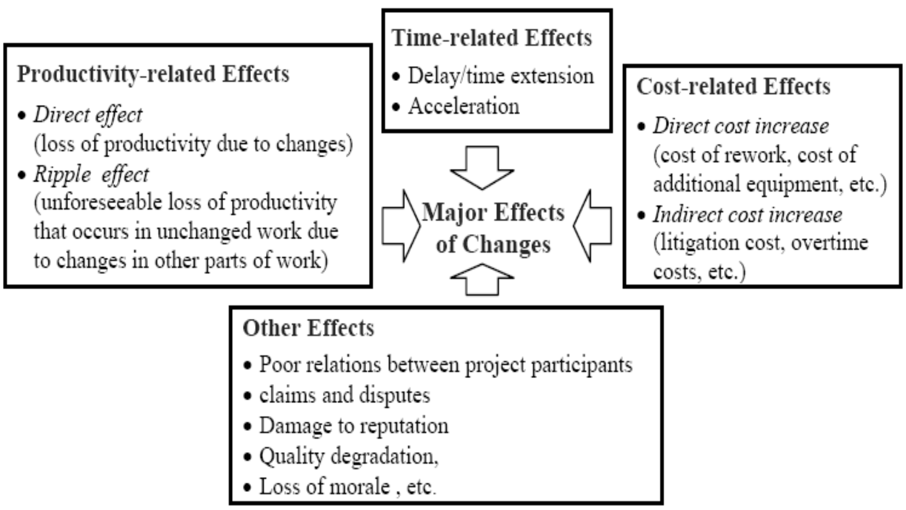

Figure 1. Summary of the detrimental effects of changes

The first effort to quantify the effect of change orders on labor efficiency was Leonard's [14, 15]. The results of his study revealed that the type of work affects the degree of the impact of change orders on labor productivity. Construction Industry Institute (CII) change order research team also conducted significant studies on the impact of project changes [2, 3], and these studies confirmed a productivity loss due to changes. Years later, Hanna et al. (1999a, 1999 b) quantified the labor efficiency lost due to change orders in the electrical and mechanical construction industry [11, 12]. The impact of project changes has also been investigated with the combined analysis of a number of influential factors including the magnitude of changes, the timing of changes, the presence of fast tracking, and the project delivery method [16-19]. The main findings have been:

- Amount of change is negatively correlated with productivity and total project costs.
- Amount of construction changes for a fast-tracked project is not significantly greater than for non fast-tracked projects. However, aggressively scheduled projects do have higher amount of design changes.
- Cost changes are more toward the positive increase side for Design-Build (D/B) projects, while they tend to decrease for Design-Bid-Build (D/B/B) projects.

The relationship between project delivery system and project changes was examined by Konchar and Sanvido [20]. They found that Design-Build (D/B) approach, in general, experienced fewer changes than Design-Bid-Build (D/B/B) approach.

2.3. Change Management System

In the early 1990s, the Construction Industry Institute (CII) research team carried out a number of studies on project change management [21]. According to CII report, the principles of effective change management are: promoting a balanced change culture, recognizing change, evaluating change, implementing change, and continuously improving from lessons learned. A set of recommended best practices was then published by CII to improve project change management system. In addition to CII publications, other researchers have investigated methods to improve current change management practices [22-27]. Studies conducted by Sanders and Zou and Lee [28, 29] investigated the impact of change management practices on project change cost. The results of these studies revealed that the individual practices have different levels of influence on project change cost and that applying change management system is helpful in lowering change costs. They also explored the relationship between project characteristics and the implementation of project change management best practices.

2.4. Research Rationale and Motivation

Review of the literature shows that current research largely quantifies the impact of change orders on labour efficiency in the construction industry. There has also been limited research on cause and effect analysis of changes on project cost and schedule. While these existing studies present valuable empirical work on the nature and impact of change orders, very few have focused on issues related to design changes—factors contributing to this kind of change have not been thoroughly investigated. As there is not any significant study demonstrating which factors most contribute to design changes, particularly in oil and gas projects, further research is clearly needed in developing tools to deal with design changes for each sector of the industry.

Building on the foundation of existing research works on the subject of project changes, the present study was conducted to identify key factors contributing to design changes, to understand the behaviour of these factors, and to prioritize the factors that should be considered in the impact analysis of design changes.

3. Objectives and Scope

The main goal of this study is to provide a knowledge-based foundation for the evaluation and prediction of the impact of design changes on project performance, by identifying and analyzing the main factors which contribute to this kind of change.

The specific objectives of this research include:

1. To identify and categorize the principal factors influencing design changes in oil and gas projects
2. To evaluate the relative importance of contributing factors as perceived by project management team
3. To outline a conceptual model for pattern recognition of the impact of design changes on project performance, with consideration of the crucial factors prioritized earlier in the study

The scope of this study is the investigation of factors influencing design changes throughout different phases of project execution, from authorization for expenditure to project completion. The focus here is on oil and gas projects located in Alberta, Canada.

4. Research Methodology

The research method was a combination of qualitative and quantitative techniques, undertaken in two stages. The first stage began with data collection through a comprehensive literature review, a number of semi-structured interviews with key experts in the industry, and knowledge-mining from four completed projects. The results were then qualitatively analyzed to form a list of 28 factors grouped into four major categories (refer to section 4.3.1). The interviews were used to refine the list of factors and to facilitate development of the empirical research questionnaire. The majority of interviewees were senior experts with a strong technical and work background on the subject of the study (average experience of 23 years).

