

2018

CONSTRUCTION PROJECT CHANGE IMPACTS:

Research into the interactions among multiple project changes

ABHISHEK BORPUJARI

MASTER THESIS

CONSTRUCTION PROJECT CHANGE IMPACTS: Research into the interactions among multiple project changes

By

Abhishek Borpujari

Master Thesis

Construction management & Engineering (CME)
Delft University of Technology

20 December 2018



PROJECT DETAILS

Title: Construction project change impacts: Research into the Interactions among multiple project changes.

Date: 20 December 2018

Student:

Name: Abhishek Borpujari
Student number: 4621654
Email: borpujariabhishek@gmail.com
University: Delft University of Technology
Faculty: Civil Engineering and geosciences
Master: Construction Management and Engineering

Graduation Committee:

Chairman:	Prof.dr.H.L.M. Bakker	TU-Delft CiTG
Committee supervisor:	Prof. Dr. Ir. R.M. (Rob) Stikkelman	TU-Delft TBM
Thesis supervisor:	Ir. Erfan Hoseini	TU-Delft CiTG
External supervisor:	Jacques Slingerland	ENGIE Services

Preface

This report is written for the completion of the master program Construction Management and Engineering at the Delft University of Technology. This master thesis contains an elaboration of a structured approach for determining and showing the interactions among significant multiple changes in construction projects, backed by the theory of cumulative impacts of changes, which suggests that the interactions are a crucial factor leading to a synergistic effect that results in a larger combined impact from the changes than their individual impacts. The project can be regarded as a guide to show the direct and the indirect effects from significant changes, to determine their interactions and provide a reasoning for their impacts on project outcome. This could also serve as a base for future reference to show and prove the cumulative impact of changes resulting from the interactions among the major changes.

I would like to thank my graduation committee from the TU Delft, which consists of Hans Bakker, Rob Stikkelman and Erfan Hoseini for their supervision, support and guidance during the period of my research. Although this period has been challenging, the members of my graduation committee kept supporting me and helping me with finding new interesting subjects for my research.

This master thesis is written during an internship at ENGIE Services West Industry, Rotterdam. I am extremely thankful to them for giving me this opportunity, letting me make use of their knowledge, resources and introducing me to the world of construction project management. Most importantly, I want to thank my graduation supervisor at ENGIE, Jacques Slingerland, for giving me knowledge, inspiration and helping me throughout the research.

Last but not least, I would like to thank all my family and friends for their mental support and their continued confidence in me. I hope my result will prove to be valuable for construction companies to determine and understand the cumulative nature of changes.

Abhishek Borpujari

Executive Summary

This research focusses on delivering a proposed procedure that determines interactions among multiple changes. The basis for this is obtained from literature and research papers that focus on the cumulative impacts of multiple project changes. Thereby, the objective of this research is twofold

1: To provide a framework to construction companies that aids in determining and showing points of interactions among multiple changes

2: Provide a reasonable understanding regarding the cumulative impacts of multiple changes

The construction industry is a dominant industry with big market value and its massive size, but despite being one of the largest global industries in the world, it continuously faces the problem of low labour efficiency and overall productivity. A lot has to do with numerous changes at site during the course of the project (Rodrigo,2016), most changes requiring strategic and dynamic interventions. A Change results in a modification of the original scope, execution time, cost, and/or quality of work (Ibbs and Allen 1995; Revay 2003). It is an incessant process in construction projects and all changes have something in common, namely additions or deletions to the scope of work, which consequently creates rework and possibly schedule resequencing, acceleration, delay, or suspension. These events in turn may impair labour productivity (W. Ibbs,2012).

Productivity loss is a big concern for construction companies as increases in project input compared to its output will result in losses. Past research suggests that as the number of changes increase in a project, project productivity decreases. Change management efficiency in dealing with changes also decreases as the number of changes increases which become a big problem for the management team. While this is a broader problem, a more specific problem is that more and more construction companies are faced with the task of proving the cumulative impacts that result from the multiple changes for compensation matters. This means that the combined impacts from multiple changes turn out to be more than estimated, something that the client is not willing to pay for, unless proven. Literatures focus on the subject determines that interactions among the multiple changes may lead to their larger impacts. While there is an understanding for this, there is no way of determining and showing it. In this research, the problem is formulated as: ***Currently, there is no method to determine and show the interactions among multiple changes, occurring in construction projects.***

The focus of the research is to show the interactions that occur among considerable changes with the development of a change interaction model constituting the research framework. Determining how interactions among significant multiple changes can be illustrated signifies the main research question with a series of sub-questions generated to answer the main research question, which is ***How can the interactions among significant multiple changes in construction projects be illustrated?*** The answering of the research question requires a proper methodology in order to determine the answer to the main research question. In this case, a literature review on multiple changes and their cumulative impacts is conducted to develop a new procedure. Focus on cumulative impact theories with earlier learnings from literature provide substantial understanding to propose a new framework.

