QATAR UNIVERSITY

COLLEGE OF ENGINEERING

# IMPACTS OF CHANGE ORDERS ON CONSTRUCTION PROJECTS

BY

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A Project Submitted to

the Faculty of the College of

Engineering

In Partial Fulfillment

of the Requirements

for the Degree of

Masters of Science in Engineering Management

January 2018

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# ABSTRACT

MOHAMMAD, KHALED OMAR, Masters: January: [2018], Master of Science in Engineering Management.

Title: Impacts of Change Orders on Construction Projects

Supervisor of project: Murat, Gunduz

The purpose of this project is to provide comprehensive analysis of the impacts of change orders in construction projects to improve the understanding of their impacts. This understanding would be helpful for the construction professionals to be able to take proactive measures to reduce their impacts. Literature review was performed to study previous related researches and to identify factors of change orders impacts.

Based on interviews with professionals in construction industry, these factors were reduced to most prominent 16 factors. Questionnaire was conducted to collect information about the perception of change order impacts by construction professionals. 102 complete responses were analyzed by using Relative Important Index (RII) and Analytical Hierarchy Process (AHP). Analysis results present the most significant impacts factors of change orders were: increased project re-planning, increased in project management efforts, increased reworks/demolition works, loss of efficiency due to work interruption and delay of payments.

The results of this project could lead professionals to better understanding of the impacts of change orders and take proactive measures to control and reduce their impacts.

ACKNOWLEDGMENT

First, I would like to express my sincere gratitude and deep thankful to Allah Almighty as with Allah blessing I have successfully complete this project. I would like to express my appreciation to Prof. Murat Gunduz for his professional support, patience, guidance, motivation and encouragement. In addition, I would like to express my special thanks for my wife, sons and parents for their supports, inspirations and motivations.

Finally, I would like to express my appreciation to the people who participate in the interviews and survey from construction industry.

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# CHAPTER 1: INTRODUCTION

## 1.1. Overview

Construction industry is one of the most complex sectors in the world as many variables and factors are involved. Through the design stage of any construction project, assumptions have to be considered based on incomplete information or uncertainty, design errors commonly occur, change in original requirement also common issue in construction project and many other issues which lead to adjustment on later stage of the project. These adjustments lead to change orders and the impact of the change orders increase as much as the project progresses. The impact of the same change order during design stage is much less than if it happens during construction or commissioning stage.

Construction projects are unique and have a limited time and budget assigned at the early stage of the project. Changes are always required during the execution phase due to different reasons such as owner's request, design changes and unforeseen conditions. Change orders preparation, evaluation and determination may represent a challenge to any construction project. Common practice of delaying and ignoring the processing of change order could lead to disputes between the parties, increase the project cost and time, Bolin (2017) . Change order is almost a must in any construction project. They might add, omit or modify works in original scope.

Definition of change order in construction industry is an alteration or an amendment to original requirement, information or conditions. It involves additional cost, time extensions and other impacts. O'Brien (1998) & CII (1995) Change order is a written instruction of a change signed by the owner/client to the contractor, issued after signing the contract, authorizing a change to the contract agreement.

When change orders occur during the project execution, project performance factors are impacted. Any deviation from the original scope represents a variation; a change order instruction is required when the variation has an impact on the project. This includes deviation from the original plans, specifications or any other contract documents. Change order is an official document used to modify the original contract agreement and becomes a part of the contract documents.

Whenever a change order is instructed, the contractor should adjust the planned resources and durations. This affects the ongoing works progress and the planned work sequence. Consequently, time delays and cost overruns occur as the main impacts and many other impacts, which will be analyzed in detail.

Many past studies were conducted about the impact of change orders. The aim of this research is to study the impact of the change orders that affects the project performance.

The evaluation of total impact of multiple change orders is complicated due to the interconnected nature of construction activities, which usually results in disagreement on the total impact between the owner and the contractor. The impacts of multi change orders are cumulative in nature and usually cannot be identified until the project completion.

Change orders resolution may become a source of dispute between parties especially when ineffectively managed. Owners usually aim to control the project’s allocated budget. Contractors on the other hand, consider change orders as an opportunity to obtain additional revenue. Different approaches towards change order cause disputes , Bolin (2017) .

## 1.2. Statement of the Problem

Project management team should understand the total impact of change orders to be able to take the required proactive measures, to control and minimize these impacts. Therefore, identifying the total impact of change orders is crucial. Relative Important Index (RII) and Analytical Hierarchy Process (AHP) were used to identify factors most impacting change orders. The data was collected with the help of an online questionnaire.

## 1.3. Objectives

The purpose of this study is to provide a comprehensive analysis of the impacts of change orders in construction projects. Change orders have different types represented as additions, omissions and substitutions.

Interviews and questionnaire were conducted to collect data from professionals in construction industry about the impacts of change orders based on their experience. Data were analyzed using relative important index (RII) and Analytical Hierarchy Process (AHP) to provide an overall ranking of the impacts for all types of change orders.

This project provides a detailed analysis of change orders total impact on construction projects based on the different types of change orders. This will help professionals from construction industry to have a better understanding of the total impacts of change orders to take proactive measures in order to control these impacts.

## 1.4. Methodology

1. Literature review of related studies was performed to study previous research outcomes and to list out the factors of change order impacts on construction project.
2. Interviews with professionals from construction industry were conducted to reduce the factors into 16 factors.
3. Questionnaire was conducted to collect data from professionals in construction industry to identify the impact level of each factor in relation to the different types of change orders and the impact level of each type.
4. Relative importance index, Spearman's correlation and Analytical Hierarchy Process were used to analyze the data.
5. Change order impacts of each type were ranked and an overall ranking was provided for all types.
6. Conclusions and recommendations were presented at the end of this project

## 1.5. Project Organization

- Chapter 1: Introduction that includes an overview, the statement of the problem, the objectives, the methodology and the project organization.
- Chapter 2: Comprehensive literature review.
- Chapter 3: Research methodology that includes discussions.
- Chapter 4: Data analysis and results.
- Chapter 5: Discussion, conclusion, recommendations, and future works.

# CHAPTER 2: LITERATURE REVIEW

## 2.1. Literature Review

A change is any deviation from the agreed scope and schedule, Arain & Pheng (2005). Change order is a formal written document issued to modify the original contract agreement and becomes a part of the project contractual documents, O'Brien (1998) & CII (1995) . Change order is an instruction to the contractor signed by the owner, issued after contract agreement execution and authorizes change to the contract agreement, Moselhi et al. (2005) & O'Brien (1998).

The effects of change orders on the construction projects are complex and influenced by many interrelated factors, the uncertainties of the total impact of change orders make the impact estimation a difficult task, Moselhi et al. (2005) . Impact factors of change orders are interrelated as some factors are linked to other factors like, decrease in quality and safety could impact the contractor reputation, CII (1995) . Reworks and demolition works impact project planning and payments which require more management efforts. New material and methods require additional logistic, impact the efficiency of works and safety and quality plans CII (1995) .

Change orders are classified in three groups based on the type of change of original scope as follows: additional works, omission works and substitution works. As change order could add new works to the original scope, omit works from the original scope or change the requirement from the original requirement, Staiti et al. (2016) .

Main causes of change orders are poor understanding and interpretation of the owner's requirement, poor contractual process, work omissions, designer changes, wrong information, owner's inconsistency and poor coordination, Moselhi et al. (2005) . The

most significant impacts of change orders are cost, time overruns, disputes and project failure. Effective project management can be achieved by identifying change orders impacts, reduce or eliminate them if possible, Oyewobi el al (2016). Change orders are normally used to cover deviations in the scope of works, design problems and material requirement, Alnuaimi et al (2010). Cost and time overruns are the two main known impacts of change orders on construction projects, Oyewobi el al (2016).

Change orders may reduce the planned productivity, which would delay the project schedule. Measuring this impact is usually subjective generating disputes between owner and contractor. Owner normally considers productivity reduction due to the contractor's poor management. On the other hand, the contractor considers these loses are because of the disruptions of works sequence, Hanna et al (2002).

Change orders normally have significant impact on construction project performance as they disrupt ongoing works and effect their planned sequence, which lead to affect the productivity, schedule delays and cost overruns, Anees et al. (2013).

Change order disagreement lead to disputes between the parties, which negatively impact the project execution and may risk the success of project completion. Change orders in one project may adversely affect other projects as it may require to keep resources to perform the changes whom are require on other projects, Alaryan (2014) .

Change orders impacts could be controlled by effective project management, good relation between all parties and select an experienced contractor, Keane el al (2010).

The teams involved at construction project should effectively analyze the change order and study its impacts on the project in details to take proactive measures to minimize the impacts, CII (1994) .

Gunduza & Hanna (2004) Conducted analysis on change orders impacts on productivity losses and defined the most important factors that affect productivity. This paper split the projects into three groups: small, medium and large.

For small projects: generally, cost and labor are not properly planned, lack of planning lead to conflicts. Change order project management is the most significant factor impacting the labor productivity. For medium projects: more change orders and duration extension observed and require more peak labor. Relationship between owner and contractor is important and when there is good relation, the project is less impacted. For large projects: normally have special team for productivity control which reduce the impact of change orders, project manager experience and present play important factor to reduce the productivity losses.

Change orders impacts increase on the projects managed by consultant. Conditions and process followed by consultant need to be reviewed for better management of change orders to reduce their impacts, Sunday(2010) .

Change orders have major impact on every construction project. Hanna & Gunduz (2004) Analyzed 34 projects to develop a model to quantify the impacts of change orders on labor productivity and concluded that this would help for better understanding of change orders impacts on labor productivity for small projects.

16 impacts of change orders were identified by Arain & Pheng (2005) as follows: progress impact, cost increase, hiring new professional, increase overhead expenses, payments delays, decrease in quality, decrease in efficiency, procurement of new resources delays, reworks and demolition, logistic issues, firm’s reputation, safety issues and relations issues.

The study by Arain & Pheng (2005) concludes that the most frequent impacts of change orders for institutional projects are project cost increase, additional payments to the contractor, progress impacted, overhead expenses increase, reworks and demolition works. Analysis by Alnuaimi et al (2010) covered four real case studies and questionnaire. This determined that additional works and modifications to design were the most significant factors causing change orders. The study summarized that the main effects of change orders are disputes, schedules delay and cost overruns for a study conducted in Oman.

Evaluation of the total impacts of multi change orders is very difficult task due to the interconnected nature of construction activities. This result to a disagreement between the owner and the contractor on the total impact, Hanna et al. (2004) . They studied the impact of change orders on labor productivity and provides a quantitative analysis method to define the amount of productivity loss for electrical and mechanical construction projects only.

The top 5 impacts of change orders by Anees et al. (2013) in descending order are:

1. Project cost increase.
2. Project time overrun.
3. Disputes between parties.
4. Impact quality standards.
5. Complaints of one or more of the parties to the contract.

Keane el al (2010) Grouped the impacts of change orders under four groups as follows:

- Cost related impacts: overhead expenses increase. Additional payments, increase reworks and demolitions.
- Quality related impacts: decrease in quality standard.
- Time related impacts: schedule delays, payment delays and logistics delays.
- Organization related impacts: company reputation, decrease in safety standard, impact relationships, disputes.

They conclude that the main impacts of change orders are cost, time, quality and organization. Change orders impacts can be minimized through strong contact preparation, proactive project management and good relationships between involved parties.

Change orders add values to the project. However, destructive impacts are consequence of change orders, Wayo & Haupt (2009) . They indicated that, time and cost overruns and disputes are the major impacts on the project performance, pour common understanding of the contract is the source of disputes between the parties.

Change orders issued during the construction phase of a project negatively affect the cost and time of the project. Also, increase on the number of change orders lead to have more productivity losses and low quality of the works. Change orders require revisions of the safety consideration, changes require additional safety information and resources to execute these changes, this is due to changes on construction methods, Wayo & Haupt (2009) .

They listed the impacts of changes orders as follows:

1. Time and cost overrun
2. Disputes
3. Requirement of additional equipment and personal
4. Impact quality standards
5. Reputation of parties affected
6. Impact health and safety

The top five common impacts of change orders by Alaryan (2014) are: increase in the project cost, increase the activities duration, schedule delays, additional payment to the contractor and payments delays

An analysis was conducted by Osman et al (2009) about the potential effects of change orders in construction projects in Malaysia. This analysis summarized that the top five most impacts of change orders are: cost overrun, additional payments to the contractor, increase the overhead expenses, delay on the completion schedule increase in reworks. Change orders normally carry serious problems to contractor and owner, which direct to disputes and additional cost. This could be link to insufficient understanding of impacts of change orders on project performance.

Teams involved on a project must totally understand the impacts of change orders to be able to take the required proactive measures to control and minimize the impacts of change orders. Hence, identifying the impacts of change orders is very important, Osman et al (2009) .

Impacts of change orders on project cost and schedule are complex and influenced by multi-linked factors. The uncertainties of change orders impact make it challenging task to manage them, Gokulk. & Gowrish. (2015) .

They studied the impacts of change order through literature review and survey, below list of change orders impacts identified:

1. Productivity losses
2. Schedule delays
3. Disputes between parties
4. Quality issues
5. Cost overruns
6. Material and tools delays
7. Work interruption
8. Increase overhead expenses
9. Increase reworks and demolition
10. Payments delays

They conclude that the top five impacts of change orders in ascending order are schedule delay, cost overrun, increase overhead expenses and productivity losses.

The impacts of change orders on both private and public construction projects by Sunday(2010) are: cost increase, payments delays, hiring new professionals, overhead increase, quality issues, logistic issues, efficiency losses, procurement delays, impact company reputation and schedule delays. Change orders impacts increase on projects managed by consultant.

## 2.2. Summary of Change Orders Impacts Factors

### 2.2.1. Delay of progress payments

Delay of progress payments result from change orders in construction projects as change orders interrupt ongoing progress and generate progress delays, this lead to delay on the original scope of works which at the end impact the progress payments, Osman et al (2009) & CII (1990) . Also, substitution works change orders require changes of agreed ongoing works and after execution of this works including the changes, the progress payment of these works get delayed until the value of substitution works is agreed between the parties.

The contractor and subcontractor highly depend on the progress payment to execute the works specially for material supplier payments and the delay of progress payment generate delays on the project overall progress due to cash flow problems.

### 2.2.2. Delay of retention payment

Retention money is an amount detected from certified progress payments as a percentage (normally 5%) and reserved by the owner to ensure that the contractor at the end of the project completes the all works without defects, CII (1990) .

Change orders generate disputes between the parties to agree on project final account value, which lead to delay the release of retention payment. Retention payment delays cause cash flow problems for contractors.

### 2.2.3. Increased project financing

Contractor estimates a cost for project financing requirement based on the project original scope and duration. Change orders generate additional scope of works, project

completion delays and progress payments delays, all these items increase the project financing cost.

As well, additional financial resources paid out on the claims and legal disputes as a result of change orders.

#### 2.2.4. Increased reworks and demolition works

When change order occurs after starting the construction works, it may require work demolition and changes on some completed works specially with substitution works change orders, CII (1990) & Keane el al (2010) .

#### 2.2.5. Decrease in contractor reputation

Change orders are one of the main causes of claim and construction disputes. The contractor reputation may be affected severely by change orders disputes specially that it is very difficult to agree on the impacts of change orders between all parties due to lack of understanding of change orders impacts CII (1995) & Keane el al (2010) .

#### 2.2.6. Poor contractor relationship with the client

As mentioned above, change orders cause disputes between parties. Contractors always aim to claim the maximum to cover all the expenses of change orders and make profits out of them. Client always aim to minimize the claims of change orders to protect the owner and limit the project cost within the original budget. Conflicts between contractor and client aims generate disputes and eventually affect the relationship between them, Keane el al (2010) CII (1995) .

#### 2.2.7. Loss of opportunity for new projects

Change orders at one project may impact other projects for the contract as it may require to keep resources which may be required by other projects, Alaryan (2014) . Also delays on the project final account commercial agreement due to change orders generate

cash flow problems to the contractor which may obstruct the contractor to join new projects.

2.2.8. Increased contractor overhead expenses

Change orders require many processing procedures such as: evaluation, pricing, engineering, implementation, commissioning and a lot of commercial negotiation between the parties, Osman et al (2009) & Keane el al (2010) . All of this generate additional overhead expenses.

2.2.9. Increased site logistics requirements

Change orders require revise logistics plans for the new material and equipment CII (1995) & Keane el al (2010) . Revised logistics plans generate construction delays and additional cost to the contractor.

2.2.10. Increased project re-planning

Change orders impact the project plan normally with delays, time delays occur not only because of the time require for change orders execution but also due the cumulative impacts of change orders on project performance. This results in the update of the plan and revision of the works sequence.

2.2.11. Loss of efficiency due to work interruption

Change orders normally associated with work interruption which have negative impact on the labor efficiency, Thomas and Napolitan (1995) .