In the second stage, a questionnaire survey was designed and administered to 115practitioners in oil and gas companies to investigate their perceptions of the significance of influencing factors associated with design changes. The survey data was then statistically analyzed and validated to create a conceptual framework used to outline development of a predictive model for impact analysis of design changes in oil industry projects.

4.1. Identification and Classification of Factors

To identify a preliminary list of factors influencing design changes, data obtained from literature survey was qualitatively analyzed and refined through the researchers' own experience, interviews with an expert group of seven project management professionals in the industry, and in-depth analysis of project documentation taken from four completed EPC (Engineering, Procurement, and Construction) projects in the oil and gas sector, located in Alberta, Canada.

The interviewees were selected using convenience sampling; a number of project managers and project engineers working in oil and gas companies were first contacted by telephone or email, informed of the purpose of the study and invited to participate. Those who indicated interest were requested to arrange a time for an interview. The interviews generally spanned between 45 minutes to one hour, and focused on the experience of practitioners in relation to evaluation and administration of design changes in projects. Using the content analysis method, the researchers simultaneously analysed the information obtained through interviews and knowledge mining of project documentation at different stages of data collection.

The main factors contributing to design changes have been categorized into four groups:

1. Project-related factors
2. Factors related to project management practices
3. Human-related factors
4. Change-related factors

The list of factors and a brief description of each factor, is provided in Table 2 for clarity.

4.1.1. Project-related Factors

The importance of project-related factors in the impact analysis of project changes has been echoed in previous research works [11, 12, 16-18, 30-32]. Oil industry projects have particular characteristics that may contribute to design changes, but type, size, and complexity of a project; contract type and delivery method; level of schedule overlapping and compression; project organization structure and the percent complete of a project are among the main attributes categorized here.

4.1.2. Factors related to Project Management Practices

Project management practices, tools and techniques play an important role in controlling design changes and the impact of changes on project performance. The main factors in this group include pre-project planning; scope definition; project management systems, tools, and procedures; design data freezing; level of stakeholders' participation during project execution and design interdisciplinary coordination. Kuprenas (2003) considered the influence of project management practices as a significant factor on design phase cost performance [33]. The study performed by Zou and Lee [29] explored the relationship between change management practices and the project change cost. The results revealed that the application of a change management system is helpful in lowering the project change cost.

4.1.3. Human-related Factors

Human-related factors are another group influencing project changes and their impacts in turn on project performance. This group consists of a wide range of attributes reflecting work experience, educational level, skills, personality and background, management support, and staff turnover. The study performed by Hanna et al. [11, 12] emphasized the role of a management team's work experience in handling change orders.

4.1.4. Change-related Factors

Change-related factors are central to our understanding of the origin and nature of changes and their impacts. Type of changes, timing of change occurrence, frequency of changes, and processing time of changes are included in this category. A number of previous research studies have investigated change-related factors [11, 12, 16, 19, 34]. Studies by Ibbs [16, 19] revealed that the greater the amount of change, the lower the efficiency—and also, late project changes more adversely affect labour productivity than early changes.

4.2. Questionnaire Design

A web-based survey administration tool, "Survey Monkey", was used for design and hosting of the questionnaire. The first version was developed after the literature review and empirical interviews. Before an industry-wide survey was launched, a pilot study was conducted, aimed at testing its suitability and comprehensibility. The final version of the questionnaire has two parts: the participant demographic questions and the principal section ranking the factors on a five-point Likert scale.

The survey consisted of 38 questions, including open-ended questions soliciting feedback on additional comments on the topic. Only a few additions were made to the list by respondents, and these additions were related to the 28 factors originally presented to the respondents.

4.3. Sample Size and Population Characteristics

Sample size determines the degree of statistical confidence available for analysis and interpretation. When sample size increases, sample error decreases and sample reliability increases. Similarly, when population variance increases, sampling error increases and sample reliability decreases [35].