The framework contains the following steps leading to a change interaction model:

- 1- Identify the significant changes
- 2- Determine and demonstrate the effects from the significant changes
- 3- Isolate the common and the causal effects
- 4- Illustrate the common and the causal effects
- 5- Determine interactions from the illustration

The illustration below follows the principles of synergistic effect that may result from the interactions leading to their cumulative impacts. Based on this principle, there are two types of interactions

- Direct- Causal effect from one change to another**
- Indirect- due to sharing of similar effects (resources)**

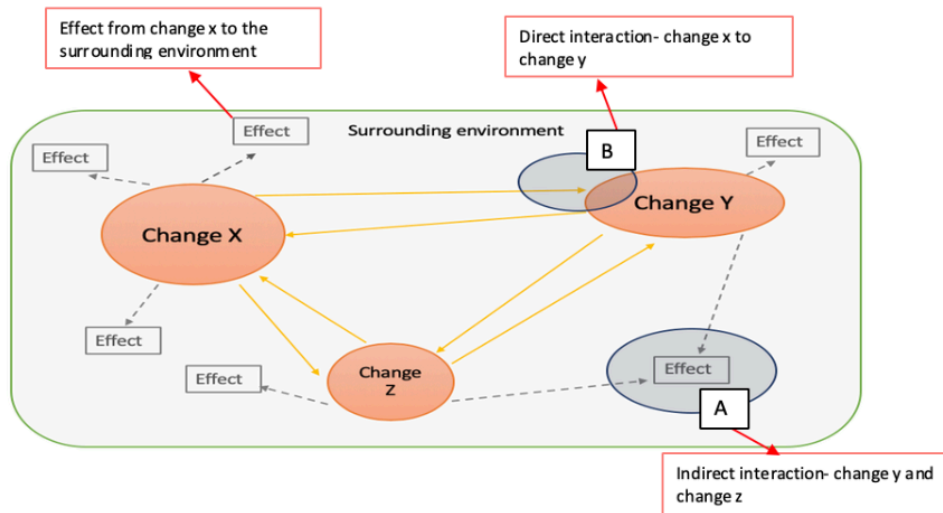


Figure: proposed change interaction model

This procedure is then validated by testing it in real projects. Data is obtained from ENGIE services, Rotterdam, on changes and their associated costs occurring in their projects. Three projects have been selected. With the projects selected, required data is collected and interviews conducted with the project managers of the selected projects. Detailed analysis of the cases along with determination of significant changes, their causes and controls are obtained from the interviews. This is followed by case study analysis, where the significant changes are further analysed, illustrating the effects of each of the significant change following the steps in the proposed procedure. Finally, results are obtained.

The three projects show interactions among their significant changes. The effects aid in interactions as similar effects result in extra resource demand due to multiple changes requiring same resources at a particular time. This is based on the theories of negative synergy that elaborates on extra resource demand resulting from a self-destructive relation, where productivity shows $1+1 < 2$. This suggests that, at points of interactions, project input increases. As the number of changes increase, the probability of change interactions will increase as a result of which resource demand will increase. To satisfy the increases in resource demand, project will endure cost increases and delays, something that might not be estimated as the number of changes cannot be predicted in the planning phases.

This research provides a path for future research to determine the impacts that result from the interactions. Also, research can be conducted to consider interactions among all the change that occur in a project, allowing for a better understanding of cumulative multiple impacts. **The resulting framework can be used by construction companies to determine points of interactions among changes that could lead to a better understanding of the extra costs resulting from the changes, which might be crucial to be compensated by the clients.**

Finally, a few limitations were determined. This research has taken only the significant changes into consideration when determining interactions. Also, the resulting synergy from the interactions is not shown due to lack of more financial data and time, which means that the impacts from the changes are not proven.