2.2.12. Loss of efficiency due to lack of equipment

New equipment may be required when change order occur during the construction phase of the project, O'Brien (1998) . Lack of equipment disruption and working out of sequence result in loss of efficiency CII (1995) & Keane el al (2010) . Increased in project management efforts

Change orders require a lot of management efforts to evaluate the exact change, estimate the additional resources requirement, change work ongoing sequence to execute the change, negotiate volume of change in relation to time and cost, control and minimize the change orders impact on project through proactive measures, Gokulk. & Gowrish. (2015) .

2.2.13. Increased material unit prices

Adjustment on the contract budgeted material items, quantity or types is a reason for increase on material unit price ,Bolin (2017) , for example, unit price increase if change order requires to make new order with small quantity compare to original order with main quantity.

2.2.14. Decrease in project health and safety

Change orders may impact the project health and safety as it may require new safety plans and precautions. Moreover, acceleration of works to avoid schedule delays would cause reduced safety control and increased incidents rates, O'Brien (1998) & Keane el al (2010) .

2.2.15. Decrease in project quality

Frequent change orders impact the project quality in negative way, Osman et al (2009) CII (1995) , CII (1994) & Keane el al (2010) . Quality plans and procedures are developed based on original scope. Deviations from original scope through change orders may lead to decreases project quality controls. Acceleration due to change orders affect the project quality CII (1995) .

Table 1 lists the factors discussed above and their relevant references from the literature.

Table 1 Factor List of Change Orders Impacts on Construction Project Based on Literature Review

| ID | Factors | Reference |
|---|---|---|
| F01 | Delay of progress payments | [2], [6], [8], [9], [10], [18], [20], [21] |
| F02 | Delay of retention payment | [6], [9], [10], [20] |
| F03 | Increased project financing | [3], [5], [6], [8], [9], [13], [15], [19], [20], [21] , [24], [26] |
| F04 | Increased reworks and demolition works | [1], [4], [5], [6], [9], [10], [13], [15], [18], [26], [27] |
| F05 | Decrease in contractor reputation | [2], [4], [5], [8], [9], [10], [15], [18], [26] |
| F06 | Poor contractor relationship with the client | [1], [2], [4], [5], [6], [8], [9], [10], [12], [13], [18], [20], [21] |
| F07 | Loss of opportunity for new projects | [4], [8], [10], [12], [15], [19], [20], [24], [26] |
| F08 | Increased contractor overhead expenses | [1], [6], [8], [9], [10], [12], [18], [20], [21] , [26] |
| F09 | Increased site logistics requirements | [2], [3], [9], [13], [15], [18], [24] |
| F10 | Increased project re-planning | [3], [4], [5], [8], [9], [10], [13], [15], [18], [20], [21] , [26] |
| F11 | Loss of efficiency due to work interruption | [1], [3], [4], [6], [8], [10], [18], [20], [21] , [24], [26] |
| F12 | Loss of efficiency due to lack of equipment | [1], [4], [5], [9], [10], [15], [18], [20], [21] , [26] |
| F13 | Increased in project management efforts | [2], [4], [5], [6], [8], [10], [13], [15], [20], [21] |
| F14 | Increased material unit prices | [1], [10], [12], [13], [15], [20], [21] , [26] |
| F15 | Decrease in project health and safety | [2], [4], [5], [9], [15], [18], [21] |
| F16 | Decrease in project quality | [1], [2], [4], [5], [6], [8], [9], [10], [12], [13], [15], [18], [21] |

## 2.3. Analytical Hierarchy Process (AHP)

Construction management usually has many multiple criteria decision-making problems such as project management, contractor selection, procurement decisions, facility locations, proposal evaluation, equipment selection, Doloi (2008) . Analytical Hierarchy Process (AHP) method was used in many research studies in construction industry as a multiple criteria decision-making tool, Doloi (2008) & Lin et al (2008) .

AHP uses pairwise comparisons between criteria to measure the relative importance of each of them. Inconsistency in pairwise comparisons may occur as outcome of improper conceptualization of data-hierarchy. Consistency ratio must be less than 0.1 to be at an acceptable level and if otherwise, pairwise comparison matrix need to be revised, Doloi (2008) .

The importance of AHP is that it arranges the factors in a systematic way and provide simple solution to support project management taking the correct decision of multiple criteria problem.

## 2.4. Literature Review Summary

To summarize, many research studies were carried out to identify change order impacts on construction project. Some focused on analyzing their impact on productivity and some focused on analyzing their impact on cost and time. Change orders cause negative impacts for all parties involved in construction projects. These impacts vary among projects and depend on the type, size and timing of change orders.

Change orders are classified in three groups based on the type of change of original scope as follows: additional works, omissions and substitutions.

All parties involved in the project must recognize the impacts of change orders to be able to take the proactive measures in order to control and minimize their impacts. Therefore, it is very important to understand the impacts of change orders.

# CHAPTER 3: METHODOLOGY

## 3.1. Introduction

This section describes the methodology followed in this project to collect and evaluate data starting by a comprehensive literature review and ending with a discussion about the methods used in data evaluation.

Preliminary list of factors of the impacts of change orders was identified through conducting a comprehensive literature study as discussed in the previous chapter. After that, this list was finalized through conducting interviews with professionals from the construction industry. The list included 16 impact factors

A questionnaire was prepared and circulated requesting professionals to evaluate the importance of each factor to identify the most influencing factors affecting the construction projects due to change orders.

The Relative Importance Index (RII) technique and Spearman's Rank Correlation Test were used to evaluate the questionnaire responses and to check the accurateness and precision of date.

## 3.2. Questionnaire Design

The questionnaire consists of two parts, the first part covers the respondent's general information such as years of experience, job title, company role and country, and the second part covers the ranking of the three types of change orders and the impact factors.

The questionnaire was developed using online website (Survey Monkey) and a website link was shared with the professionals to be filled online.

The first part of the questionnaire helps in classifying the respondents into groups in order to be used in developing comparisons between responses.

The second part starts with the rating of the three different types of change orders. The respondents were asked to rate the impact (how much does each type of change order impact the construction project performance) of each type of change order, change orders types are classified as additional works, omission works and substitution works.

The second part continues with the rating of the 16 impact factors. The respondents were asked to evaluate these impact factors and rank them in relation to each type of change orders (what is the impact of *additional works* change order on the factor of *loss of efficiency due to work interruption*).

A scale of 9 points was used in this questionnaire to rank the impact factors and the different types of change orders. (1 represents very low impact, 5 medium impact and 9 represents very high impact).

Construction industry professionals and academicians received the questionnaire, 102 completed responses were received and used for data analysis. The questionnaire is available in Appendix A.

### 3.4. Relative Importance Index (RII)

RII technique is used to provide a score for each type of change orders and for the 16 impact factors using the following formula.

$$\boldsymbol{RII} = (\sum \boldsymbol{P_i}\, \boldsymbol{X_i}\,)/\boldsymbol{N}(\boldsymbol{n})$$

$\boldsymbol{RII}$ = relative importance index

$\boldsymbol{P_i}$ = weight given to each attribute by the respondent (1 to 9)

$\boldsymbol{X_i}$ = number of respondents selects the same weight $P_i$

$\boldsymbol{n}$ = the highest scale weight (9 in this case)

$\boldsymbol{N}$ = total number of respondents (102)

### 3.5. Correlation Test (Spearman's Rank Correlation Test)

Spearman's Rank Correlation Test is used to evaluate the accuracy and the precision of data by studying the monotonic relationship strength between different factors and different parties using the following formula.

$$\boldsymbol{\rho = 1 - 6 * \sum d_i^2 \ / \ n(n^2 - 1)}$$

Where,

ρ = Spearman correlation coefficient.

$d_i$ = parties rank difference assigned to each factor.

n = the total number of impact factors used on this study which is 16.

Spearman's correlation test was used to study the relationship strength of the factor ranks from different classification, these ranks were calculated using RII calculation. Spearman's coefficient value ranges from -1 to +1, where +1 indicates positive relationship and -1 indicates negative relationship.

# CHAPTER 4: DATA COLLECTION AND ANALYSIS

## 4.1. Introduction

This chapter presents the collected data, respondents' profiles and data analysis using Spearman's Rank Correlation, Relative Important Index (RII) and Analytical Hierarchy Process (AHP).

## 4.2. Respondents Profile

This part presents the details of the participants represented in the years of experience, job title, company role and country.

### 4.2.1. Respondents Years of Experience

The respondents are classified according to the years of experience as follows:

- 24% of the participants have experience of 15 years and above.
- 27% of the participants have experience between 10-15 years.
- 39% of the participants have experience between 5-15 years.
- 10% of the participants have experience less than 5 years

More than 50% of the participants have an experience of 10 years and above. The following figure shows the classification of respondents based on years of experience.

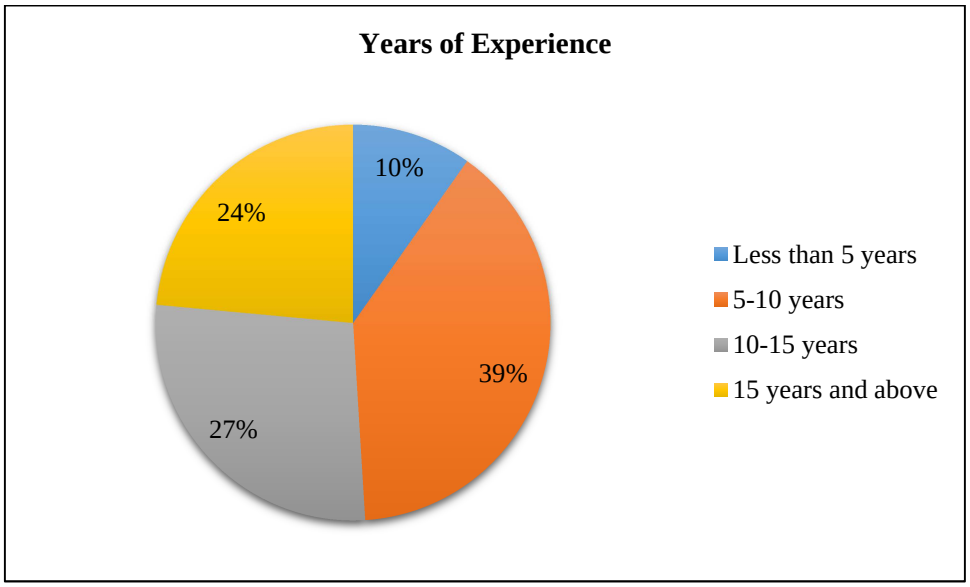


**Figure 1 Respondents Years of Experience**

4.2.2. Respondents Company Role

The respondents are classified according to the company role as follows:

- 60% of the participants are working as contractor.
- 17% of the participants are working as consultant.
- 13% of the participants are owners.
- 8% of the participants are working as project management.
- 2% of the participants are working at higher education.

The contractors represented more than 60% of the participants in this study. The following figure shows the classification of respondents based on their role.

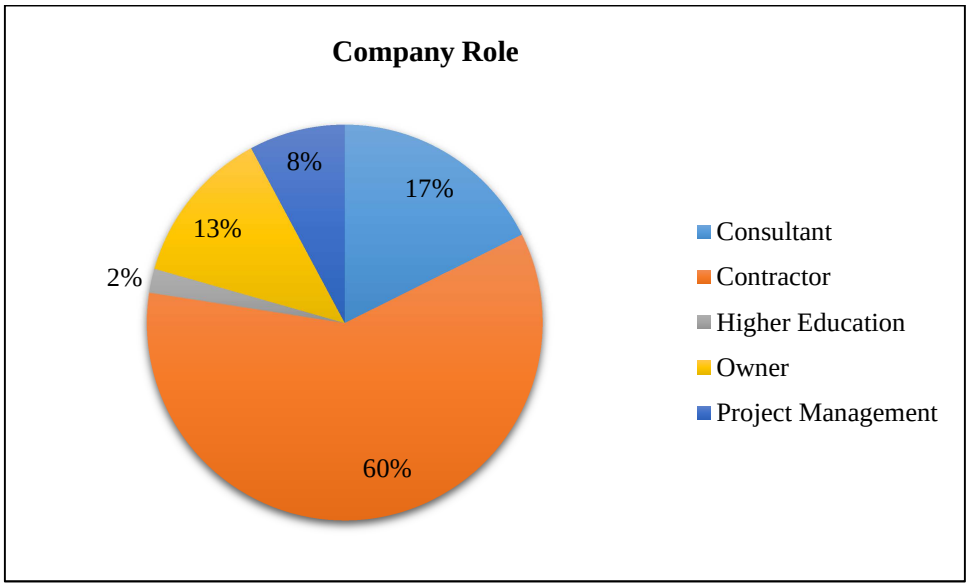


**Figure 2 Respondents Company Role**

4.2.3. Respondents Job Title

The respondents are classified according to the job title as follows:

- 21% of the participants are working as project engineer
- 18% of the participants are working as engineer.
- 17% of the participants are working as manager.
- 14% of the participants are construction manager.
- 12% of the participants are working as project manager.

- Remaining of the participants are working as academician, commercial manager, contract manager and others.

The following figure shows the classification of respondents based on their job designations.

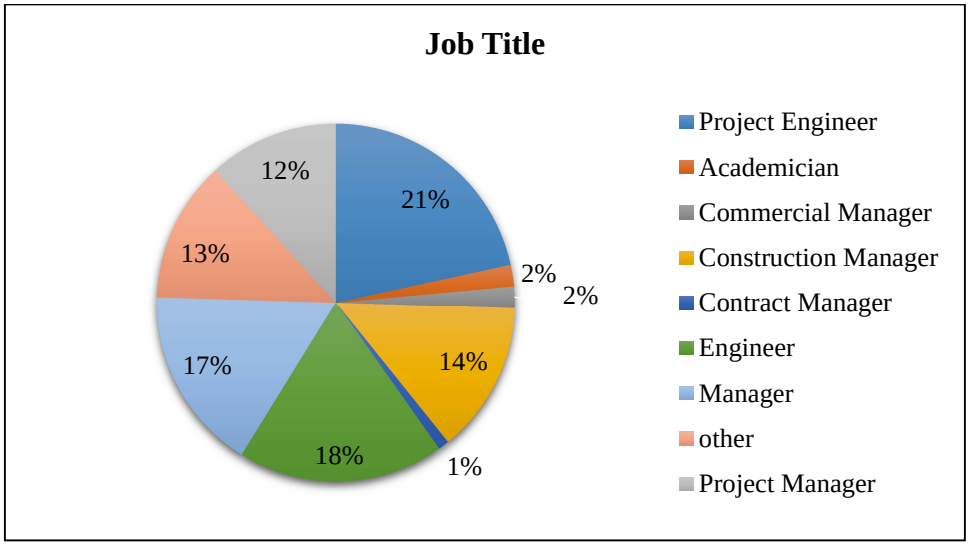


**Figure 3 Respondents Job Title**

4.2.4. Respondents Country

The participants in this study were located in different countries and classified as follows:

- 72% of the participants are from Qatar.
- 19% of the participants are from Middle East.
- 4% of the participants are from Asia.
- 2% of the participants are from Europe.
- 1% of the participants are from America.

The following figure shows the distribution of respondents among different countries around the world.

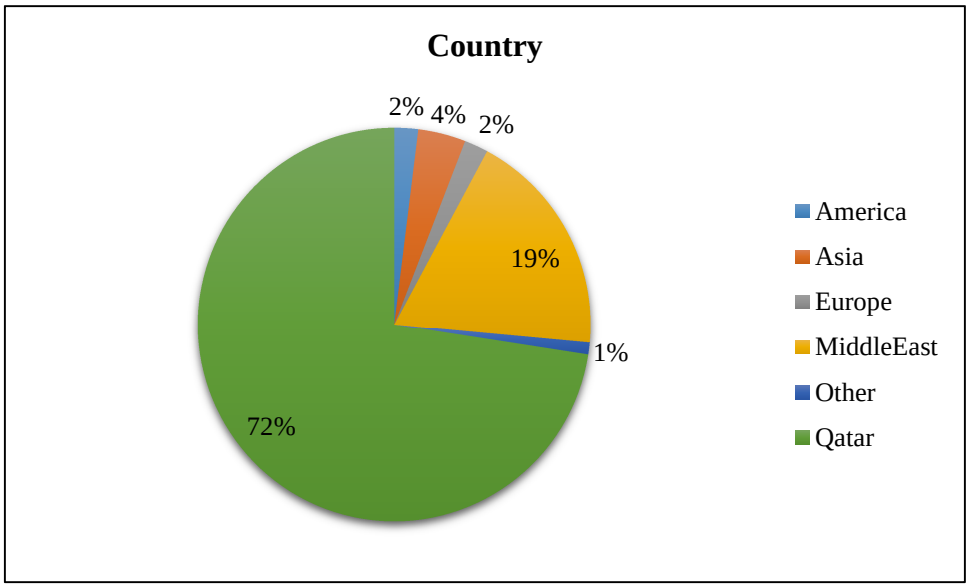


**Figure 4 Respondents Country**

## 4.4. Relative Importance Index (RII) Ranking

The questionnaire date analyzed using statistical technique by calculating the relative importance index for each factor of the impacts of change orders studied in this project. MS Excel software used to apply the RII computations on the participant score of each factor.