Table 2. Factors Influencing Design Changes

Category	Factors	Descriptions
Project-related factors	Size of project	Indicators that identify the size of a project includes total estimated duration, total estimated cost, total budgeted manhours, number of equipment, and diversity of design disciplines.
	Type of Project	The focus of this survey is on oil and gas projects. Accordingly, projects are categorized into three major groups: Upstream (exploration and production), Midstream (transportation and storage/pipeline), downstream (oil refineries, petrochemical facilities, gasification plants, etc.)
	Complexity of project	The complexity is described by use of proven or unproven technology, number of process steps, facility size / process capacity, and proven or new construction methods.
	Contract type	This applies to the contracts awarded after project authorization. Different types of contract include Cost Reimbursable, Guaranteed Maximum Price, Lump Sum, Unit Price, and Hybrid – Reimbursable Converted to Lump Sum.
	Project delivery method	Commonly used project delivery approaches in the oil sector are: EPC (engineering, procurement, and construction), EPCM (engineering, procurement, and construction management), EP and C (separated).
	Level of schedule overlapping	The degree of overlapping between various phases of a project or between key activities at each phase of a project.
	Level of schedule compression	The degree of compression of project duration (overall duration and the duration of each phase).
	Project Organization structure	Three basic organization structures are: Functional Structure, Project Task Force Structure, and Matrix or Combined Structure.
	Project percent complete	This refers to the percent complete of works at the time a change arises.
	Availability of vendor information	The degree of availability of vendor data for equipment at the first stage of a project.
	Level of multi-office execution	The degree of involvement of multiple offices to complete the scope of work. The two main elements of multiple office execution are a lead office which provides leadership and supporting offices which participate in the work under control of the lead office.
Factors related to project management practices	Pre-project planning efforts	This refers to the adequacy of PPP activities. Pre-project planning includes organizing project team, analyzing technology, preparing conceptual scope, defining project risks and developing project execution plan.
	Project scope definition	The focus is on the completeness of project scope definition as well as the integrity of the design scope before the execution phase (at Authorization For Expenditure /AFE).
	Project management systems and tools	The effectiveness and integration of project management systems and tools (time and cost management, change management, risk management, quality management, etc.) during project execution.
	Project management procedures	This refers to how well management procedures (including coordination procedure, project control procedures, safety and quality assurance procedures, etc.) have been defined.
	Level of stakeholders' participation during project execution	Participation of project stakeholders, including owner, designers, engineering consultants, vendors, and contractors affects the impact of design changes during project execution.
	Design data freezing	The level of freezing project basic design data before the execution phase (at AFE).
	Constructability reviews	The degree to which constructability is considered during the design phase of a project.
	Design interdisciplinary coordination	The level of coordination between different design disciplines is described by the frequency of design review meetings.
Human-related factors	Project management team's work experience	This refers to the aggregated work experience of a project management team.
	Project Management team's education level	This refers to the average education level of project management team.
	Project key personnel's skills and characteristics	The effectiveness of a project team is described by managerial and technical skills, social background, customs, life style, personal characteristics, etc.
	Project key personnel turnover	This refers to the turnover rate of the key personnel during project execution. High employee turnover costs companies time, money and effort and contributes to project changes and performance.
	Level of senior management support/engagement	The involvement of Company's senior management during project execution phase is considered.

Table 2. Factors Influencing Design Changes (Continued)

Category	Factors	Descriptions
Change-related factors	Type of changes	Design changes are classified in different ways. Two major types of changes are: Design Development Changes which are required to execute the original scope of work and Scope Changes which occurs in the base scope of work.
	Timing of change occurrence	Changes may occur at different stages of a project. Changes occurring later in the project have a different level of impact compared to changes occurring early in the project.
	Frequency/number of changes/trends	This factor indicates the relationship between the frequency of changes/trends and the impact of changes on project performance.
	Processing time of changes	This refers to the time between initiation of a change and implementation of a change.

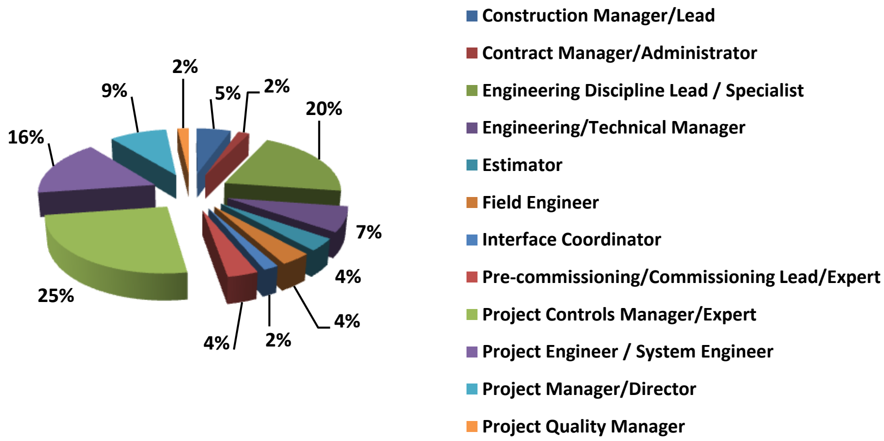

Figure 2. Respondents' positions demographics

The population of interest for this study was project team members involved in administrating and controlling project changes in oil and gas projects located in Alberta, Canada. A number of contact persons were identified for the companies to coordinate the administration of the survey. The questionnaires were addressed to the contact persons and then were distributed to the team members of the projects.

For the purposes of this study, the desired sample size was calculated from Eq. (1) [36]:

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

Where: n = sample size

Z = Z value (e.g. 1.645 for 90% confidence level)

p = percentage possibility of picking a choice, expressed as decimal.

e = margin of error, expressed as decimal

According to Lohr [36], generally a value of 0.5 is assumed for the value of p. Considering a level of confidence of 90% and a margin of error of 10% for this research, the required sample size is 67.

To achieve the target sample size, the survey was distributed to a total of 115 professionals representing a wide range of professions dealing with project changes. However, from 115 questionnaire administered, a total of 71 questionnaires were returned of which only 55 were properly completed. This represents a response rate of 48%, and was achieved after several efforts in follow-up. Table 3 provides a summary of the statistics of the survey.

The analysis was thus completed on the basis of 55 responses. Using the same formula, the margin of error was calculated as 12%, which remains acceptable. Although the sample size was not large, the quality of the data was considered to be reliable due to the relevant industry experience of the respondents.

Table 3. Summary Statistics of Questionnaire Survey

Survey	Values
No. of questionnaire distributed	115
No. of responses received	71
No. of incomplete/invalid responses	16
No. of valid responses (considered in the data analysis)	55
Valid response rate %	48%

4.4. Demographic Analysis of Survey Participants

Descriptive statistics were applied to the demographic variables, allowing the researchers to examine the characteristics of participants in the sample. Given 55 valid responses from the web-based questionnaire, Figure 2 and Figure 3 show the position and the years of experience demographics of the respondents, respectively.