TABLE OF CONTENT

FIGURES.....	11
TABLES.....	12
1.INTRODUCTION	13
1.1 BACKGROUND	13
1.2 PROBLEM DEFINITION	14
1.2.1 CURRENT SITUATION.....	14
1.2.2 THEROTICAL BACKGROUND.....	14
1.3. RESEARCH CONTEXT	15
1.3.1 RESEARCH FRAMEWORK	15
1.3.2. RESEARCH QUESTION.....	15
1.3.3 RESEARCH METHODOLOGY	16
2. LITERATURE REVIEW	17
2.1. PROJECT CHANGES	17
2.1.1. CLASSIFICATION OF CONSTRUCTION PROJECT CHANGES.....	18
2.2. REWORK, CHANGE ORDER AND CONSTRUCTION CHANGE DIRECTIVE (CCD)	19
2.2.1. CHANGE ORDER	19
2.2.2. CONSTRUCTION CHANGE DIRECTIVE (CCD)	20
2.2.3. REWORK	20
2.3. MAJOR CAUSES INFLUENCING THE OCCURRENCES OF CHANGES.....	21
2.4. GENERAL IMPACTS FROM CHANGES IN THE CONSTRUCTION INDUSTRY	24
2.5. CONTROL OF CHANGES.....	25
2.6. MULTIPLE CHANGES IN A PROJECT	26
2.6.1 CUMULATIVE IMPACTS FROM MULTIPLE CHANGES	26
2.6.2 SYNERGISTIC EFFECT.....	27
3. INTRODUCING A NEW PROCEDURE.....	28
3.1 LEARNINGS FROM LITERATURE	28
3.2 PROPOSED PROCEDURE.....	29
3.3 APPLICATION.....	31
3.4 METHODOLOGY TO EXAMINE THE PROCEDURE.....	32
3.4.1 Selection of projects	32
3.4.2 Expert interviews.....	32
4. CASE STUDIES	34
4.1. PROJECT 1	34
4.1.1. DATA COLLECTION.....	35
4.1.2. ANALYSIS.....	36
4.1.3 Control measures	43
4.2. PROJECT 2	44
4.2.1. DATA COLLECTION.....	45
4.2.2. ANALYSIS.....	46
4.2.3 Control measures	54
4.3 PROJECT 3	55
4.3.1. DATA COLLECTION.....	56
4.3.2. ANALYSIS.....	57
4.3.3 CONTROL MEASURES	66

5. RESULTS OF THE CASE STUDIES.....	67
5.1 CASE STUDY 1	67
5.2 CASE STUDY 2	67
5.3 CASE STUDY 3	68
6. DISCUSSIONS	69
7. CONCLUSIONS AND RECOMMENDATIONS.....	72
7.1 CONCLUSIONS.....	72
7.1.1 Framework.....	74
7.2. ANSWERS TO THE SUB-QUESTIONS	75
7.3. ANSWER TO THE MAIN RESEARCH QUESTION.....	76
7.4. LIMITATIONS	77
7.5. RECOMMENDATIONS	77
7.6 PERSONAL REFLECTION ON THIS ASSIGNMENT	78
REFERENCES	79
Appendix A- List of general causes of changes	
Appendix B- Methods to quantify cumulative changes	
Appendix C- Interview project 1	
Appendix D- Interview project 2	
Appendix E- Interview project 3	

FIGURES

EXECUTIVE SUMMARY

FIGURE: PROPOSED CHANGE INTERACTION MODEL.....	8
--	---

Chapter 1

FIGURE 1.1- (A)- REAL GROSS VALUE ADDED PER HOUR WORKED BY PERSONS ENGAGED,	13
---	----

FIGURE 1.2: IMPACT OF CHANGES ON MECHANICAL/ELECTRICAL WORK AND CIVIL/ARCHITECTURAL WORKS (IBBS, McENIRY,2008)	14
---	----