The RII values calculated by multiplying the number of responses of each score by the related score, then divide the result by the highest score (which is 9) and the total number of participants (which is 102) for each factor.

For example, the computation of the RII value for factor F10 - Increased project re-planning in relation to additional works type of change orders as follows:

RII (F10–additionalworks)=(1*1+1*2+8*3+10*4+12*5+9*6+14*7+17*8+30*9)/(9*102)=0.746

The factors analyzed and ranked using RII. Below tables represent the outcome of RII analysis and sort the factors starting with highest RII values for each type of change orders.

Table 2 *RII Calculation for the Factors of Additional Works Change Orders*

| ID | FACTORS | NUMBER OF RESPONDENTS OF EACH SCORE | | | | | | | | | RII |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **9** | |
| F10 | Increased project re-planning | 1 | 1 | 8 | 10 | 12 | 9 | 14 | 17 | 30 | 0.746 |
| F13 | Increased in project management efforts | 1 | 2 | 9 | 9 | 14 | 15 | 26 | 15 | 11 | 0.685 |
| F03 | Increased project financing | 8 | 10 | 8 | 2 | 10 | 9 | 11 | 16 | 28 | 0.676 |
| F09 | Increased site logistics requirements | 7 | 4 | 8 | 6 | 11 | 9 | 24 | 18 | 15 | 0.674 |
| F07 | Loss of opportunity for new projects | 11 | 4 | 8 | 4 | 10 | 13 | 23 | 13 | 16 | 0.649 |
| F08 | Increased contractor overhead expenses | 10 | 11 | 7 | 4 | 7 | 10 | 14 | 19 | 20 | 0.647 |
| F02 | Delay of retention payment | 7 | 11 | 2 | 10 | 9 | 17 | 22 | 18 | 6 | 0.625 |
| F11 | Loss of efficiency due to work interruption | 5 | 10 | 13 | 11 | 15 | 4 | 17 | 13 | 14 | 0.606 |
| F12 | Loss of efficiency due to lack of equipment | 11 | 11 | 11 | 12 | 16 | 13 | 13 | 11 | 4 | 0.531 |
| F04 | Increased reworks and demolition works | 12 | 13 | 11 | 10 | 15 | 10 | 12 | 15 | 4 | 0.529 |
| F01 | Delay of progress payments | 5 | 18 | 20 | 11 | 12 | 7 | 9 | 12 | 8 | 0.521 |
| F16 | Decrease in project quality | 17 | 14 | 10 | 9 | 16 | 13 | 11 | 7 | 5 | 0.487 |
| F15 | Decrease in project health and safety | 18 | 19 | 13 | 10 | 10 | 5 | 11 | 7 | 9 | 0.467 |
| F06 | Poor contractor relationship with the client | 25 | 13 | 13 | 9 | 10 | 8 | 9 | 10 | 5 | 0.449 |
| F14 | Increased material unit prices | 18 | 17 | 23 | 7 | 14 | 6 | 4 | 9 | 4 | 0.426 |
| F05 | Decrease in contractor reputation | 29 | 17 | 9 | 15 | 7 | 5 | 8 | 5 | 7 | 0.407 |

Table 3 RII Calculation for the Factors of Omission Works Change Orders

| ID | FACTORS | SCORES WITH NUMBER OF RESPONDENTS | | | | | | | | | RII |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | |
| F06 | Poor contractor relationship with the client | 12 | 6 | 9 | 9 | 10 | 7 | 16 | 13 | 20 | 0.626 |
| F10 | Increased project re-planning | 7 | 8 | 13 | 7 | 13 | 10 | 15 | 11 | 18 | 0.621 |
| F08 | Increased contractor overhead expenses | 12 | 11 | 6 | 10 | 12 | 27 | 11 | 9 | 4 | 0.544 |
| F05 | Decrease in contractor reputation | 16 | 10 | 8 | 9 | 15 | 14 | 17 | 10 | 3 | 0.524 |
| F13 | Increased in project management efforts | 5 | 13 | 16 | 17 | 17 | 8 | 13 | 7 | 6 | 0.524 |
| F01 | Delay of progress payments | 6 | 10 | 12 | 19 | 20 | 17 | 11 | 5 | 2 | 0.517 |
| F11 | Loss of efficiency due to work interruption | 5 | 19 | 15 | 20 | 12 | 6 | 8 | 9 | 8 | 0.505 |
| F04 | Increased reworks and demolition works | 15 | 16 | 12 | 10 | 16 | 10 | 9 | 8 | 6 | 0.484 |
| F02 | Delay of retention payment | 15 | 24 | 10 | 7 | 11 | 13 | 14 | 6 | 2 | 0.455 |
| F16 | Decrease in project quality | 27 | 11 | 8 | 9 | 17 | 14 | 6 | 2 | 8 | 0.444 |
| F14 | Increased material unit prices | 25 | 18 | 12 | 7 | 15 | 6 | 9 | 6 | 4 | 0.417 |
| F07 | Loss of opportunity for new projects | 28 | 24 | 16 | 4 | 2 | 4 | 5 | 3 | 16 | 0.411 |
| F12 | Loss of efficiency due to lack of equipment | 34 | 14 | 6 | 12 | 8 | 9 | 7 | 8 | 4 | 0.404 |
| F03 | Increased project financing | 28 | 21 | 18 | 8 | 7 | 4 | 4 | 4 | 8 | 0.378 |
| F09 | Increased site logistics requirements | 40 | 15 | 13 | 8 | 12 | 4 | 4 | 4 | 2 | 0.33 |
| F15 | Decrease in project health and safety | 38 | 17 | 14 | 13 | 4 | 7 | 3 | 4 | 2 | 0.326 |

Table 4 RII Calculation for the Factors of Substitution Works Change Orders

| ID | FACTORS | SCORES WITH NUMBER OF RESPONDENTS | | | | | | | | | RII |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | |
| F10 | Increased project re-planning | 3 | 0 | 3 | 2 | 11 | 14 | 20 | 23 | 26 | 0.781 |
| F04 | Increased reworks and demolition works | 2 | 3 | 4 | 5 | 9 | 15 | 19 | 21 | 24 | 0.754 |
| F13 | Increased in project management efforts | 0 | 1 | 4 | 6 | 23 | 12 | 19 | 17 | 20 | 0.734 |
| F11 | Loss of efficiency due to work interruption | 3 | 1 | 3 | 5 | 15 | 20 | 22 | 18 | 15 | 0.721 |
| F01 | Delay of progress payments | 2 | 5 | 4 | 4 | 20 | 21 | 25 | 11 | 10 | 0.674 |
| F02 | Delay of retention payment | 2 | 5 | 9 | 8 | 15 | 15 | 23 | 17 | 8 | 0.659 |
| F06 | Poor contractor relationship with the client | 7 | 2 | 4 | 8 | 15 | 18 | 26 | 13 | 9 | 0.659 |
| F09 | Increased site logistics requirements | 8 | 9 | 7 | 12 | 16 | 4 | 22 | 11 | 13 | 0.608 |
| F08 | Increased contractor overhead expenses | 5 | 13 | 15 | 7 | 13 | 8 | 16 | 15 | 10 | 0.587 |
| F05 | Decrease in contractor reputation | 11 | 9 | 7 | 9 | 13 | 17 | 18 | 10 | 8 | 0.578 |
| F07 | Loss of opportunity for new projects | 12 | 8 | 17 | 6 | 10 | 18 | 13 | 7 | 11 | 0.552 |
| F16 | Decrease in project quality | 14 | 14 | 12 | 9 | 6 | 6 | 14 | 15 | 12 | 0.551 |
| F12 | Loss of efficiency due to lack of equipment | 7 | 4 | 18 | 16 | 16 | 17 | 12 | 10 | 2 | 0.541 |
| F03 | Increased project financing | 16 | 11 | 12 | 8 | 14 | 9 | 8 | 8 | 16 | 0.538 |
| F14 | Increased material unit prices | 10 | 11 | 23 | 14 | 18 | 4 | 7 | 8 | 7 | 0.487 |
| F15 | Decrease in project health and safety | 15 | 20 | 13 | 8 | 10 | 7 | 13 | 8 | 8 | 0.485 |

For additional works change orders as per RII results, the three most impacted factors are increased project re-planning, Increased in project management efforts and increased project financing.

For omission works change orders as per RII results, the three most impacted factors are poor contractor relationship with the client, increased project re-planning and increased contractor overhead expenses.

For substitution (change) works change orders as per RII results, the three most impacted factors are poor contractor relationship with the client, increased project re-planning and increased contractor overhead expenses.

RII provides factors ranking for each type of change orders individually and these ranking used as the basis of the Analytical Hierarchy Process (AHP) to develop the AHP pairwise comparisons.

In addition, the types of change orders analyzed and ranked using RII as described above and the outcome represented on below table.

Table 5 RII Calculation for the Types of change orders

| ID | Types of Change Orders | SCORES WITH NUMBER OF RESPONDENTS | | | | | | | | | RII |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | |
| T03 | Substitution (Change) works | 1 | 5 | 1 | 5 | 10 | 16 | 29 | 16 | 19 | 0.743 |
| T01 | Additional Works | 1 | 0 | 7 | 9 | 12 | 15 | 29 | 20 | 9 | 0.71 |
| T02 | Omission Works | 8 | 8 | 15 | 16 | 19 | 17 | 13 | 4 | 2 | 0.513 |

Substitution works has the highest RII value that mean it has the highest impact on the construction projects among other types of change orders.

## 4.5. Spearman’s Rank Correlation Test

Spearman’s Rank Correlation Test studies the monotonic relationship strength between different factors and different parties. Spearman’s test is used to compare the strength of different rankings by different participants using the rankings obtained from RII results.

Spearman’s correlation coefficients were calculated to evaluate the correlation between the respondents’ different groups as follows.

**Qatar vs World**

This part represents the ranking comparison of the participant responses between Qatar and the rest of the world as shown in table below.

Spearman’s correlation factors are 0.974 for additional works, 0.871 for Omission Works and 0.885 for Substitution (Change) works. These values reflect strong agreement between the participants.

Table 6 Spearman's Correlation Test - Qatar Versus Word - Additional Works

| ID | FACTORS | QATAR RANK | WORLD RANK | d2 |
|---|---|---|---|---|
| F01 | Delay of progress payments | 10 | 11 | 1 |
| F02 | Delay of retention payment | 7 | 6 | 1 |
| F03 | Increased project financing | 3 | 3 | 0 |
| F04 | Increased reworks and demolition works | 11 | 9 | 4 |
| F05 | Decrease in contractor reputation | 16 | 16 | 0 |
| F06 | Poor contractor relationship with the client | 14 | 13 | 1 |
| F07 | Loss of opportunity for new projects | 5 | 7 | 4 |
| F08 | Increased contractor overhead expenses | 6 | 5 | 1 |
| F09 | Increased site logistics requirements | 4 | 4 | 0 |
| F10 | Increased project re-planning | 1 | 1 | 0 |
| F11 | Loss of efficiency due to work interruption | 8 | 8 | 0 |
| F12 | Loss of efficiency due to lack of equipment | 9 | 10 | 1 |
| F13 | Increased in project management efforts | 2 | 2 | 0 |
| F14 | Increased material unit prices | 15 | 15 | 0 |
| F15 | Decrease in project health and safety | 12 | 14 | 4 |
| F16 | Decrease in project quality | 13 | 12 | 1 |
| | | **Spearman's Correlation Factor** | | **0.973529** |

Table 7 Spearman's Correlation Test - Qatar Versus Word - Omission Works

| ID | FACTORS | QATAR RANK | WORLD RANK | d2 |
|---|---|---|---|---|
| F01 | Delay of progress payments | 4 | 9 | 25 |
| F02 | Delay of retention payment | 9 | 12 | 9 |
| F03 | Increased project financing | 14 | 14 | 0 |
| F04 | Increased reworks and demolition works | 8 | 6 | 4 |
| F05 | Decrease in contractor reputation | 5 | 4 | 1 |
| F06 | Poor contractor relationship with the client | 1 | 2 | 1 |
| F07 | Loss of opportunity for new projects | 13 | 10 | 9 |
| F08 | Increased contractor overhead expenses | 3 | 7 | 16 |
| F09 | Increased site logistics requirements | 15 | 15 | 0 |
| F10 | Increased project re-planning | 2 | 1 | 1 |
| F11 | Loss of efficiency due to work interruption | 7 | 5 | 4 |
| F12 | Loss of efficiency due to lack of equipment | 11 | 13 | 4 |
| F13 | Increased in project management efforts | 6 | 3 | 9 |
| F14 | Increased material unit prices | 12 | 11 | 1 |
| F15 | Decrease in project health and safety | 16 | 16 | 0 |
| F16 | Decrease in project quality | 10 | 8 | 4 |
| | | **Spearman's Correlation Factor** | | **0.870588** |

Table 8 Spearman's Correlation Test - Qatar Versus Word - Substitution (Change) works

| ID | FACTORS | QATAR RANK | WORLD RANK | d2 |
|---|---|---|---|---|
| F01 | Delay of progress payments | 6 | 5 | 1 |
| F02 | Delay of retention payment | 7 | 6 | 1 |
| F03 | Increased project financing | 12 | 13 | 1 |
| F04 | Increased reworks and demolition works | 2 | 2 | 0 |
| F05 | Decrease in contractor reputation | 9 | 14 | 25 |
| F06 | Poor contractor relationship with the client | 5 | 9 | 16 |
| F07 | Loss of opportunity for new projects | 11 | 12 | 1 |
| F08 | Increased contractor overhead expenses | 10 | 7 | 9 |
| F09 | Increased site logistics requirements | 8 | 8 | 0 |
| F10 | Increased project re-planning | 1 | 1 | 0 |
| F11 | Loss of efficiency due to work interruption | 4 | 3 | 1 |
| F12 | Loss of efficiency due to lack of equipment | 14 | 10 | 16 |
| F13 | Increased in project management efforts | 3 | 4 | 1 |
| F14 | Increased material unit prices | 16 | 15 | 1 |
| F15 | Decrease in project health and safety | 15 | 16 | 1 |
| F16 | Decrease in project quality | 13 | 11 | 4 |
| | | **Spearman's Correlation Factor** | | **0.885294** |

**Contractor vs Others**

This part represents the ranking comparison of the participant responses between the contractor and the others. Results are listed in Table 9,10 and 11.

Spearman’s correlation factors are 0.929 for additional works, 0.923 for Omission Works and 0.779 for Substitution (Change) works. These reflect strong agreement between the participants.

Table 9 Spearman's Correlation Test - Contractor VERSUS Others - Additional works

| ID | FACTORS | QATAR RANK | WORLD RANK | d2 |
|---|---|---|---|---|
| F01 | Delay of progress payments | 11 | 10 | 1 |
| F02 | Delay of retention payment | 6 | 8 | 4 |
| F03 | Increased project financing | 4 | 4 | 0 |
| F04 | Increased reworks and demolition works | 9 | 11 | 4 |
| F05 | Decrease in contractor reputation | 16 | 15 | 1 |
| F06 | Poor contractor relationship with the client | 15 | 13 | 4 |
| F07 | Loss of opportunity for new projects | 7 | 3 | 16 |
| F08 | Increased contractor overhead expenses | 5 | 6 | 1 |
| F09 | Increased site logistics requirements | 2 | 5 | 9 |
| F10 | Increased project re-planning | 1 | 1 | 0 |
| F11 | Loss of efficiency due to work interruption | 8 | 7 | 1 |
| F12 | Loss of efficiency due to lack of equipment | 10 | 9 | 1 |
| F13 | Increased in project management efforts | 3 | 2 | 1 |
| F14 | Increased material unit prices | 14 | 16 | 4 |
| F15 | Decrease in project health and safety | 13 | 14 | 1 |
| F16 | Decrease in project quality | 12 | 12 | 0 |
| | | **Spearman's Correlation Factor** | | **0.929412** |

Table 10 Spearman's Correlation Test - Contractor VERSUS Others - Omission works

| ID | FACTORS | QATAR RANK | WORLD RANK | d2 |
|---|---|---|---|---|
| F01 | Delay of progress payments | 8 | 5 | 9 |
| F02 | Delay of retention payment | 9 | 8 | 1 |
| F03 | Increased project financing | 14 | 12 | 4 |
| F04 | Increased reworks and demolition works | 7 | 9 | 4 |
| F05 | Decrease in contractor reputation | 6 | 3 | 9 |
| F06 | Poor contractor relationship with the client | 2 | 1 | 1 |
| F07 | Loss of opportunity for new projects | 13 | 11 | 4 |
| F08 | Increased contractor overhead expenses | 3 | 4 | 1 |
| F09 | Increased site logistics requirements | 15 | 16 | 1 |
| F10 | Increased project re-planning | 1 | 2 | 1 |
| F11 | Loss of efficiency due to work interruption | 5 | 7 | 4 |
| F12 | Loss of efficiency due to lack of equipment | 12 | 14 | 4 |
| F13 | Increased in project management efforts | 4 | 6 | 4 |
| F14 | Increased material unit prices | 11 | 13 | 4 |
| F15 | Decrease in project health and safety | 16 | 15 | 1 |
| F16 | Decrease in project quality | 10 | 10 | 0 |
| | | **Spearman's Correlation Factor** | | **0.923529** |

Table 11 Spearman's Correlation Test - Contractor VERSUS Others - Substitution (Change) *works*

| ID | FACTORS | QATAR RANK | WORLD RANK | d2 |
|---|---|---|---|---|
| F01 | Delay of progress payments | 8 | 3 | 25 |
| F02 | Delay of retention payment | 7 | 5 | 4 |
| F03 | Increased project financing | 15 | 9 | 36 |
| F04 | Increased reworks and demolition works | 2 | 2 | 0 |
| F05 | Decrease in contractor reputation | 11 | 8 | 9 |
| F06 | Poor contractor relationship with the client | 5 | 7 | 4 |
| F07 | Loss of opportunity for new projects | 13 | 11 | 4 |
| F08 | Increased contractor overhead expenses | 9 | 10 | 1 |
| F09 | Increased site logistics requirements | 6 | 12 | 36 |
| F10 | Increased project re-planning | 1 | 1 | 0 |
| F11 | Loss of efficiency due to work interruption | 3 | 6 | 9 |
| F12 | Loss of efficiency due to lack of equipment | 10 | 14 | 16 |
| F13 | Increased in project management efforts | 4 | 4 | 0 |
| F14 | Increased material unit prices | 16 | 15 | 1 |
| F15 | Decrease in project health and safety | 14 | 16 | 4 |
| F16 | Decrease in project quality | 12 | 13 | 1 |
| | | **Spearman's Correlation Factor** | | **0.779412** |

**Contractor vs Owner**

This part represents the ranking comparison of the participant responses between the contractor and owner. The results are listed in Table 12,13 and 14.