The majority of respondents (60%) have relevant experience of between 10 to 20 years in oil and gas projects. Furthermore, the majority of the respondents were from disciplines directly involved in design change administration (project management and design engineering teams). This suggests most of the respondents have been dealing with project changes for a considerable number of years and thus were suited to comment on the issues dealt with in the survey.

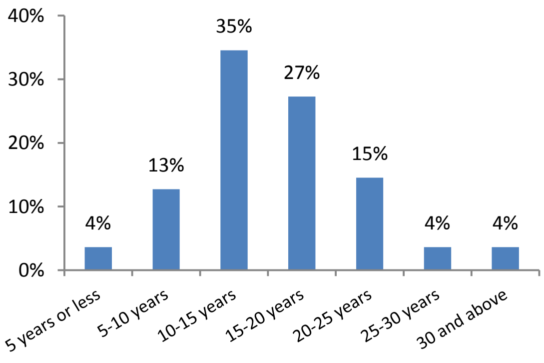

Figure 3. Respondents' work experience demographics

4.5. Analysis and Ranking of Factors Contributing to Design Changes

The quantitative analysis of factors was conducted using *Microsoft Excel* and the tool *Statistical Package for the Social Sciences* (SPSS 21). The survey required practitioners to use a five-point Likert scale (1 for "not important at all", through "slightly important", "moderately important", and "important" to 5 meaning "very important") to indicate their perceptions of the significance of different factors affecting design changes. The procedure used in analysing the results established the relative importance index (RII) for various factors. This index was computed for each factor according to Eq. (2) and Eq. (3):

$$RII = \left[\sum_{i=1}^{i=5} wifi \right] \times \frac{100\%}{n} \quad (2)$$

$$wi = \frac{i}{A} \quad (3)$$

Where: RII = relative importance index for each factor
f_i = frequency of responses for rating point i in the scale
n= total number of responses
w_i= weight for rating point i in the scale
A = highest possible score (i.e. 5 in this case)
i = rating 1-5

The same approach was used by References [37- 40] for the analysis of ordinal data collected through a Likert scale.

Table 4 presents the results of data analysis from the survey. This table contains a summary of all factors contributing to design changes and the respondents' perceived values for the level of importance of each factor. It also includes the sum of weighted values, the relative importance index, a ranking of factors in each group, and the overall ranking of each factor.

The sum of weighted values is calculated by multiplying the weight for each rating point (the level of importance) with the relevant frequency of response. The relative importance index is measured by dividing the sum of weighted values by the total number of respondents for each factor. The factors are then ranked within and across the categories.

The results presented in Table 4 show the most important factors influencing design changes are: level of schedule overlapping (among project related factors), project scope definition (among factors related to project management practices), project management team work experience (among human-related factors), and type of changes (among change-related factors).

5. Results and Discussions

Figure 4 represents a comparison of average relative importance indices for the different categories of factors. This comparison demonstrates that all categories have significant influence on the impact of design changes, with an average importance index of 66% to 76%. The top-ranked category is factors related to project management practices, with an average relative importance index (RII) value of 76%.

The following sections are devoted to a more detailed discussion of the main findings regarding the three highest-ranking factors (across the categories) contributing to design changes in oil and gas projects. An overview of the overall ranking of the factors in Table 4 shows that "project scope definition" ranks first with an RII of {997.8}, followed by "level of schedule overlapping" with an RII of {95.3}, and then "project management team's work experience" with an RII of {92.0}.

5.1. Project Scope Definition

Success during the detailed design, construction and start-up phases of a project depends profoundly on the level of effort expended during the scope definition phase, as well as the integrity of the project definition package [41]. According to the Construction Industry Institute [42], one of the most significant problems to affect a construction project is poor or inadequate scope definition. Poor scope definition results in high amounts of design changes throughout the execution phase, causing scope growth, loss of productivity, rework and ultimately an increase in the total cost and duration of project.

The importance of project scope definition and its contribution to the project success have also been highlighted in other previous research studies [42, 43]. These studies indicate that there is a positive relationship between the level of project scope definition and the level of project success.

Table 4. Relative Importance Index Computation and Ranking for Factors Influencing Design Changes

Factors	No. of Respondents	Unknown	Not Important	Slightly Important	Moderately important	Important	Very important	Sum of Weighted Values	Relative Importance Index (RII)	Rank in Category	Overall Rank
Project-related factors											
Size of project	55		15	16	11	7	6	27.6	50.2	9	26
Type of Project	55		9	29	11	4	2	25.2	45.8	11	28
Complexity of project	55		1	7	21	15	11	38.6	70.2	5	18
Contract type	55		5	23	10	7	10	31.8	57.8	7	23
Project delivery method	55		10	18	10	9	8	30.4	55.3	8	24
Level of schedule overlapping	55				2	9	44	52.4	95.3	1	2
Level of schedule compression	54	1			7	16	31	48	88.9	2	4
Project Organization structure	53	2	16	12	13	9	3	26	49.1	10	27
Project percent complete	54	1		1	14	22	17	43.4	80.4	3	5
Availability of vendor information	55		5	13	17	11	9	34.2	62.2	6	21
Level of multi-office execution	55			4	25	18	8	39	70.9	4	15
Factors related to project management practice											
Pre-project planning efforts	54	1		1	11	29	13	43.2	80	2	6
Project scope definition	55			1		3	51	53.8	97.8	1	1
Project management systems and tools	55			5	17	23	10	40.6	73.8	5	12
Project management procedures	55			3	22	20	10	40.4	73.5	6	13
Level of stakeholders' participation during project execution	55		2	17	17	10	9	34.4	62.5	8	20
Design data freezing	55				20	24	11	42.2	76.7	3	9
Constructability reviews	55			2	28	19	6	38.8	70.5	7	16
Design interdisciplinary coordination	55			1	14	34	6	42	76.4	4	10
Human-related factors											
Project management team's work experience	55			1	2	15	37	50.6	92	1	3