Spearman’s correlation factors are 0.85 for additional works, 0.944 for Omission Works and 0.738 for Substitution (Change) works. These reflect strong agreement between the participants.

Table 12 Spearman's Correlation Test - Contractor VERSUS Owner - Additional works

| ID | FACTORS | QATAR RANK | WORLD RANK | d2 |
|---|---|---|---|---|
| F01 | Delay of progress payments | 11 | 8 | 9 |
| F02 | Delay of retention payment | 6 | 9 | 9 |
| F03 | Increased project financing | 4 | 6 | 4 |
| F04 | Increased reworks and demolition works | 9 | 11 | 4 |
| F05 | Decrease in contractor reputation | 16 | 15 | 1 |
| F06 | Poor contractor relationship with the client | 15 | 13 | 4 |
| F07 | Loss of opportunity for new projects | 7 | 2 | 25 |
| F08 | Increased contractor overhead expenses | 5 | 5 | 0 |
| F09 | Increased site logistics requirements | 2 | 7 | 25 |
| F10 | Increased project re-planning | 1 | 1 | 0 |
| F11 | Loss of efficiency due to work interruption | 8 | 4 | 16 |
| F12 | Loss of efficiency due to lack of equipment | 10 | 10 | 0 |
| F13 | Increased in project management efforts | 3 | 3 | 0 |
| F14 | Increased material unit prices | 14 | 16 | 4 |
| F15 | Decrease in project health and safety | 13 | 14 | 1 |
| F16 | Decrease in project quality | 12 | 12 | 0 |
| | | **Spearman's Correlation Factor** | | **0.85** |

Table 13 Spearman's Correlation Test - Contractor VERSUS Owner - Omission works

| ID | FACTORS | QATAR RANK | WORLD RANK | d2 |
|---|---|---|---|---|
| F01 | Delay of progress payments | 8 | 5 | 9 |
| F02 | Delay of retention payment | 9 | 10 | 1 |
| F03 | Increased project financing | 14 | 14 | 0 |
| F04 | Increased reworks and demolition works | 7 | 8 | 1 |
| F05 | Decrease in contractor reputation | 6 | 3 | 9 |
| F06 | Poor contractor relationship with the client | 2 | 1 | 1 |
| F07 | Loss of opportunity for new projects | 13 | 13 | 0 |
| F08 | Increased contractor overhead expenses | 3 | 4 | 1 |
| F09 | Increased site logistics requirements | 15 | 16 | 1 |
| F10 | Increased project re-planning | 1 | 2 | 1 |
| F11 | Loss of efficiency due to work interruption | 5 | 6 | 1 |
| F12 | Loss of efficiency due to lack of equipment | 12 | 11 | 1 |
| F13 | Increased in project management efforts | 4 | 7 | 9 |
| F14 | Increased material unit prices | 11 | 12 | 1 |
| F15 | Decrease in project health and safety | 16 | 15 | 1 |
| F16 | Decrease in project quality | 10 | 9 | 1 |
| | | **Spearman's Correlation Factor** | | **0.944** |

Table 14 Spearman's Correlation Test - Contractor VERSUS Owner - Substitution (Change) *works*

| ID | FACTORS | QATAR RANK | WORLD RANK | d2 |
|---|---|---|---|---|
| F01 | Delay of progress payments | 8 | 6 | 4 |
| F02 | Delay of retention payment | 7 | 3 | 16 |
| F03 | Increased project financing | 15 | 9 | 36 |
| F04 | Increased reworks and demolition works | 2 | 2 | 0 |
| F05 | Decrease in contractor reputation | 11 | 10 | 1 |
| F06 | Poor contractor relationship with the client | 5 | 5 | 0 |
| F07 | Loss of opportunity for new projects | 13 | 8 | 25 |
| F08 | Increased contractor overhead expenses | 9 | 12 | 9 |
| F09 | Increased site logistics requirements | 6 | 13 | 49 |
| F10 | Increased project re-planning | 1 | 1 | 0 |
| F11 | Loss of efficiency due to work interruption | 3 | 7 | 16 |
| F12 | Loss of efficiency due to lack of equipment | 10 | 14 | 16 |
| F13 | Increased in project management efforts | 4 | 4 | 0 |
| F14 | Increased material unit prices | 16 | 15 | 1 |
| F15 | Decrease in project health and safety | 14 | 16 | 4 |
| F16 | Decrease in project quality | 12 | 11 | 1 |
| | | **Spearman's Correlation Factor** | | **0.738** |

**Owner vs Others**

This part represents the ranking comparison of the participant responses between the owner and others. The results are listed in Tables 15,16 and 17.

Spearman’s correlation factors are 0.885 for additional works, 0.956 for Omission Works and 0.829 for Substitution (Change) works. These reflect strong agreement between the participants.

Table 15 Spearman's Correlation Test - Owner VERSUS Others - Additional works

| ID | FACTORS | QATAR RANK | WORLD RANK | d2 |
|---|---|---|---|---|
| F01 | Delay of progress payments | 8 | 11 | 9 |
| F02 | Delay of retention payment | 9 | 7 | 4 |
| F03 | Increased project financing | 6 | 2 | 16 |
| F04 | Increased reworks and demolition works | 11 | 9 | 4 |
| F05 | Decrease in contractor reputation | 15 | 16 | 1 |
| F06 | Poor contractor relationship with the client | 13 | 14 | 1 |
| F07 | Loss of opportunity for new projects | 2 | 6 | 16 |
| F08 | Increased contractor overhead expenses | 5 | 5 | 0 |
| F09 | Increased site logistics requirements | 7 | 4 | 9 |
| F10 | Increased project re-planning | 1 | 1 | 0 |
| F11 | Loss of efficiency due to work interruption | 4 | 8 | 16 |
| F12 | Loss of efficiency due to lack of equipment | 10 | 10 | 0 |
| F13 | Increased in project management efforts | 3 | 3 | 0 |
| F14 | Increased material unit prices | 16 | 15 | 1 |
| F15 | Decrease in project health and safety | 14 | 13 | 1 |
| F16 | Decrease in project quality | 12 | 12 | 0 |
| | | **Spearman's Correlation Factor** | | **0.885** |

Table 16 Spearman's Correlation Test - Owner VERSUS Others - Omission works

| ID | FACTORS | QATAR RANK | WORLD RANK | d2 |
|---|---|---|---|---|
| F01 | Delay of progress payments | 5 | 5 | 0 |
| F02 | Delay of retention payment | 10 | 9 | 1 |
| F03 | Increased project financing | 14 | 14 | 0 |
| F04 | Increased reworks and demolition works | 8 | 8 | 0 |
| F05 | Decrease in contractor reputation | 3 | 6 | 9 |
| F06 | Poor contractor relationship with the client | 1 | 1 | 0 |
| F07 | Loss of opportunity for new projects | 13 | 12 | 1 |
| F08 | Increased contractor overhead expenses | 4 | 3 | 1 |
| F09 | Increased site logistics requirements | 16 | 15 | 1 |
| F10 | Increased project re-planning | 2 | 2 | 0 |
| F11 | Loss of efficiency due to work interruption | 6 | 7 | 1 |
| F12 | Loss of efficiency due to lack of equipment | 11 | 13 | 4 |
| F13 | Increased in project management efforts | 7 | 4 | 9 |
| F14 | Increased material unit prices | 12 | 11 | 1 |
| F15 | Decrease in project health and safety | 15 | 16 | 1 |
| F16 | Decrease in project quality | 9 | 10 | 1 |
| | | **Spearman's Correlation Factor** | | **0.956** |

Table 17 Spearman's Correlation Test - Owner VERSUS Others - Substitution (Change) works

| ID | FACTORS | QATAR RANK | WORLD RANK | d2 |
|---|---|---|---|---|
| F01 | Delay of progress payments | 6 | 5 | 1 |
| F02 | Delay of retention payment | 3 | 7 | 16 |
| F03 | Increased project financing | 9 | 14 | 25 |
| F04 | Increased reworks and demolition works | 2 | 2 | 0 |
| F05 | Decrease in contractor reputation | 10 | 10 | 0 |
| F06 | Poor contractor relationship with the client | 5 | 6 | 1 |
| F07 | Loss of opportunity for new projects | 8 | 13 | 25 |
| F08 | Increased contractor overhead expenses | 12 | 9 | 9 |
| F09 | Increased site logistics requirements | 13 | 8 | 25 |
| F10 | Increased project re-planning | 1 | 1 | 0 |
| F11 | Loss of efficiency due to work interruption | 7 | 4 | 9 |
| F12 | Loss of efficiency due to lack of equipment | 14 | 12 | 4 |
| F13 | Increased in project management efforts | 4 | 3 | 1 |
| F14 | Increased material unit prices | 15 | 15 | 0 |
| F15 | Decrease in project health and safety | 16 | 16 | 0 |
| F16 | Decrease in project quality | 11 | 11 | 0 |
| | | **Spearman's Correlation Factor** | | **0.829** |

**Experience Less than 10 years vs more than 10 years**

This part represents the ranking comparison of the responses of participants with less than 10 years and more than 10 years. The results are listed in Tables 18,19 and 20.

Spearman's correlation factors are 0.768 for additional works, 0.732 for Omission Works and 0.75 for Substitution (Change) works. These reflect agreement between the participants.

Table 18 Spearman's Correlation Test – Less VERSUS more than 10 years' experience - Additional works

| ID | FACTORS | QATAR RANK | WORLD RANK | d2 |
|---|---|---|---|---|
| F01 | Delay of progress payments | 13 | 9 | 16 |
| F02 | Delay of retention payment | 7 | 5 | 4 |
| F03 | Increased project financing | 2 | 6 | 16 |
| F04 | Increased reworks and demolition works | 12 | 10 | 4 |
| F05 | Decrease in contractor reputation | 16 | 15 | 1 |
| F06 | Poor contractor relationship with the client | 14 | 12 | 4 |
| F07 | Loss of opportunity for new projects | 5 | 4 | 1 |
| F08 | Increased contractor overhead expenses | 3 | 8 | 25 |
| F09 | Increased site logistics requirements | 4 | 3 | 1 |
| F10 | Increased project re-planning | 1 | 1 | 0 |
| F11 | Loss of efficiency due to work interruption | 8 | 7 | 1 |
| F12 | Loss of efficiency due to lack of equipment | 11 | 11 | 0 |
| F13 | Increased in project management efforts | 6 | 2 | 16 |
| F14 | Increased material unit prices | 15 | 13 | 4 |
| F15 | Decrease in project health and safety | 9 | 16 | 49 |
| F16 | Decrease in project quality | 10 | 14 | 16 |
| | | **Spearman's Correlation Factor** | | **0.768** |

Table 19 Spearman's Correlation Test – Less VERSUS more than 10 years' experience - Omission works

| ID | FACTORS | QATAR RANK | WORLD RANK | d2 |
|---|---|---|---|---|
| F01 | Delay of progress payments | 7 | 4 | 9 |
| F02 | Delay of retention payment | 10 | 8 | 4 |
| F03 | Increased project financing | 13 | 14 | 1 |
| F04 | Increased reworks and demolition works | 9 | 6 | 9 |
| F05 | Decrease in contractor reputation | 3 | 10 | 49 |
| F06 | Poor contractor relationship with the client | 1 | 1 | 0 |
| F07 | Loss of opportunity for new projects | 11 | 12 | 1 |
| F08 | Increased contractor overhead expenses | 4 | 7 | 9 |
| F09 | Increased site logistics requirements | 15 | 15 | 0 |
| F10 | Increased project re-planning | 2 | 2 | 0 |
| F11 | Loss of efficiency due to work interruption | 8 | 5 | 9 |
| F12 | Loss of efficiency due to lack of equipment | 14 | 11 | 9 |
| F13 | Increased in project management efforts | 6 | 3 | 9 |
| F14 | Increased material unit prices | 12 | 9 | 9 |
| F15 | Decrease in project health and safety | 16 | 16 | 0 |
| F16 | Decrease in project quality | 5 | 13 | 64 |
| | | **Spearman's Correlation Factor** | | **0.732** |

Table 20 Spearman's Correlation Test – Less VERSUS more than 10 years' experience - Substitution (Change) works

| ID | FACTORS | QATAR RANK | WORLD RANK | d2 |
|---|---|---|---|---|
| F01 | Delay of progress payments | 8 | 5 | 9 |
| F02 | Delay of retention payment | 9 | 6 | 9 |
| F03 | Increased project financing | 12 | 15 | 9 |
| F04 | Increased reworks and demolition works | 2 | 2 | 0 |
| F05 | Decrease in contractor reputation | 7 | 13 | 36 |
| F06 | Poor contractor relationship with the client | 5 | 7 | 4 |
| F07 | Loss of opportunity for new projects | 13 | 10 | 9 |
| F08 | Increased contractor overhead expenses | 6 | 11 | 25 |
| F09 | Increased site logistics requirements | 10 | 8 | 4 |
| F10 | Increased project re-planning | 1 | 1 | 0 |
| F11 | Loss of efficiency due to work interruption | 4 | 4 | 0 |
| F12 | Loss of efficiency due to lack of equipment | 15 | 9 | 36 |
| F13 | Increased in project management efforts | 3 | 3 | 0 |
| F14 | Increased material unit prices | 16 | 12 | 16 |
| F15 | Decrease in project health and safety | 14 | 16 | 4 |
| F16 | Decrease in project quality | 11 | 14 | 9 |
| | | **Spearman's Correlation Factor** | | **0.75** |

## 4.6. Analytical Hierarchy Process (AHP)

This section represents data analysis using Analytical Hierarchy Process (AHP) decision technique. Relative importance index (RII) is used at the initial stage to rank the

impact factors of each type of change orders individually, AHP was used to provide an overall ranking of the impact factors for all types of change orders.

Analytical Hierarchy Process (AHP) was used as a method in different research works in construction industry and showed successful results, as AHP is a useful method for multi-criteria decision making in construction management.

AHP uses pairwise comparisons between criteria to measure the relative importance of each of them. Inconsistency in pairwise comparisons may occur as outcome of improper conceptualization of data-hierarchy. Consistency ratio must be less than 0.1 to be acceptable and if not, pairwise comparison matrix needs to be revised.

The strength of AHP appears in arranging the factors in a systematic way and provides a simple solution to support project management by taking the correct decision of multiple criteria problem. This is why AHP method have been used in this research project to provide overall ranking for the factors considering the different types of change orders. Change orders types represent the multiple criteria of AHP method.

AHP results are subjective as they depend on the relative weight assigned to each factor at pairwise comparisons.

AHP arrange the decision problem into multiple level hierarchical structures starting at the top level with problem objectives, next level with multi criteria and last level with alternatives.

The objective of using AHP in this study is to provide an overall ranking of the impact factors, by considering the three types of change orders as criteria and the 16 impact factors as alternatives.

AHP analysis is applied using the procedure shown below.

1. Define the problem objective.
2. Define the problem multiple criteria.
3. Define the problem alternatives.
4. Assign relative weights for each alternative and criteria.
5. Create the AHP multi-level hierarchical structure.
6. Generate pairwise comparison matrices for the alternatives and the criteria in relation to the assigned relative weights.
7. Check consistency ration, if less than 0.1, revision is required for pairwise comparison matrix.
8. Compute priority values to obtain the alternatives overall ranking.

RII ranking was used to determine the relative weights, which are required to develop the pairwise comparison matrices using AHP 9-point scale described in below table. Pairwise comparison matrices were developed for the 16 impact factors for each type of change orders and were also developed for the three types of change orders.

Pairwise comparison requires n*n matrix, where ‘n’ represents the alternatives number, ‘n’ equals 16 while representing the factors and equals 3 while representing the types of change orders.

A total of n(n-1)/2 comparisons were made between the elements in the comparison matrix, the diagonal values are always equal to 1.

Computer software (SuperDecision) was used to calculate the consistency ratio (CR) and the priority of each element. CR value should be less than 0.1 to be considered as acceptable, otherwise reassigning of the relative weights is required to make a consistent

matrix. The sum of the priorities should be equal to 1 and higher priority value indicates a higher ranking of the element.

AHP priority values were used to rank the elements and were used to obtain a hierarchy of the impact factors for the three types of change orders concurrently. The AHP hierarchical structure is presented in the below figure.

Table 21 AHP - Scale for Pairwise Comparisons

| Intensity of Importance | Definition | Explanation |
|---|---|---|
| 1 | Equal Importance | Both items contribute equally to the objective |
| 2 | Intermediate value | Intermediate value between 1 and 3 |
| 3 | Moderate Importance | One element has slightly more importance over another |
| 4 | Intermediate value | Intermediate value between 3 and 5 |
| 5 | Strong Importance | One element has strongly more importance over another |
| 6 | Intermediate value | Intermediate value between 5 and 7 |
| 7 | Very Strong Importance | One element has very strongly more importance over another |
| 8 | Intermediate value | Intermediate value between 7 and9 |
| 9 | Extreme Importance | One element has extreme more importance over another |

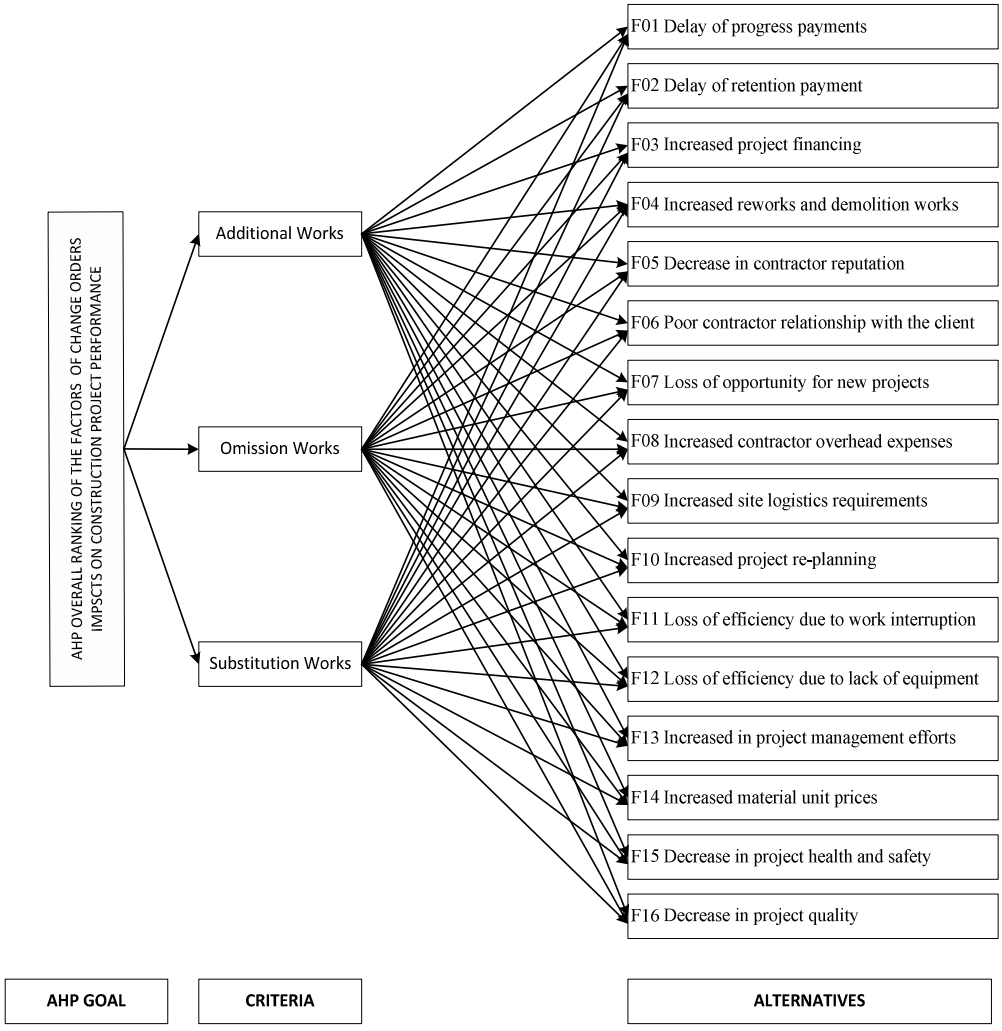


**Figure 5 AHP Overall Ranking Model for Multi Criteria of the Factors of Change Orders Impacts**

RII ranking values in the below tables are used to assign the relative weights of AHP pairwise comparison.

Table 22 RII Factors Ranking of Additional Works Change Orders

| ID | FACTORS | RII | FACTORS RANKING |
|---|---|---|---|
| F10 | Increased project re-planning | 0.746 | 1 |
| F13 | Increased in project management efforts | 0.685 | 2 |
| F03 | Increased project financing | 0.676 | 3 |
| F09 | Increased site logistics requirements | 0.674 | 4 |
| F07 | Loss of opportunity for new projects | 0.649 | 5 |
| F08 | Increased contractor overhead expenses | 0.647 | 6 |
| F02 | Delay of retention payment | 0.625 | 7 |
| F11 | Loss of efficiency due to work interruption | 0.606 | 8 |
| F12 | Loss of efficiency due to lack of equipment | 0.531 | 9 |
| F04 | Increased reworks and demolition works | 0.529 | 10 |
| F01 | Delay of progress payments | 0.521 | 11 |
| F16 | Decrease in project quality | 0.487 | 12 |
| F15 | Decrease in project health and safety | 0.467 | 13 |
| F06 | Poor contractor relationship with the client | 0.449 | 14 |
| F14 | Increased material unit prices | 0.426 | 15 |
| F05 | Decrease in contractor reputation | 0.407 | 16 |

Table 23 RII Factors Ranking of Omission Works Change Orders

| ID | FACTORS | RII | FACTORS RANKING |
|---|---|---|---|
| F06 | Poor contractor relationship with the client | 0.626 | 1 |
| F10 | Increased project re-planning | 0.621 | 2 |
| F08 | Increased contractor overhead expenses | 0.544 | 3 |
| F05 | Decrease in contractor reputation | 0.524 | 4 |
| F13 | Increased in project management efforts | 0.524 | 5 |
| F01 | Delay of progress payments | 0.517 | 6 |
| F11 | Loss of efficiency due to work interruption | 0.505 | 7 |
| F04 | Increased reworks and demolition works | 0.484 | 8 |
| F02 | Delay of retention payment | 0.455 | 9 |
| F16 | Decrease in project quality | 0.444 | 10 |
| F14 | Increased material unit prices | 0.417 | 11 |
| F07 | Loss of opportunity for new projects | 0.411 | 12 |
| F12 | Loss of efficiency due to lack of equipment | 0.404 | 13 |
| F03 | Increased project financing | 0.378 | 14 |
| F09 | Increased site logistics requirements | 0.33 | 15 |
| F15 | Decrease in project health and safety | 0.326 | 16 |

Table 24 RII Factors Ranking of Substitution Works Change Orders

| ID | FACTORS | RII | FACTORS RANKING |
|---|---|---|---|
| F10 | Increased project re-planning | 0.781 | 1 |
| F04 | Increased reworks and demolition works | 0.754 | 2 |
| F13 | Increased in project management efforts | 0.734 | 3 |
| F11 | Loss of efficiency due to work interruption | 0.721 | 4 |
| F01 | Delay of progress payments | 0.674 | 5 |
| F02 | Delay of retention payment | 0.659 | 6 |
| F06 | Poor contractor relationship with the client | 0.659 | 7 |
| F09 | Increased site logistics requirements | 0.608 | 8 |
| F08 | Increased contractor overhead expenses | 0.587 | 9 |
| F05 | Decrease in contractor reputation | 0.578 | 10 |
| F07 | Loss of opportunity for new projects | 0.552 | 11 |
| F16 | Decrease in project quality | 0.551 | 12 |
| F12 | Loss of efficiency due to lack of equipment | 0.541 | 13 |
| F03 | Increased project financing | 0.538 | 14 |
| F14 | Increased material unit prices | 0.487 | 15 |
| F15 | Decrease in project health and safety | 0.485 | 16 |

Table 25 RII Ranking of the Types of Change Orders

| ID | Types of Change Orders | RII | TYPES RANKING |
|---|---|---|---|
| T03 | Substitution (Change) works | 0.743 | 1 |
| T01 | Additional Works | 0.71 | 2 |
| T02 | Omission Works | 0.513 | 3 |

**AHP Pairwise Comparison Matrix Development**

Relative weights were assigned to each element of the comparison matrix with reference to the RII values. These matrices were developed for each type of change orders to compare the 16 impact factors using the AHP scale described earlier. Also, pairwise comparison matrix was developed to compare the types of change orders. Computer software (SuperDecisions) used to develop the pairwise comparison matrices. Tables below show three matrices of the 16 factors with a size of 16*16 and 1 matrix of the three types of change orders with a size of 3*3.

**Example of assigning relative weights and element comparisons**

- For the additional works change order, Factor number 10 ( F10) was assigned the highest weight (9) as it has the highest RII value and factor F01 was assigned the weight of 3 as it has a much lower RII value.
- After the assigning the weights, pairwise comparisons were developed between each element, for example for additional works, F10 has value of 6 in comparison to F01 which means that F10 is strongly more important than F01, where F10 was assigned a weight of 9 and F01 was assigned a weight of 3.

Table 26 Sample of pairwise comparison – Additional works (F01 & F10 weights and comparison)

| ID | | F01 | F02 | F03 | F04 | F05 | F06 | F07 | F08 | F09 | F10 | F11 | F12 | F13 | F14 | F15 | F16 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | WGT | **3** | 6 | 7 | 3 | 1 | 1 | 6 | 6 | 7 | 9 | 5 | 3 | 7 | 1 | 2 | 2 |
| **F10** | **9** | **6** | 3 | 2 | 6 | 9 | 8 | 3 | 3 | 2 | 1 | 4 | 6 | 2 | 8 | 7 | 7 |

Table 27 AHP Pairwise Comparisons Matrix - Additional Works Impact Factors

| ID | | F01 | F02 | F03 | F04 | F05 | F06 | F07 | F08 | F09 | F10 | F11 | F12 | F13 | F14 | F15 | F16 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | WGT | 3 | 6 | 7 | 3 | 1 | 1 | 6 | 6 | 7 | 9 | 5 | 3 | 7 | 1 | 2 | 2 |
| F01 | 3 | 1 | 1/3 | 1/4 | 1 | 3 | 2 | 1/3 | 1/3 | 1/4 | 1/6 | 1/2 | 1 | 1/4 | 3 | 1 | 1 |
| F02 | 6 | 3 | 1 | 1 | 3 | 6 | 5 | 1 | 1 | 1 | 1/3 | 1 | 2 | 1/2 | 5 | 4 | 4 |
| F03 | 7 | 4 | 1 | 1 | 4 | 7 | 6 | 1 | 1 | 1 | 1/2 | 2 | 4 | 1 | 7 | 6 | 5 |
| F04 | 3 | 1 | 1/3 | 1/4 | 1 | 3 | 2 | 1/3 | 1/3 | 1/4 | 1/6 | 1/2 | 1 | 1/4 | 3 | 2 | 1 |
| F05 | 1 | 1/3 | 1/6 | 1/7 | 1/3 | 1 | 1 | 1/6 | 1/6 | 1/7 | 1/9 | 1/5 | 1/3 | 1/7 | 1 | 1/2 | 1/2 |
| F06 | 1 | 1/2 | 1/5 | 1/6 | 1/2 | 1 | 1 | 1/5 | 1/5 | 1/6 | 1/8 | 1/4 | 1/2 | 1/6 | 1 | 1 | 1 |
| F07 | 6 | 3 | 1 | 1 | 3 | 6 | 5 | 1 | 1 | 1 | 1/3 | 1 | 3 | 1 | 6 | 5 | 4 |
| F08 | 6 | 3 | 1 | 1 | 3 | 6 | 5 | 1 | 1 | 1 | 1/3 | 1 | 3 | 1 | 6 | 5 | 4 |
| F09 | 7 | 4 | 1 | 1 | 4 | 7 | 6 | 1 | 1 | 1 | 1/2 | 2 | 4 | 1 | 7 | 5 | 5 |
| F10 | 9 | 6 | 3 | 2 | 6 | 9 | 8 | 3 | 3 | 2 | 1 | 4 | 6 | 2 | 8 | 7 | 7 |
| F11 | 5 | 2 | 1 | 1/2 | 2 | 5 | 4 | 1 | 1 | 1/2 | 1/4 | 1 | 2 | 1/2 | 5 | 4 | 3 |
| F12 | 3 | 1 | 1/2 | 1/4 | 1 | 3 | 2 | 1/3 | 1/3 | 1/4 | 1/6 | 1/2 | 1 | 1/4 | 3 | 2 | 1 |
| F13 | 7 | 4 | 2 | 1 | 4 | 7 | 6 | 1 | 1 | 1 | 1/2 | 2 | 4 | 1 | 7 | 6 | 5 |
| F14 | 1 | 1/3 | 1/5 | 1/7 | 1/3 | 1 | 1 | 1/6 | 1/6 | 1/7 | 1/8 | 1/5 | 1/3 | 1/7 | 1 | 1 | 1 |
| F15 | 2 | 1 | 1/4 | 1/6 | 1/2 | 2 | 1 | 1/5 | 1/5 | 1/5 | 1/7 | 1/4 | 1/2 | 1/6 | 1 | 1 | 1 |
| F16 | 2 | 1 | 1/4 | 1/5 | 1 | 2 | 1 | 1/4 | 1/4 | 1/5 | 1/7 | 1/3 | 1 | 1/5 | 1 | 1 | 1 |

Table 28 AHP Pairwise Comparisons Matrix – Omission Works Impact Factors

| ID | | F01 | F02 | F03 | F04 | F05 | F06 | F07 | F08 | F09 | F10 | F11 | F12 | F13 | F14 | F15 | F16 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | WGT | 6 | 4 | 2 | 5 | 6 | 9 | 3 | 7 | 1 | 9 | 5 | 2 | 6 | 3 | 1 | 4 |
| F01 | 6 | 1 | 2 | 4 | 1 | 1 | 1/3 | 3 | 1 | 6 | 1/3 | 1 | 3 | 1 | 3 | 6 | 2 |
| F02 | 4 | 1/2 | 1 | 2 | 1 | 1/2 | 1/5 | 1 | 1/3 | 4 | 1/5 | 1 | 2 | 1/2 | 1 | 4 | 1 |
| F03 | 2 | 1/4 | 1/2 | 1 | 1/3 | 1/4 | 1/7 | 1 | 1/5 | 1 | 1/7 | 1/4 | 1 | 1/4 | 1 | 2 | 1/2 |
| F04 | 5 | 1 | 1 | 3 | 1 | 1 | 1/4 | 2 | 1/2 | 5 | 1/4 | 1 | 2 | 1 | 2 | 5 | 1 |
| F05 | 6 | 1 | 2 | 4 | 1 | 1 | 1/3 | 3 | 1 | 6 | 1/3 | 1 | 5 | 1 | 3 | 6 | 2 |
| F06 | 9 | 3 | 5 | 7 | 4 | 3 | 1 | 6 | 2 | 9 | 1 | 4 | 7 | 3 | 6 | 9 | 5 |
| F07 | 3 | 1/3 | 1 | 1 | 1/2 | 1/3 | 1/6 | 1 | 1/4 | 2 | 1/6 | 1/3 | 1 | 1/3 | 1 | 1/3 | 1 |
| F08 | 7 | 1 | 3 | 5 | 2 | 1 | 1/2 | 4 | 1 | 6 | 1/2 | 1 | 4 | 1 | 4 | 7 | 3 |
| F09 | 1 | 1/6 | 1/4 | 1 | 1/5 | 1/6 | 1/9 | 1/2 | 1/6 | 1 | 1/9 | 1/5 | 1/2 | 1/6 | 1/3 | 1 | 1/3 |
| F10 | 9 | 3 | 5 | 7 | 4 | 3 | 1 | 6 | 2 | 9 | 1 | 3 | 7 | 3 | 6 | 9 | 5 |
| F11 | 5 | 1 | 1 | 4 | 1 | 1 | 1/4 | 3 | 1 | 5 | 1/3 | 1 | 3 | 1 | 3 | 5 | 2 |
| F12 | 2 | 1/3 | 1/2 | 1 | 1/2 | 1/5 | 1/7 | 1 | 1/4 | 2 | 1/7 | 1/3 | 1 | 1/4 | 1 | 2 | 1 |
| F13 | 6 | 1 | 2 | 4 | 1 | 1 | 1/3 | 3 | 1 | 6 | 1/3 | 1 | 4 | 1 | 3 | 6 | 2 |
| F14 | 3 | 1/3 | 1 | 1 | 1/2 | 1/3 | 1/6 | 1 | 1/4 | 3 | 1/6 | 1/3 | 1 | 1/3 | 1 | 3 | 1 |
| F15 | 1 | 1/6 | 1/4 | 1/2 | 1/5 | 1/6 | 1/9 | 3 | 1/7 | 1 | 1/9 | 1/5 | 1/2 | 1/6 | 1/3 | 1 | 1/4 |
| F16 | 4 | 1/2 | 1 | 2 | 1 | 1/2 | 1/5 | 1 | 1/3 | 3 | 1/5 | 1/2 | 1 | 1/2 | 1 | 4 | 1 |