Table 4. Relative Importance Index Computation and Ranking for Factors Influencing Design Changes (Continued)

Factors	No. of Respondents	Unknown	Not Important	Slightly Important	Moderately important	Important	Very important	Sum of Weighted Values	Relative Importance Index (RII)	Rank in Category	Overall Rank
Project Management team's education level	55		4	13	19	15	4	33.4	60.7	5	22
Project key personnel's skills and characteristics	55			7	13	24	11	40.8	74.2	2	11
Project key personnel turnover	54	1		6	17	21	10	39.4	73	3	14
Level of senior management support/engagement	55			16	22	10	7	34.6	62.9	4	19
Change-related factors											
Type of changes	55		2	2	8	25	18	44	80	1	6
Timing of change occurrence	55		1	3	13	20	18	43.2	78.5	2	8
Frequency/number of changes/trends	54	1	1	5	21	19	8	38	70.4	3	17
Processing time of changes	55		10	18	9	12	6	30.2	54.9	4	25

5.2. Level of Schedule Overlapping

Use of schedule overlapping is becoming increasingly common in oil industry projects due to tight project schedules and budgets. To shorten project overall duration, the design and construction phases are overlapped to allow different sections to be designed and built in parallel. Many industry practitioners believe that such scheduling may result in more changes and reworks, leading to more delays, and higher costs to projects. According to the Fast Track Manual published by the European Construction Institute (ECI) in 2002, the overlapping of design and construction introduces significant additional risks due to the inter-relationship between various parts of the design [44].

The findings of the current study (i.e. Table 4) identify level of schedule overlapping as one of the most significant factors contributing to design changes. This finding supports the results of the study performed by Ibbs [17] showing that aggressively scheduled projects do have higher amounts of design change than non-aggressively scheduled projects.

5.3. Project Management Team's Work Experience

Of human-related factors, the project management team's work experience emerged as the most influential factor, based on the relative importance indices presented in Table 5. This finding is consistent with the study conducted by Hanna et al. [11, 12]. They investigated the impact of change orders on labour efficiency with consideration of project manager's work experience as one of the independent variables. The study showed that the more experience a project manager has, the more that individual is able to reduce inefficiency.

A project management team consists of different key roles including project managers, engineering managers, project control experts, design discipline leads, contract administrators, procurement and construction managers, and so forth. The work experience of these team members is one of the significant elements of team competency in dealing with project changes.

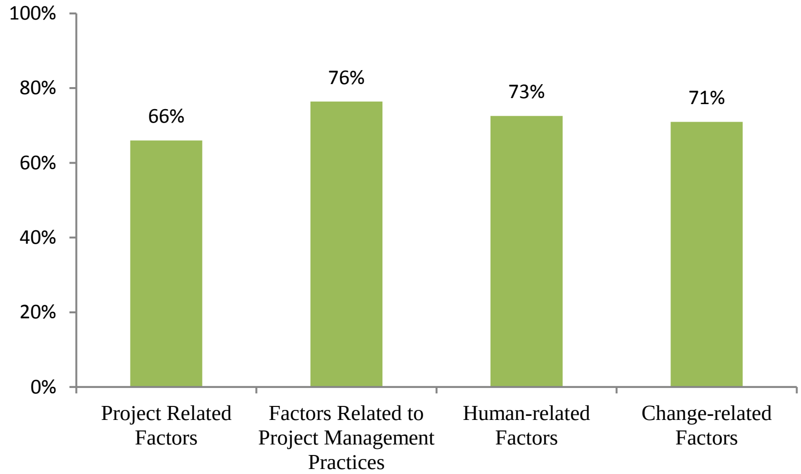

Figure 4. Average relative importance indices for different categories of factors

Table 5. Summary of the Interviewees' Profile for Validation

No.	Role / Designation	Years of Experience	Industry	Interview Duration (min)
1	Project Director	29	Oil and Gas	30
2	Project Manager	24	Oil and Gas	45
3	Project Manager	21	Oil and Gas	30
4	Project Control Manager	22	Oil and Gas	45
5	Planning Lead	16	Oil and Gas	20
6	Engineering Manager	21	Oil and Gas	45
7	Project Engineer	15	Oil and Gas	30
8	Contract Manager	19	Oil and Gas	30

6. Validity and Reliability

6.1. Validity

"Validity" refers to the degree to which a survey instrument measures what it is supposed to be measuring [45]. It is thus a measure of the soundness of the research.

The validity of this survey tool was determined using the face validity of the questionnaire. This validity was addressed by obtaining feedback from different experts in the field of study and from that feedback deriving corrections to be made to the questionnaire. In addition, a pilot study was conducted to make sure that the questionnaire was evaluating what it was intended to evaluate.

For validation of the results, the researchers used a number of semi-structured interviews with experienced experts who were dealing with design changes in the industry. Table 5 provides information on the interviewees' profiles, and indicates that the interviewees had extensive experience in handling oil and gas projects ranging from 15 to 29 years, with an average of 21 years of professional experience. All of them were also familiar with change administration and management practices. Analysis of the responses shows that the respondents endorsed the validity of the results.

6.2. Reliability

Reliability is a measure of consistency and stability of data [46]. The reliability of this survey instrument was determined using Cronbach's α statistics, one of the most common reliability tests. This statistics uses interim correlations to determine whether constituent items are measuring the same domain [47]. Cronbach'sα reliability coefficient normally ranges between 0 and 1. The closer α is to 1.0, the greater the internal consistency of the items in the scale [48]. Reliability of data is considered at low level when Cronbach's α is less than 0.3—this suggests the data is not reliable and cannot be accepted. Reliability is at high level when Cronbach's α is more than 0.7 [40, 49-51].

In this study, the value of Cronbach's α for all factors is 0.879, which indicates that strong agreement exists between industry practitioners in ranking of the factors and accordingly that the survey instrument is a reliable tool. The reliability test was conducted using *SPSS* version 21; the test results for each group of factors and the overall Cronbach's α for the entire data are presented in Table 6.

Table 6. Reliability Test Results

Category	Cronbach's α
Project Related Factors	0.783
Factors Related to Project Management Practices	0.716
Human-related Factors	0.733
Change-related Factors	0.680
Overall Data	0.879

7. A Conceptual Model to Predict the Impact of Design Changes on Project Performance

Based on the results of the industry-wide questionnaire survey, the authors intend to demonstrate how the findings of this study can serve to develop a predictive model for pattern recognition of the impact of design changes on project cost and schedule performance. This predictive model assists project participants to more accurately estimate contingency and budget reserves at the point of project sanction.

Taking into consideration the most significant factors identified in the previous stage, a number of indices are proposed as the independent variables of the model, while the dependent variables include the cost and schedule performance indicators. The following section briefly describes the basis of the predictive model and its components. Detailed steps to develop the model linking the variables and testing the hypotheses will be addressed in the authors' future research.

The structure of the model is shown in Figure 5. The predictive model will be developed through three main stages:

1. Determining the predictive/independent variables among the most influential factors identified and prioritized in the current study.
2. Determining reasonable dependent variables, taking into consideration the performance indicators that properly reflect the impact of design changes.
3. Formulating the predictive model using the existing techniques for prediction of the outcomes of engineering and management systems.

The findings of the current study (i.e. Table 4) show that the three most influential factors maintaining a relative importance index greater than 90 are: project scope definition, level of schedule overlapping, and project management team's work experience. These factors have been used to define the rating indices being considered as independent variables in the model.

The option of considering these factors is justified by the availability of information before the project execution phase (i.e. the point of project sanction) and also the predictability potential of the factors, as verified through interviews with industry experts.

Independent variables/predictive variables

Three rating indices have been suggested by the authors to quantify the most influential factors having predictive potential in assessing design changes. They will be referred to in the model as the independent variables.

Project Definition Rating Index (PDRI)

The Project Definition Rating Index (PDRI), developed by Construction Industry Institute [42], will be used to evaluate the completeness of the scope definition—one of the most significant factors contributing to design changes. This index is a comprehensive checklist of 70 scope definition elements grouped into 15 categories, and further classified into three main sections.

The extent of definition of the individual elements is evaluated and scored. The lowest score possible is 70, which refers to a perfectly-defined scope definition package incorporating all of the seventy elements. The highest obtainable score is 1000, which refers to a completely undefined project. CII reports [42, 52] present more detailed information on the development and application of PDRI.

Project Schedule Overlapping Index (PSOI)

Commencing the construction of a facility before the design activities are complete is a common practice in the oil industry. Overlapping the design and construction phases is presumed to shorten the overall duration of a project. However, one of the major risks associated with this overlapping is an increase in the magnitude of design changes. For the purpose of the predictive model, the degree of schedule overlapping has been measured as the maximum number of weeks in common between the completion of the design and the start of fabrication or construction (see Eq. (4)).

$$PSOI = \left(\frac{Max\left(X_1, X_2\right)}{Y} \right) \times 100 \qquad (4)$$

Where: X_1 = Number of weeks common between detailed design and fabrication

X_2 = Number of weeks common between detailed design and construction

Y = Total project duration (weeks)

Figure 6 illustrates a schematic view of schedule overlapping between detailed design, fabrication and construction phases of an EPC project. The index variables (X_1, X_2, Y) have also been shown in the figure.

Project Management Team Competency Index (PMCI)

There are different perceptions of project management competency between project managers and senior industry management. A number of research studies have been conducted focusing on different behavioural and personal characteristics, and various skill areas of high performing project managers [53-57]. The term "competency" has been defined in the literature as the "underlying characteristics of an individual…causally related to criterion-referenced effective and/or superior performance in a job or situation" [58, 59]. A Project Management Team Competency Index (PMCI) has been defined by the authors, and is an independent variable in the predictive model. To develop the index, the competency has been broken down into three main component parts derived from the human-related factors identified in this study: work experience, education level, skills and characteristics.

The PMCI is a numerical aggregate of these three components, and references to the overall competency level of a project management team in handling design changes. An example table for project management team competency index is presented in Figure 7.

The process of developing the index is not in the scope of this paper and will be presented in the authors' future research papers.