Table 29 AHP Pairwise Comparisons Matrix – Substitution Works Impact Factors

| ID | | F01 | F02 | F03 | F04 | F05 | F06 | F07 | F08 | F09 | F10 | F11 | F12 | F13 | F14 | F15 | F16 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | WGT | 6 | 5 | 2 | 8 | 3 | 5 | 2 | 3 | 4 | 9 | 7 | 2 | 8 | 1 | 1 | 2 |
| F01 | 6 | 1 | 1 | 4 | 1/2 | 3 | 1 | 4 | 3 | 2 | 1/3 | 1 | 4 | 1/2 | 6 | 6 | 4 |
| F02 | 5 | 1 | 1 | 4 | 1/3 | 2 | 1 | 3 | 2 | 2 | 1/4 | 1/2 | 4 | 1/2 | 5 | 5 | 3 |
| F03 | 2 | 1/4 | 1/4 | 1 | 1/7 | 1 | 1/4 | 1 | 1 | 1/2 | 1/7 | 1/6 | 1 | 1/6 | 2 | 2 | 1 |
| F04 | 8 | 2 | 3 | 7 | 1 | 5 | 3 | 6 | 5 | 4 | 1 | 1 | 6 | 1 | 8 | 8 | 6 |
| F05 | 3 | 1/3 | 1/2 | 1 | 1/5 | 1 | 1/2 | 1 | 1 | 1 | 1/6 | 1/4 | 1 | 1/5 | 3 | 3 | 1 |
| F06 | 5 | 1 | 1 | 4 | 1/3 | 2 | 1 | 3 | 2 | 2 | 1/4 | 1/2 | 4 | 1/2 | 5 | 5 | 3 |
| F07 | 2 | 1/4 | 1/3 | 1 | 1/6 | 1 | 1/3 | 1 | 1 | 1/2 | 1/7 | 1/5 | 1 | 1/6 | 2 | 2 | 1 |
| F08 | 3 | 1/3 | 1/2 | 1 | 1/5 | 1 | 1/2 | 1 | 1 | 1 | 1/6 | 1/4 | 1 | 1/4 | 3 | 3 | 1 |
| F09 | 4 | 1/2 | 1/2 | 2 | 1/4 | 1 | 1/2 | 2 | 1 | 1 | 1/5 | 1/3 | 2 | 1/4 | 4 | 4 | 2 |
| F10 | 9 | 3 | 4 | 7 | 1 | 6 | 4 | 7 | 6 | 5 | 1 | 2 | 7 | 1 | 9 | 9 | 7 |
| F11 | 7 | 1 | 2 | 6 | 1 | 4 | 2 | 5 | 4 | 3 | 1/2 | 1 | 5 | 1 | 7 | 7 | 5 |
| F12 | 2 | 1/4 | 1/4 | 1 | 1/6 | 1 | 1/4 | 1 | 1 | 1/2 | 1/7 | 1/5 | 1 | 1/6 | 2 | 2 | 1 |
| F13 | 8 | 2 | 2 | 6 | 1 | 5 | 2 | 6 | 4 | 4 | 1 | 1 | 6 | 1 | 8 | 8 | 6 |
| F14 | 1 | 1/6 | 1/5 | 1/2 | 1/8 | 1/3 | 1/5 | 1/2 | 1/3 | 1/4 | 1/9 | 1/7 | 1/2 | 1/8 | 1 | 1 | 1/2 |
| F15 | 1 | 1/6 | 1/5 | 1/2 | 1/8 | 1/3 | 1/5 | 1/2 | 1/3 | 1/4 | 1/9 | 1/7 | 1/2 | 1/8 | 1 | 1 | 1/2 |
| F16 | 2 | 1/4 | 1/3 | 1 | 1/6 | 1 | 1/3 | 1 | 1 | 1/2 | 1/7 | 1/5 | 1 | 1/6 | 2 | 2 | 1 |

Table 30 AHP Pairwise Comparisons – Type of Change orders

| ID | | T01 | T02 | T03 |
|---|---|---|---|---|
| | WGT | 7 | 1 | 9 |
| T01 Additional Works | 7 | 1 | 7 | 1/2 |
| T02 Omission Works | 1 | 1/7 | 1 | 1/9 |
| T03 Substitution works | 9 | 2 | 9 | 1 |

**Normalized pairwise comparison matrices, Consistency ratio and priority values**

The summation of each column was computed and then all values within each column were divided by the column's summation. Then, the new summation of each column becomes equal to one, which means that the matrices became normalized.

The priority value of each row equals the average of all values in the row and the summation of all priority values equals one.

Computer software (SuperDecisions) was used to calculate the consistency ratio (CR).

The normalized matrices with the priority values are provided below.

**Example of normalizing matrices with the priority values**

- For the additional works matrix, the sum of the first column equals to:

$$(1+3+4+1+1/3+1/2+3+3+4+6+2+1+4+1/3+1+1) = 35.17$$

Table 31 Sample for Column Summation of Pairwise Comparison Matrix

| ID | | F01 | F02 | F03 | F04 | F05 | F06 | F07 | F08 | F09 | F10 | F11 | F12 | F13 | F14 | F15 | F16 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | WGT | 3 | 6 | 7 | 3 | 1 | 1 | 6 | 6 | 7 | 9 | 5 | 3 | 7 | 1 | 2 | 2 |
| F01 | 3 | 1 | 1/3 | 1/4 | 1 | 3 | 2 | 1/3 | 1/3 | 1/4 | 1/6 | 1/2 | 1 | 1/4 | 3 | 1 | 1 |
| F02 | 6 | 3 | 1 | 1 | 3 | 6 | 5 | 1 | 1 | 1 | 1/3 | 1 | 2 | 1/2 | 5 | 4 | 4 |
| F03 | 7 | 4 | 1 | 1 | 4 | 7 | 6 | 1 | 1 | 1 | 1/2 | 2 | 4 | 1 | 7 | 6 | 5 |
| F04 | 3 | 1 | 1/3 | 1/4 | 1 | 3 | 2 | 1/3 | 1/3 | 1/4 | 1/6 | 1/2 | 1 | 1/4 | 3 | 2 | 1 |
| F05 | 1 | 1/3 | 1/6 | 1/7 | 1/3 | 1 | 1 | 1/6 | 1/6 | 1/7 | 1/9 | 1/5 | 1/3 | 1/7 | 1 | 1/2 | 1/2 |
| F06 | 1 | 1/2 | 1/5 | 1/6 | 1/2 | 1 | 1 | 1/5 | 1/5 | 1/6 | 1/8 | 1/4 | 1/2 | 1/6 | 1 | 1 | 1 |
| F07 | 6 | 3 | 1 | 1 | 3 | 6 | 5 | 1 | 1 | 1 | 1/3 | 1 | 3 | 1 | 6 | 5 | 4 |
| F08 | 6 | 3 | 1 | 1 | 3 | 6 | 5 | 1 | 1 | 1 | 1/3 | 1 | 3 | 1 | 6 | 5 | 4 |
| F09 | 7 | 4 | 1 | 1 | 4 | 7 | 6 | 1 | 1 | 1 | 1/2 | 2 | 4 | 1 | 7 | 5 | 5 |
| F10 | 9 | 6 | 3 | 2 | 6 | 9 | 8 | 3 | 3 | 2 | 1 | 4 | 6 | 2 | 8 | 7 | 7 |
| F11 | 5 | 2 | 1 | 1/2 | 2 | 5 | 4 | 1 | 1 | 1/2 | 1/4 | 1 | 2 | 1/2 | 5 | 4 | 3 |
| F12 | 3 | 1 | 1/2 | 1/4 | 1 | 3 | 2 | 1/3 | 1/3 | 1/4 | 1/6 | 1/2 | 1 | 1/4 | 3 | 2 | 1 |
| F13 | 7 | 4 | 2 | 1 | 4 | 7 | 6 | 1 | 1 | 1 | 1/2 | 2 | 4 | 1 | 7 | 6 | 5 |
| F14 | 1 | 1/3 | 1/5 | 1/7 | 1/3 | 1 | 1 | 1/6 | 1/6 | 1/7 | 1/8 | 1/5 | 1/3 | 1/7 | 1 | 1 | 1 |
| F15 | 2 | 1 | 1/4 | 1/6 | 1/2 | 2 | 1 | 1/5 | 1/5 | 1/5 | 1/7 | 1/4 | 1/2 | 1/6 | 1 | 1 | 1 |
| F16 | 2 | 1 | 1/4 | 1/5 | 1 | 2 | 1 | 1/4 | 1/4 | 1/5 | 1/7 | 1/3 | 1 | 1/5 | 1 | 1 | 1 |
| Summation = | | 35.17 | 13.23 | 10.07 | 34.67 | 69.00 | 56.00 | 11.98 | 11.98 | 10.10 | 4.90 | 16.73 | 33.67 | 9.57 | 65.00 | 51.50 | 44.50 |

All the values within the first column were divided by 35.17 to normalize them, the same were followed for all columns, after complete the normalization for all the values, the average of each row gives the priority value (PV) of each factor. The average value of the first row of the normalized matrix is equal to 0.030.

Table 32 Sample for Row Average Value of Pairwise Comparison Matrix

| ID | | F01 | F02 | F03 | F04 | F05 | F06 | F07 | F08 | F09 | F10 | F11 | F12 | F13 | F14 | F15 | F16 | PV |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | WGT | 3 | 6 | 7 | 3 | 1 | 1 | 6 | 6 | 7 | 9 | 5 | 3 | 7 | 1 | 2 | 2 | |
| F01 | 3 | 0.03 | 0.03 | 0.02 | 0.03 | 0.04 | 0.04 | 0.03 | 0.03 | 0.02 | 0.03 | 0.03 | 0.03 | 0.03 | 0.05 | 0.02 | 0.02 | 0.030 |

Table 33 AHP Normalized Pairwise Comparisons – Additional Works with Priority Values and Consistency Ratio

| ID | | F01 | F02 | F03 | F04 | F05 | F06 | F07 | F08 | F09 | F10 | F11 | F12 | F13 | F14 | F15 | F16 | PV |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | WGT | 3 | 6 | 7 | 3 | 1 | 1 | 6 | 6 | 7 | 9 | 5 | 3 | 7 | 1 | 2 | 2 | |
| F01 | 3 | 0.03 | 0.03 | 0.02 | 0.03 | 0.04 | 0.04 | 0.03 | 0.03 | 0.02 | 0.03 | 0.03 | 0.03 | 0.03 | 0.05 | 0.02 | 0.02 | 0.030 |
| F02 | 6 | 0.09 | 0.08 | 0.10 | 0.09 | 0.09 | 0.09 | 0.08 | 0.08 | 0.10 | 0.07 | 0.06 | 0.06 | 0.05 | 0.08 | 0.08 | 0.09 | 0.080 |
| F03 | 7 | 0.11 | 0.08 | 0.10 | 0.12 | 0.10 | 0.11 | 0.08 | 0.08 | 0.10 | 0.10 | 0.12 | 0.12 | 0.10 | 0.11 | 0.12 | 0.11 | 0.104 |
| F04 | 3 | 0.03 | 0.03 | 0.02 | 0.03 | 0.04 | 0.04 | 0.03 | 0.03 | 0.02 | 0.03 | 0.03 | 0.03 | 0.03 | 0.05 | 0.04 | 0.02 | 0.031 |
| F05 | 1 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.02 | 0.01 | 0.01 | 0.01 | 0.02 | 0.01 | 0.01 | 0.01 | 0.02 | 0.01 | 0.01 | 0.013 |
| F06 | 1 | 0.01 | 0.02 | 0.02 | 0.01 | 0.01 | 0.02 | 0.02 | 0.02 | 0.02 | 0.03 | 0.01 | 0.01 | 0.02 | 0.02 | 0.02 | 0.02 | 0.017 |
| F07 | 6 | 0.09 | 0.08 | 0.10 | 0.09 | 0.09 | 0.09 | 0.08 | 0.08 | 0.10 | 0.07 | 0.06 | 0.09 | 0.10 | 0.09 | 0.10 | 0.09 | 0.087 |
| F08 | 6 | 0.09 | 0.08 | 0.10 | 0.09 | 0.09 | 0.09 | 0.08 | 0.08 | 0.10 | 0.07 | 0.06 | 0.09 | 0.10 | 0.09 | 0.10 | 0.09 | 0.087 |
| F09 | 7 | 0.11 | 0.08 | 0.10 | 0.12 | 0.10 | 0.11 | 0.08 | 0.08 | 0.10 | 0.10 | 0.12 | 0.12 | 0.10 | 0.11 | 0.10 | 0.11 | 0.103 |
| F10 | 9 | 0.17 | 0.23 | 0.20 | 0.17 | 0.13 | 0.14 | 0.25 | 0.25 | 0.20 | 0.20 | 0.24 | 0.18 | 0.21 | 0.12 | 0.14 | 0.16 | 0.187 |
| F11 | 5 | 0.06 | 0.08 | 0.05 | 0.06 | 0.07 | 0.07 | 0.08 | 0.08 | 0.05 | 0.05 | 0.06 | 0.06 | 0.05 | 0.08 | 0.08 | 0.07 | 0.065 |
| F12 | 3 | 0.03 | 0.04 | 0.02 | 0.03 | 0.04 | 0.04 | 0.03 | 0.03 | 0.02 | 0.03 | 0.03 | 0.03 | 0.03 | 0.05 | 0.04 | 0.02 | 0.032 |
| F13 | 7 | 0.11 | 0.15 | 0.10 | 0.12 | 0.10 | 0.11 | 0.08 | 0.08 | 0.10 | 0.10 | 0.12 | 0.12 | 0.10 | 0.11 | 0.12 | 0.11 | 0.108 |
| F14 | 1 | 0.01 | 0.02 | 0.01 | 0.01 | 0.01 | 0.02 | 0.01 | 0.01 | 0.01 | 0.03 | 0.01 | 0.01 | 0.01 | 0.02 | 0.02 | 0.02 | 0.015 |
| F15 | 2 | 0.03 | 0.02 | 0.02 | 0.01 | 0.03 | 0.02 | 0.02 | 0.02 | 0.02 | 0.03 | 0.01 | 0.01 | 0.02 | 0.02 | 0.02 | 0.02 | 0.019 |
| F16 | 2 | 0.03 | 0.02 | 0.02 | 0.03 | 0.03 | 0.02 | 0.02 | 0.02 | 0.02 | 0.03 | 0.02 | 0.03 | 0.02 | 0.02 | 0.02 | 0.02 | 0.023 |
| Summation = | | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |

Consistency Ratio = 0.00917 < 0.1

Table 34 AHP Normalized Pairwise Comparisons – Omission Works with Priority Values and Consistency Ratio

| ID | | F01 | F02 | F03 | F04 | F05 | F06 | F07 | F08 | F09 | F10 | F11 | F12 | F13 | F14 | F15 | F16 | PV |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | WGT | 6 | 4 | 2 | 5 | 6 | 9 | 3 | 7 | 1 | 9 | 5 | 2 | 6 | 3 | 1 | 4 | |
| F01 | 6 | 0.07 | 0.08 | 0.08 | 0.05 | 0.07 | 0.06 | 0.08 | 0.09 | 0.09 | 0.06 | 0.06 | 0.07 | 0.07 | 0.08 | 0.09 | 0.07 | 0.073 |
| F02 | 4 | 0.03 | 0.04 | 0.04 | 0.05 | 0.03 | 0.04 | 0.03 | 0.03 | 0.06 | 0.04 | 0.06 | 0.05 | 0.03 | 0.03 | 0.06 | 0.04 | 0.041 |
| F03 | 2 | 0.02 | 0.02 | 0.02 | 0.02 | 0.02 | 0.03 | 0.03 | 0.02 | 0.01 | 0.03 | 0.02 | 0.02 | 0.02 | 0.03 | 0.03 | 0.02 | 0.021 |
| F04 | 5 | 0.07 | 0.04 | 0.06 | 0.05 | 0.07 | 0.05 | 0.05 | 0.04 | 0.07 | 0.05 | 0.06 | 0.05 | 0.07 | 0.05 | 0.07 | 0.04 | 0.056 |
| F05 | 6 | 0.07 | 0.08 | 0.08 | 0.05 | 0.07 | 0.06 | 0.08 | 0.09 | 0.09 | 0.06 | 0.06 | 0.12 | 0.07 | 0.08 | 0.09 | 0.07 | 0.076 |
| F06 | 9 | 0.21 | 0.19 | 0.15 | 0.21 | 0.21 | 0.19 | 0.15 | 0.18 | 0.13 | 0.19 | 0.25 | 0.16 | 0.21 | 0.16 | 0.13 | 0.18 | 0.180 |
| F07 | 3 | 0.02 | 0.04 | 0.02 | 0.03 | 0.02 | 0.03 | 0.03 | 0.02 | 0.03 | 0.03 | 0.02 | 0.02 | 0.02 | 0.03 | 0.00 | 0.04 | 0.025 |
| F08 | 7 | 0.07 | 0.11 | 0.11 | 0.10 | 0.07 | 0.10 | 0.10 | 0.09 | 0.09 | 0.09 | 0.06 | 0.09 | 0.07 | 0.11 | 0.10 | 0.11 | 0.092 |
| F09 | 1 | 0.01 | 0.01 | 0.02 | 0.01 | 0.01 | 0.02 | 0.01 | 0.01 | 0.01 | 0.02 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.014 |
| F10 | 9 | 0.21 | 0.19 | 0.15 | 0.21 | 0.21 | 0.19 | 0.15 | 0.18 | 0.13 | 0.19 | 0.19 | 0.16 | 0.21 | 0.16 | 0.13 | 0.18 | 0.176 |
| F11 | 5 | 0.07 | 0.04 | 0.08 | 0.05 | 0.07 | 0.05 | 0.08 | 0.09 | 0.07 | 0.06 | 0.06 | 0.07 | 0.07 | 0.08 | 0.07 | 0.07 | 0.068 |
| F12 | 2 | 0.02 | 0.02 | 0.02 | 0.03 | 0.01 | 0.03 | 0.03 | 0.02 | 0.03 | 0.03 | 0.02 | 0.02 | 0.02 | 0.03 | 0.03 | 0.04 | 0.024 |
| F13 | 6 | 0.07 | 0.08 | 0.08 | 0.05 | 0.07 | 0.06 | 0.08 | 0.09 | 0.09 | 0.06 | 0.06 | 0.09 | 0.07 | 0.08 | 0.09 | 0.07 | 0.074 |
| F14 | 3 | 0.02 | 0.04 | 0.02 | 0.03 | 0.02 | 0.03 | 0.03 | 0.02 | 0.04 | 0.03 | 0.02 | 0.02 | 0.02 | 0.03 | 0.04 | 0.04 | 0.029 |
| F15 | 1 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.02 | 0.08 | 0.01 | 0.01 | 0.02 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.017 |
| F16 | 4 | 0.03 | 0.04 | 0.04 | 0.05 | 0.03 | 0.04 | 0.03 | 0.03 | 0.04 | 0.04 | 0.03 | 0.02 | 0.03 | 0.03 | 0.06 | 0.04 | 0.036 |
| Summation = | | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |

Consistency Ratio = 0.01908 < 0.1

Table 35 AHP Normalized Pairwise Comparisons – Substitutional Works with Priority Values and Consistency Ratio

| ID | | F01 | F02 | F03 | F04 | F05 | F06 | F07 | F08 | F09 | F10 | F11 | F12 | F13 | F14 | F15 | F16 | PV |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | WGT | 6 | 5 | 2 | 8 | 3 | 5 | 2 | 3 | 4 | 9 | 7 | 2 | 8 | 1 | 1 | 2 | |
| F01 | 6 | 0.07 | 0.06 | 0.09 | 0.07 | 0.09 | 0.06 | 0.09 | 0.09 | 0.07 | 0.06 | 0.11 | 0.09 | 0.07 | 0.09 | 0.09 | 0.09 | 0.081 |
| F02 | 5 | 0.07 | 0.06 | 0.09 | 0.05 | 0.06 | 0.06 | 0.07 | 0.06 | 0.07 | 0.04 | 0.06 | 0.09 | 0.07 | 0.07 | 0.07 | 0.07 | 0.066 |
| F03 | 2 | 0.02 | 0.01 | 0.02 | 0.02 | 0.03 | 0.01 | 0.02 | 0.03 | 0.02 | 0.03 | 0.02 | 0.02 | 0.02 | 0.03 | 0.03 | 0.02 | 0.023 |
| F04 | 8 | 0.15 | 0.18 | 0.15 | 0.15 | 0.14 | 0.18 | 0.14 | 0.15 | 0.15 | 0.18 | 0.11 | 0.13 | 0.14 | 0.12 | 0.12 | 0.14 | 0.145 |
| F05 | 3 | 0.02 | 0.03 | 0.02 | 0.03 | 0.03 | 0.03 | 0.02 | 0.03 | 0.04 | 0.03 | 0.03 | 0.02 | 0.03 | 0.04 | 0.04 | 0.02 | 0.029 |
| F06 | 5 | 0.07 | 0.06 | 0.09 | 0.05 | 0.06 | 0.06 | 0.07 | 0.06 | 0.07 | 0.04 | 0.06 | 0.09 | 0.07 | 0.07 | 0.07 | 0.07 | 0.066 |
| F07 | 2 | 0.02 | 0.02 | 0.02 | 0.02 | 0.03 | 0.02 | 0.02 | 0.03 | 0.02 | 0.03 | 0.02 | 0.02 | 0.02 | 0.03 | 0.03 | 0.02 | 0.024 |
| F08 | 3 | 0.02 | 0.03 | 0.02 | 0.03 | 0.03 | 0.03 | 0.02 | 0.03 | 0.04 | 0.03 | 0.03 | 0.02 | 0.04 | 0.04 | 0.04 | 0.02 | 0.030 |
| F09 | 4 | 0.04 | 0.03 | 0.04 | 0.04 | 0.03 | 0.03 | 0.05 | 0.03 | 0.04 | 0.04 | 0.04 | 0.04 | 0.04 | 0.06 | 0.06 | 0.05 | 0.040 |
| F10 | 9 | 0.22 | 0.23 | 0.15 | 0.15 | 0.17 | 0.23 | 0.16 | 0.18 | 0.18 | 0.18 | 0.23 | 0.16 | 0.14 | 0.13 | 0.13 | 0.16 | 0.176 |
| F11 | 7 | 0.07 | 0.12 | 0.13 | 0.15 | 0.12 | 0.12 | 0.12 | 0.12 | 0.11 | 0.09 | 0.11 | 0.11 | 0.14 | 0.10 | 0.10 | 0.12 | 0.114 |
| F12 | 2 | 0.02 | 0.01 | 0.02 | 0.02 | 0.03 | 0.01 | 0.02 | 0.03 | 0.02 | 0.03 | 0.02 | 0.02 | 0.02 | 0.03 | 0.03 | 0.02 | 0.023 |
| F13 | 8 | 0.15 | 0.12 | 0.13 | 0.15 | 0.14 | 0.12 | 0.14 | 0.12 | 0.15 | 0.18 | 0.11 | 0.13 | 0.14 | 0.12 | 0.12 | 0.14 | 0.134 |
| F14 | 1 | 0.01 | 0.01 | 0.01 | 0.02 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.02 | 0.02 | 0.01 | 0.02 | 0.01 | 0.01 | 0.01 | 0.013 |
| F15 | 1 | 0.01 | 0.01 | 0.01 | 0.02 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.02 | 0.02 | 0.01 | 0.02 | 0.01 | 0.01 | 0.01 | 0.013 |
| F16 | 2 | 0.02 | 0.02 | 0.02 | 0.02 | 0.03 | 0.02 | 0.02 | 0.03 | 0.02 | 0.03 | 0.02 | 0.02 | 0.02 | 0.03 | 0.03 | 0.02 | 0.024 |
| Summation = | | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |

Consistency Ratio = 0.00868 < 0.1

Table 36 AHP Normalized Pairwise Comparisons – Types of Change Orders with Priority Values and Consistency Ratio

| ID | | T01 | T02 | T03 | Priority Value |
|---|---|---|---|---|---|
| | WGT | 7 | 1 | 9 | |
| T01 Additional Works | 7 | 0.32 | 0.41 | 0.31 | 0.347 |
| T02 Omission Works | 1 | 0.05 | 0.06 | 0.07 | 0.058 |
| T03 Substitution works | 9 | 0.64 | 0.53 | 0.62 | 0.595 |
| Summation = | | 1.00 | 1.00 | 1.00 | 1.00 |

Consistency Ratio = 0.02089 < 0.1

**AHP Overall Ranking**

New matrix was generated for the factors priority values of all types of change orders. Then, this new matrix was multiplied by the matrix of the change order types to compute the factors overall ranking covering the three types of change orders. Priority values matrices and the matrices multiplication details are shown below.

Table 37 Factors Priority values matrix

| ID | Factors | Priority Value | | |
|---|---|---|---|---|
| | | Additional Works | Omission Works | Substitution works |
| F01 | Delay of progress payments | 0.030 | 0.073 | 0.081 |
| F02 | Delay of retention payment | 0.080 | 0.041 | 0.066 |
| F03 | Increased project financing | 0.104 | 0.021 | 0.023 |
| F04 | Increased reworks and demolition works | 0.031 | 0.056 | 0.145 |
| F05 | Decrease in contractor reputation | 0.013 | 0.076 | 0.029 |
| F06 | Poor contractor relationship with the client | 0.017 | 0.180 | 0.066 |
| F07 | Loss of opportunity for new projects | 0.087 | 0.025 | 0.024 |
| F08 | Increased contractor overhead expenses | 0.087 | 0.092 | 0.030 |
| F09 | Increased site logistics requirements | 0.103 | 0.014 | 0.040 |
| F10 | Increased project re-planning | 0.187 | 0.176 | 0.176 |
| F11 | Loss of efficiency due to work interruption | 0.065 | 0.068 | 0.114 |
| F12 | Loss of efficiency due to lack of equipment | 0.032 | 0.024 | 0.023 |
| F13 | Increased in project management efforts | 0.108 | 0.074 | 0.134 |
| F14 | Increased material unit prices | 0.015 | 0.029 | 0.013 |
| F15 | Decrease in project health and safety | 0.019 | 0.017 | 0.013 |
| F16 | Decrease in project quality | 0.023 | 0.036 | 0.024 |

Table 38 Change order types priority values matrix

| ID | Type of Change Orders | Priority Value |
|---|---|---|
| T01 | Additional Works | 0.347 |
| T02 | Omission Works | 0.058 |
| T03 | Substitution works | 0.595 |

| | T01 | T02 | T03 | | | | | | OVERALL |
|---|---|---|---|---|---|---|---|---|---|
| F01 | **0.030** | **0.073** | **0.081** | | | | | F01 | **0.063** |
| F02 | **0.080** | **0.041** | **0.066** | | | | | F02 | **0.069** |
| F03 | **0.104** | **0.021** | **0.023** | | | | | F03 | **0.051** |
| F04 | **0.031** | **0.056** | **0.145** | | | | | F04 | **0.100** |
| F05 | **0.013** | **0.076** | **0.029** | | | | | F05 | **0.027** |
| F06 | **0.017** | **0.180** | **0.066** | | | | | F06 | **0.056** |
| F07 | **0.087** | **0.025** | **0.024** | | T01 | **0.347** | | F07 | **0.046** |
| F08 | **0.087** | **0.092** | **0.030** | **X** | T02 | **0.058** | **=** | F08 | **0.053** |
| F09 | **0.103** | **0.014** | **0.040** | | T03 | **0.595** | | F09 | **0.060** |
| F10 | **0.187** | **0.176** | **0.176** | | | | | F10 | **0.180** |
| F11 | **0.065** | **0.068** | **0.114** | | | | | F11 | **0.094** |
| F12 | **0.032** | **0.024** | **0.023** | | | | | F12 | **0.026** |
| F13 | **0.108** | **0.074** | **0.134** | | | | | F13 | **0.122** |
| F14 | **0.015** | **0.029** | **0.013** | | | | | F14 | **0.015** |
| F15 | **0.019** | **0.017** | **0.013** | | | | | F15 | **0.016** |
| F16 | **0.023** | **0.036** | **0.024** | | | | | F16 | **0.024** |

**Figure 6 Priority Values Matrices Multiplication and Result of Overall Ranking**

The following tables show the factors ranking using AHP for each change order type and the overall ranking and presents the factors overall ranking using AHP method.

Table 39 Factors Ranking using AHP for Each Change Order Type and Overall ranking

| ID | Factors | Additional Works | | Omission Works | | Substitution works | | Overall | |
|---|---|---|---|---|---|---|---|---|---|
| | | Priority | **Rank** | Priority | **Rank** | Priority | **Rank** | Priority | **Rank** |
| F01 | Delay of progress payments | 0.030 | **11** | 0.073 | **6** | 0.081 | **5** | 0.063 | **6** |
| F02 | Delay of retention payment | 0.080 | **7** | 0.041 | **9** | 0.066 | **7** | 0.069 | **5** |
| F03 | Increased project financing | 0.104 | **3** | 0.021 | **14** | 0.023 | **14** | 0.051 | **10** |
| F04 | Increased reworks and demolition works | 0.031 | **10** | 0.056 | **8** | 0.145 | **2** | 0.100 | **3** |
| F05 | Decrease in contractor reputation | 0.013 | **16** | 0.076 | **4** | 0.029 | **10** | 0.027 | **12** |
| F06 | Poor contractor relationship with the client | 0.017 | **14** | 0.180 | **1** | 0.066 | **6** | 0.056 | **8** |
| F07 | Loss of opportunity for new projects | 0.087 | **5** | 0.025 | **12** | 0.024 | **11** | 0.046 | **11** |
| F08 | Increased contractor overhead expenses | 0.087 | **6** | 0.092 | **3** | 0.030 | **9** | 0.053 | **9** |
| F09 | Increased site logistics requirements | 0.103 | **4** | 0.014 | **16** | 0.040 | **8** | 0.060 | **7** |
| F10 | Increased project re-planning | 0.187 | **1** | 0.176 | **2** | 0.176 | **1** | 0.180 | **1** |
| F11 | Loss of efficiency due to work interruption | 0.065 | **8** | 0.068 | **7** | 0.114 | **4** | 0.094 | **4** |
| F12 | Loss of efficiency due to lack of equipment | 0.032 | **9** | 0.024 | **13** | 0.023 | **13** | 0.026 | **13** |
| F13 | Increased in project management efforts | 0.108 | **2** | 0.074 | **5** | 0.134 | **3** | 0.122 | **2** |
| F14 | Increased material unit prices | 0.015 | **15** | 0.029 | **11** | 0.013 | **15** | 0.015 | **16** |
| F15 | Decrease in project health and safety | 0.019 | **13** | 0.017 | **15** | 0.013 | **16** | 0.016 | **15** |
| F16 | Decrease in project quality | 0.023 | **12** | 0.036 | **10** | 0.024 | **12** | 0.024 | **14** |

Table 40 Factors Overall Ranking using AHP

| ID | FACTORS | Priority | RANK |
|---|---|---|---|
| F10 | Increased project re-planning | 0.181 | 1 |
| F13 | Increased in project management efforts | 0.122 | 2 |
| F04 | Increased reworks and demolition works | 0.101 | 3 |
| F11 | Loss of efficiency due to work interruption | 0.094 | 4 |
| F02 | Delay of retention payment | 0.069 | 5 |
| F01 | Delay of progress payments | 0.062 | 6 |
| F09 | Increased site logistics requirements | 0.060 | 7 |
| F06 | Poor contractor relationship with the client | 0.056 | 8 |
| F08 | Increased contractor overhead expenses | 0.053 | 9 |
| F03 | Increased project financing | 0.050 | 10 |
| F07 | Loss of opportunity for new projects | 0.045 | 11 |
| F05 | Decrease in contractor reputation | 0.026 | 12 |
| F12 | Loss of efficiency due to lack of equipment | 0.026 | 13 |
| F16 | Decrease in project quality | 0.024 | 14 |
| F15 | Decrease in project health and safety | 0.015 | 15 |
| F14 | Increased material unit prices | 0.015 | 16 |

AHP analysis provides an overall ranking of change order's impact factors covering all types of change orders concurrently. The study resulted in the following five most significant factors impacting construction projects:

1. Increased project re-planning.
2. Increased in project management efforts.
3. Increased reworks and demolition works.
4. Loss of efficiency due to work interruption.
5. Delay of payments.