Dependent variables

Researchers and industry experts have used a variety of measures to assess project performance. For the purposes of this study, those indicators providing insight into how design changes affect project cost and schedule performance are selected as dependent variables. The focus here is on the direct impact of changes on the cost and schedule performance, for which historical data can be extracted from project trend and change order logs. The indicators suggested by the authors are calculated as per Eq. (5) and (6):

$$\text{Design Change Cost Factor \%} = \left(\frac{X_c}{Y_c} \right) \times 100 \qquad (5)$$

Where: X_c = Cumulative cost of design changes to date (extracted from change and trend log)

Y_c = Project initial budget (original cost)

$$\text{Design Change Schedule Factor \%} = \left(\frac{X_s}{Y_s} \right) \times 100 \qquad (6)$$

Where: X_s = Total time extension/acceleration due to design changes to date (extracted from change and trend log)

Y_s = Project initial duration

Predictive Model

There are different modelling techniques used to predict the outcomes of engineering and management systems. The major techniques include regression models, fuzzy techniques, neural networks, and hybrid techniques.

Regression models are well established and easy to understand, so are suggested here to examine the relationship between the variables and to establish the predictive model based on the best fit line through the data. Regression methods outline the distribution of a variable ("dependent variable") with the help of one or more predictor variables ("independent variables"). Simple regression analysis involves only one predictor when investigating its relationship with the dependent variable. In multiple regression, more than one predictor is studied for their relationship with the dependent variable [43].

Considering that the predictive model proposed in this study comprises more than one continuous numerical variable, multiple linear regression analysis can be examined at the first stage. The regression equations derived to measure the impact of design changes on project cost and schedule performance can be expressed as equations (7) and (8):

$$Y_1 = a + b_1 X_1 + b_2 X_2 + b_3 X_3 + e_1 \qquad (7)$$

$$Y_2 = c + d_1X_1 + d_2X_2 + d_3X_3 + e_2 \quad (8)$$

Where: Y_1 = Design change cost factor

Y_2 = Design change schedule factor

X_1 = Project definition rating index (PDRI) value

X_2 = Project schedule overlapping index (PSOI) value

X_3 = Project management team competency index (PMCI) value

a = the constant and intercepts at Y1 axis

c = the constant and intercepts at Y2 axis

b_1 to b_3 = Estimated regression coefficients of independent variables of the regression equation (7)

d_1 to d_3 = Estimated regression coefficients of independent variables of the regression equation (8)

e_1 = Error in the regression equation (7)

e_2 = Error in the regression equation (8)

These coefficients and constants are obtained by regression analysis of dependent variables (performance indicators) and independent variables (PDRI, PSOI, PMCI), which will be acquired by using real project data. Accordingly, the regression equations maybe found to be non-linear for best fit depending on the data obtained from projects.

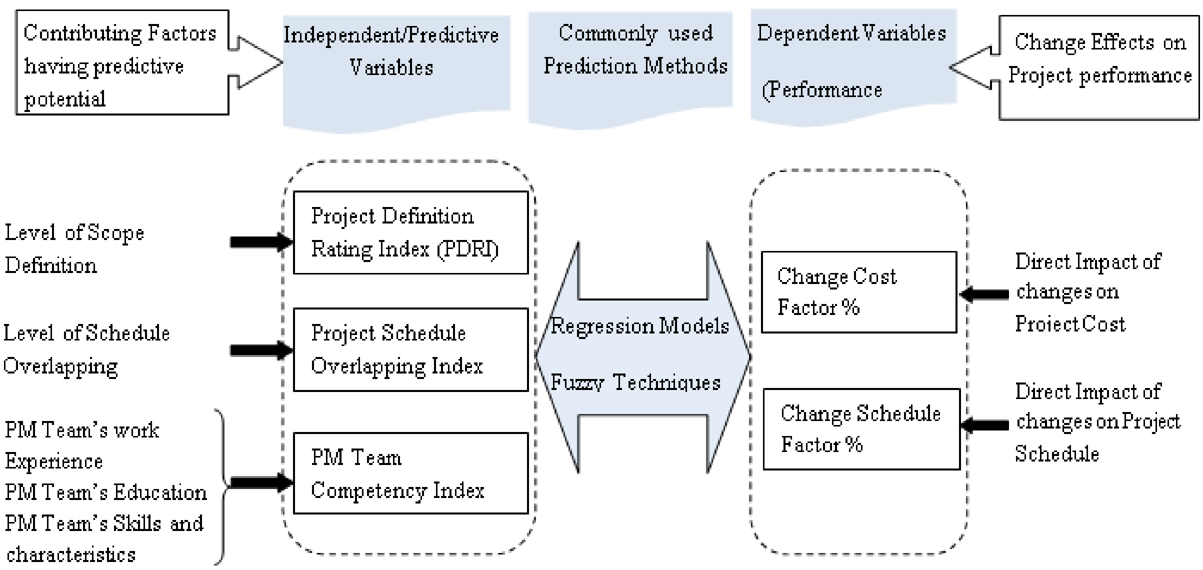

Figure 5. A conceptual framework for pattern recognition of the impact of design changes on project performance