# CHAPTER 5: DISCUSSION AND RECOMMENDATIONS

## 5.1. Discussion and Conclusion

The purpose of this project is to provide a comprehensive analysis of the impacts of change orders on construction projects to improve the understanding of change orders total impacts. This is helpful for the professionals in construction industry to be able to take proactive measures to reduce and control the impacts of change orders.

Based on literature review and interviews with professionals in construction industry, factors of the change order impacts were identified. Impact levels of the factors of each type of change orders were identified based on professional's evaluation through questionnaire. 102 Completed responses were analyzed using Relative Important Index (RII) and Analytical Hierarchy Process (AHP).

The impacts of change orders were analyzed for each type of change orders (additional, omission or substitutional) individually as change orders impact levels depend on their types and factors ranking was provided for each type of change orders. In addition, the impacts of change orders were analyzed considering all types of change orders together using AHP method and overall factors ranking was provided.

For additional works change orders, "increase project re-planning" is the most significant factor impacting construction project. This is because when additional works change order occurs, project planning needs to be revised to include the additional works with the ongoing works to be performed at same time, which could change the works sequence and may interrupt part of the ongoing works. The second most significant factor impacting construction project is "increased in project management efforts". The third, fourth and fifth most significant factors impacting construction project are increased

project financing, increased site logistics requirements and poor contractor relationship with the client.

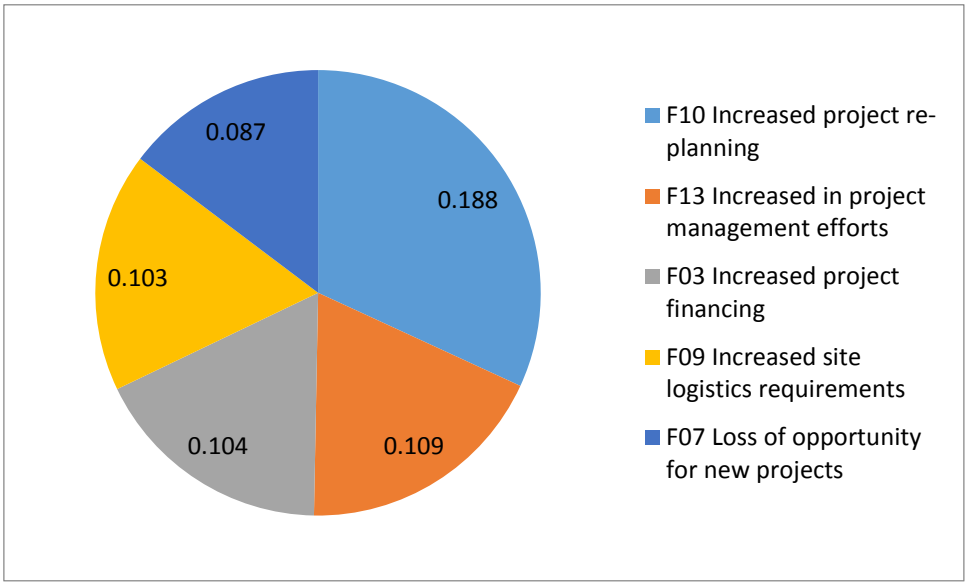


**Figure 7 Top Five Factors – Additional Works Ranking**

For omission works change orders, “Poor contractor relationship with the client” is the most significant factor impacting construction project. This could be linked to the fact that when omission works change order occurs, the client requires deduction of the full amount allocated to the omitted works, where contractor may already have executed

some related works such as planning, engineering, and procurement. The second most significant factor impacting construction project is “increased project re-planning”. The third, fourth and fifth most significant factors impacting construction project are increased contractor overhead expenses, decrease in contractor reputation and increased in project management efforts.

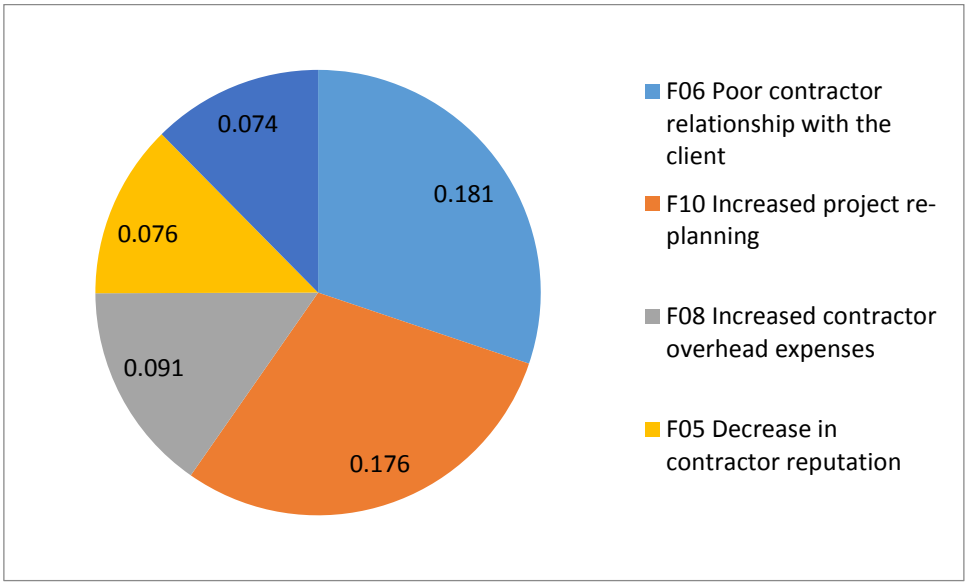


**Figure 8 Top Five Factors – Omission Works Ranking**

For substitutional works change orders, “increased project re-planning” is the most significant factor impacting construction project. This is because when substitutional works change order occurs, project planning needs to be revised to change the work details which could change the works sequence and may interrupt some ongoing works. The second most significant factor impacting construction project is “increased reworks and demolition works”. The third, fourth and fifth most significant factors impacting construction project are increased in project management efforts, loss of efficiency due to work interruption and delay of progress payments.

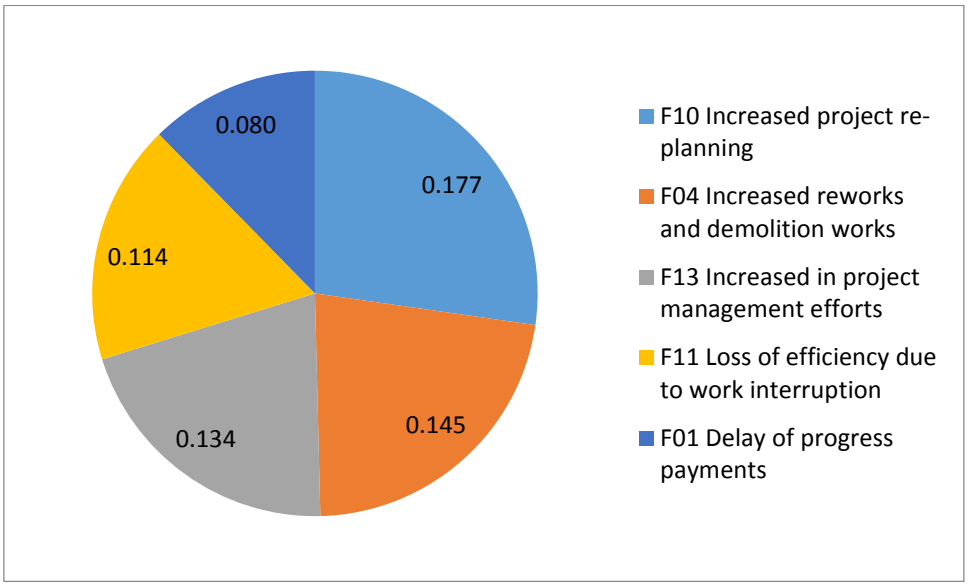


**Figure 9 Top Five Factors – Substitutional Works Ranking**

The main purpose of this research project is to study the change order impacts on construction project in reference to each type of change orders and after that to analyze the impacts considering all types of change orders concurrently using AHP analysis. For all types of change orders, increased project re-planning is the most significant factor impacting construction project. This factor is also the most significant factor for additional and substitutional change orders and is the second significant factor for omission works change orders. As discussed above, change orders impact significantly the project planning and every time a change order is being issued, it is required to revise the plan and update the work sequence to include the variations and this is a common impact of all types of change orders.

The second most significant factor impacting construction project including all types of change orders is “increased in project management efforts”. Change orders require lots of management efforts to evaluate the exact amount of change, to estimate the additional resources requirement, to change ongoing work sequence, to negotiate the change impact amount in relation to time and cost, and to control and minimize the change order impact on project through proactive measures.

The third most significant factor is “increased reworks and demolition works”. This factor is ranked as the $10^{th}$ factor for additional works, as the $8^{th}$ factor for omission works and as the $2^{nd}$ factor for substitutional works. As substitutional works has the highest relative weight compared to the other types as shown earlier, this factor becomes the $3^{rd}$ factor using AHP for overall ranking. Reworks and demolition works impact the project significantly when they occur as they may need time to demolish the completed works, which could require new methods and resources.

The forth most significant factor is “loss of efficiency due to work interruption”. Change orders results in work interruptions, which usually have an adverse impact the labor efficiency.

The fifth most significant factor is “delay of payments”. Delay of payments results from change orders in construction projects as change orders interrupt ongoing progress and generate progress delays, which consequently impacts the progress payments. The contractor and subcontractor depend on the progress payment to execute the works especially for material supplier’s payments; the delay of progress payment generates delays in the project’s overall progress due to cash flow problems.

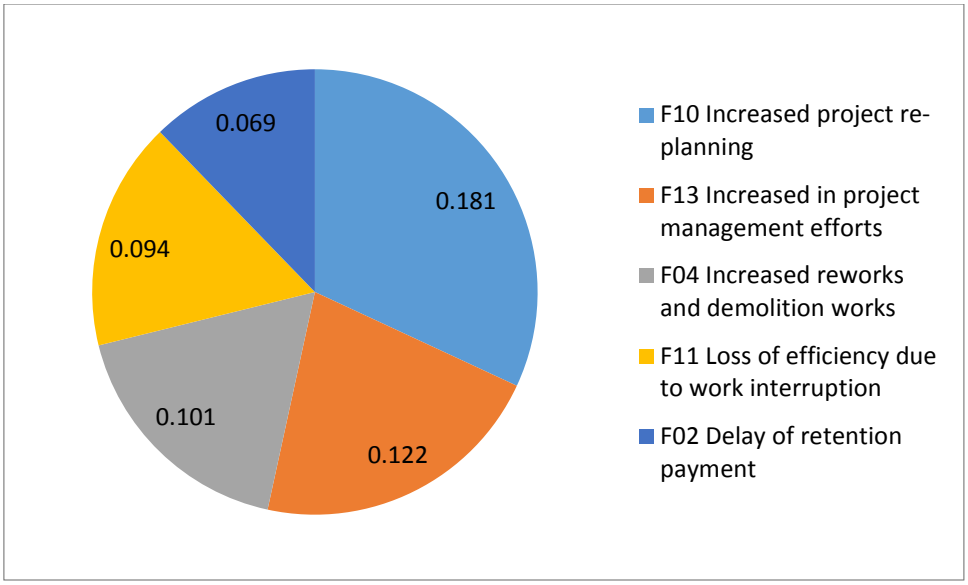


**Figure 10 Over All Ranking – Top Five Ranking**

This project provides factor ranking of each type of change orders and an overall ranking, which could assist the professionals who are working in construction projects to gain deep understanding of change order impacts and to be efficient in analyzing and controlling change orders by taking proactive measures of the identified impacts.

## 5.2. Recommendations

Professionals from construction industry need to understand the impacts of change orders and ensure taking proactive measures in order to reduce and control these impacts.

Improved communication between project team members could reduce the negative impacts of change orders and reduce the disputes.

Increased project management efforts for change orders management to control and minimize their impacts.

Early involvement of contractor at project design stage could reduce the amount of change orders and help to clarify the project requirements.

- Recommendations for Contractors:

Contractors need to assign a special team from the project start to evaluate each change order and to keep the owner aware of the overall impact of each change order. They need to consider all other identified impacts to be able to negotiate with the owner each change order's impact on the project. This is very important to reduce the disputes between the parties.

Each change order's impact needs to be analyzed separately and to link all of them at the end to understand the cumulative impacts of all change orders together.

Understanding the change orders overall impacts will help the project team to take proactive measures to reduce and control these impacts.

- Recommendations for Owners:

Owners need to keep in mind that construction project activities are interconnected and changing part of them may impact other activities. The total impact of multi change orders is higher than the summation of the individual impacts of each change order.

Change work sequence, work interruption, work delays, payment delays, plans revisions and new requirement impact the overall project performance. Prior issuing a new change order, owner needs to understand how this change order could impact the works which are already completed, how it could impact the ongoing works, and how it could impact the planning of the coming work.

## 5.3. Future Work

This study identified the impacts of change orders through conducting a questionnaire and interviews with professionals from construction industry. These impacts need to be also analyzed using real case study of a construction project.

More studies need to be conducted in order to quantify the overall impact of change orders in construction projects. This is vital to solve the disputes between involved parties during change orders negotiation stage.

Data validation can be done by collecting more data from real case studies.

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# APPENDIX

## Appendix A- Questionnaire

## Questionnaire

### Impacts of the Change Orders on Construction Projects Performance

### 1. Introduction

The survey conducted to collect data for research project for Master Degree at Qatar University.

The aim of this research project is to provide analysis of the impacts of change orders on construction project performance

The survey would take about 10 minutes of your time.

Your responses will be confidential.

We highly appreciate your time to complete the following survey.

You may contact the sender at (km1404455@qu.edu.qa)

**Questionnaire (Continued)**

**2. Personal Background**

**Years of Experience**

- ◉ Less than 5 years
- ○ 5-10 years
- ○ 10-15 years
- ○ 15 years and above

**Job Title**

- ◉ Engineer
- ○ Project Engineer
- ○ Construction Manager
- ○ Project Manager
- ○ Contract Manager
- ○ Commercial Manager
- ○ Manager
- ○ Academician
- ○ other

**Your Company Role**

- ◉ Contractor
- ○ Consultant
- ○ Owner
- ○ Project Management
- ○ Higher Education

**Country**

- ◉ Qatar
- ○ MiddleEast
- ○ Europe
- ○ Asia
- ○ America
- ○ Other

**Questionnaire (Continued)**

**Impacts of the Change Orders on Construction Projects Performance**

**3. Rating the Types of Change Order**

Change orders have been classified into three types: Additional works, Omission works or Substitution works (change of the requirement).

Please indicate the level of impact of each type of change orders on construction project's performance.

*** Change orders generated during construction phase of the project**

**(1 – lowest impact 9 – highest impact)**

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
|---|---|---|---|---|---|---|---|---|---|
| **Additional Works** | | | | | | | | | |
| **Omission Works** | | | | | | | | | |
| **Substitution (Change) works** | | | | | | | | | |

**Questionnaire(Continued)**

**Impacts of the Change Orders on Construction Projects Performance**

**4. Factors of the Impacts of Change Order**

Change Orders have impacts on the construction project due to changes on the original plans or methods, disagreement between parties, Sudden instructions.

This section list various factors of these impacts and it is require to rate the impact level of each factor

* Please evaluate the following factors based on how much is the impact of change orders on each factor.

* Change orders generated during construction phase of the project

* on a rating scale of 1 - 9 (1: Very Low impact, 5: medium impact, 9: Very High impact)

Example

Q- What is the impact of "Additional works" change orders on the “Delay of progress payments " in construction projects?

Q- What is the impact of "Omission works" change orders on the “Delay of progress payments " in construction projects?

Q- What is the impact of "Substitution works" change orders on the “Delay of progress payments " in construction projects?

**Questionnaire (Continued)**

**Impacts of the Change Orders on Construction Projects**

**Performance**

**4. Factors of the Impacts of Change Order (Continue):**

| | **Additional Works** | **Omission Works** | **Substitution (Change) works** |
|---|---|---|---|
| Delay of progress payments | | | |
| Delay of retention payment | | | |
| Increased project financing | | | |
| Increased reworks and demolition works | | | |
| Decrease in contractor reputation | | | |
| Poor contractor relationship with the client | | | |
| Loss of opportunity for new projects | | | |
| Increased contractor overhead expenses | | | |
| Increased site logistics requirements | | | |
| Increased project re-planning | | | |
| Loss of efficiency due to work interruption | | | |
| Loss of efficiency due to lack of equipment | | | |
| Increased in project management efforts | | | |
| Increased material unit prices | | | |
| Decrease in project health and safety | | | |
| Decrease in project quality | | | |