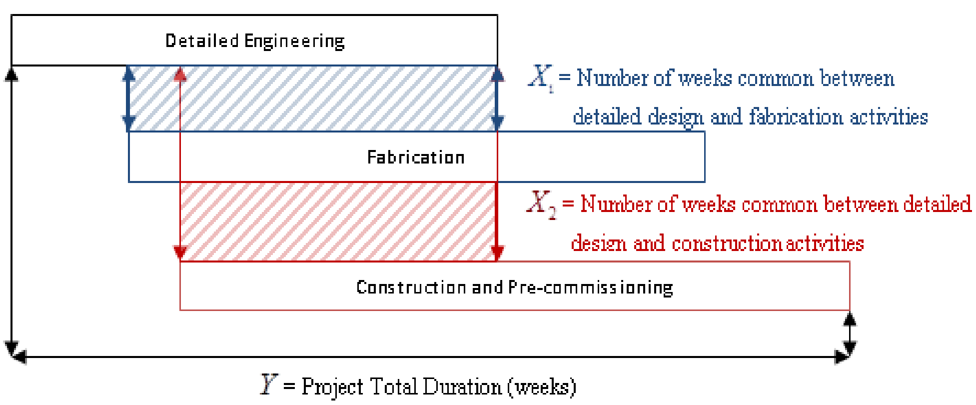

Figure 6. Schedule overlapping between design, fabrication and construction phases of an EPC project

PM Team Key Roles (i)	The importance of the Role (WF%)	Years of Work Experience (relevant) - WF% (40.5%)		Education Level - WF% (26.8%)				Skills and Characteristics - WF% (32.7%)		Competency Score for PM Role i
		Less than 30 years	30 years and above	Secondary school Diploma / Irrelevant university degree	professional certificate/vocational training (relevant)	University graduate degree (relevant)	University post graduate degree / PhD or Masters (relevant)	Technical Skills	Human-related skills and charasteristics	
		Max Score = 100		Max Score = 100				Max Score = 100		
		$\frac{100}{30} \times Years\ of\ experience$	100	10	15	60	15	Max 40	Max 60	
Project Manager/Director	8.0%									
Technical Manager	7.6%									
Procurement/Post Order Manager	5.5%									
Construction Manager	6.6%									
Project Control Manager	7.3%									
Contract Manager/Administrator	7.3%									
Project Engineer	6.8%									
Process Lead	6.7%									
Piping Lead	6.7%									
Electrical Lead	6.3%									
Civil /Structural Lead	6.3%									
Instrumentation & Control Lead	6.2%									
Mechanical/Machinery Lead	6.3%									
Pre-commissioning Lead	4.7%									
HSE Lead	4.0%									
QA/QC Lead	3.9%									
PM Competency Index										

Figure 7. An example table for PMCI

8. Summary and Conclusions

This paper reports on the findings of a survey conducted among practitioners in the oil industry to identify and prioritize factors influencing design changes during project execution. The required information has been collected through semi-structured interviews, knowledge-mining of completed projects, and a questionnaire survey. By analyzing and ranking the influencing factors from the viewpoint of industry practitioners, this study provides a fresh perspective on the most significant factors affecting design changes in oil and gas projects. The results show that the top three essential factors are:

1. Project scope definition
2. Level of schedule overlapping
3. Project management team's work experience

The reliability analysis of the results suggests a strong consistency among respondents in their perceptions of the most influential factors associated with design changes.

Good understanding of design changes, antecedents and influences is essential for effective change evaluation and management during project execution. The outcome of this study can be applied as a useful framework by project management professionals to distinguish the early warning signs of changes and to take necessary actions to prevent or mitigate the negative impacts of changes.

Based on the findings of the industry survey, the authors have also proposed a conceptual model for prediction of the impact of design changes on project performance. The independent variables of the predictive model are described by three rating indices quantifying the most influential factors identified in this study. These indices are: project definition rating index, project schedule overlapping index, and project management team competency index.

The predictive model presented in this study maybe used by project participants to assess the magnitude and the impact of design changes at the beginning stage of a project. Owners will therefore be able to assign more realistic schedule and budget to projects and contractors will be able to improve their cost estimates and more appropriately prepare their contingency plans before participating in a bid.

Furthermore, the rating indices used to develop the model may be utilized as practical tools to assess different attributes of a project throughout project execution, including scope definition, level of schedule overlapping, and competency level of project management team.

9. Contributions

The factors identified and evaluated in this research provide a knowledge-based foundation for the impact analysis of design changes, which may assist project stakeholders to improve the accuracy of cost estimates and project budgets. Through this research study, the authors have attempted to highlight the factors indicative of increasing the project cost and schedule due to design changes, so that appropriate actions can be undertaken to decrease the negative effects of changes. These findings are seen as significant contributions to the oil industry in controlling and managing design changes. By having a systematic approach in dealing with project changes, the performance of works will be improved and the likelihood of project success will be increased.

The outcome of the predictive model may also increase owners' and contractors' certainty as to the cost and schedule impact of changes, and as to the amount of compensation that should be considered in the overall estimated budget to cover the cost associated with design changes.

Academically, this research may serve as a guide and theoretical platform for further research, specially, on the subject of project design changes.

10. Limitations and Implications

As with any study employing interview and questionnaire survey and statistical data analysis techniques, the research process and the results are inherently vulnerable to some issues beyond the researchers' control. These issues include the sample selection and respondents' biases.

The sample selection was not entirely blind, as a survey across respondents with different experiences would create an excess amount of variation not relevant to the study. For the purpose of internal validity, the respondent group was limited to a relatively homogenous group of experts who were involved in coordinating and managing project changes in Alberta.

Another limitation is related to the influence upon data of the respondents' biases. To eliminate some biases, data monitoring was performed prior to the analysis stage. As there was no pattern in the demographic information of the respondents, the possibility of response biases was mitigated.

11. Future Research

For future studies, it would be of interest to examine and validate the predictive model presented in this study, using empirical data collected from oil industry projects. Another path forward will be further studies on how to improve and strengthen the predictive model. A comparative assessment between this model and some alternatives could also be the object of future studies.

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