FIGURE 1.3: RESEARCH METHODOLOGY	16
--	----

Chapter 2

FIGURE 2.1: THEORETICAL FRAMEWORK.....	17
--	----

FIGURE 2.2: TYPICAL CAUSE AND EFFECT RELATIONSHIP OF CHANGE (SOURCE: MOTAWA I.A., 2005)	18
---	----

FIGURE 2.3: RELATIONSHIP BETWEEN CHANGE ORDERS, REWORKS, AND CCDs (HAO, SHEN, NEELAMKAVIL, 2008)	21
--	----

FIGURE 2.4: PRINCIPLES OF EFFECTIVE CHANGE MANAGEMENT	26
---	----

Chapter 3

FIGURE 3.1: CHANGE FLOW DIAGRAM	28
---------------------------------------	----

FIGURE 3.2: DEMONSTRATING EFFECTS RESULTING FROM A CHANGE (CHANGE X)	30
--	----

FIGURE 3.4: METHODOLOGY TO VALIDATE THE PROPOSED MODEL	33
--	----

Chapter 4

FIGURE 4.1: GANNT CHART FOR PROJECT 1	37
---	----

FIGURE 4.2: EFFECTS RESULTING FROM FIRST CHANGE ON PROJECT 1.....	40
---	----

FIGURE 4.3: EFFECTS RESULTING FROM SECOND MAJOR CHANGE ON PROJECT 1	40
---	----

FIGURE 4.4: EFFECTS RESULTING FROM THE THIRD MAJOR CHANGE ON PROJECT 1	41
--	----

FIGURE 4.5: CHANGE INTERACTION DIAGRAM SHOWING COMMON EFFECTS AMONG THE CHANGES	42
---	----

FIGURE 4.6: GANNT CHART FOR THE SDA WS3 PROJECT	48
---	----

FIGURE 4.7: PORTION OF GANNT CHART FOCUSING ON THE WORK FRONT GAP ISSUE	49
---	----

FIGURE 4.8: EFFECTS OF THE CHANGE ORDER 'WORK FRONT GAP'	51
--	----

FIGURE 4.9: EFFECTS OF THE CHANGE ORDERS 'STAFF CHANGES' AND 'NEW SUPERVISOR'	52
---	----

FIGURE 4.10: VISUAL REPRESENTATION OF THE CAUSAL AND THE COMMON EFFECTS AMONG THE MAJOR CHANGES.....	53
--	----

FIGURE 4.11: GANNT CHART OF THE 'RUBIS TERMINAL' PROJECT UNDERTAKEN BY ENGIE	59
--	----

FIGURE 4.12: REPRESENTATION OF THE NUMBER OF CHANGE ORDERS AND INTERVENTIONS, PER WEEK, FOR THE PROJECT	60
---	----

FIGURE 4.13: DOCUMENT SHOWING THE DELAY RESULTING IN 'EXTENSION OF TIME RUBIS' CHANGE ORDER.....	61
--	----

FIGURE 4.14: CAUSAL RELATIONSHIP OF TWO CHANGES ON CHANGE ORDER 'EXTENSION OF TIME RUBIS' AND ITS EFFECTS.....	63
--	----

FIGURE 4.15: CAUSAL RELATIONSHIP AND EFFECTS OF TWO CHANGES ON CHANGE ORDER 'EXPIRATION COSTS WTK'	64
--	----

FIGURE 4.16: VISUAL REPRESENTATION OF THE COMMON AND THE CAUSAL EFFECTS AMONG THE MAJOR CHANGES.....	65
--	----

Chapter 5

FIGURE 5.1: ILLUSTRATION OF COMMON EFFECTS AMONG THE CHANGES (PROJECT 1).....	67
---	----

FIGURE 5.2: ILLUSTRATION OF COMMON AND CAUSAL EFFECTS AMONG THE CHANGES (PROJECT 2)	68
---	----

FIGURE 5.3: ILLUSTRATION OF COMMON AND CAUSAL EFFECTS AMONG THE CHANGES (PROJECT 3)	68
---	----

Chapter 6

FIGURE 6.1: EXAMPLE	70
---------------------------	----

FIGURE 6.2: RESULTS OBTAINED FROM CASE STUDY 3	70
--	----

TABLES

Chapter 2

TABLE 2.1: SUMMARY OF CONSTRUCTION CHANGES	19
TABLE 2.2: LIST OF SIGNIFICANT CAUSES FOR CHANGES IN THE CONSTRUCTION INDUSTRY	22

Chapter 3

TABLE 3.1: EFFECTS AMONG DIFFERENT CHANGE COMBINATIONS	30
TABLE 3.2: PROCEDURE TO DETERMINE AND ILLUSTRATE INTERACTIONS AMONG CHANGES	32

Chapter 4

TABLE 4.1: LIST OF TOP 10 CHANGE ORDERS BASED ON THEIR COST VALUE (DECREASING ORDER OF VALUE)	36
TABLE 4.2: LIST OF MULTIPLE IMPACTFUL CHANGE ORDERS	37
TABLE 4.3: COST IMPACT (IN PERCENTAGE) OF THE FIRST CHANGE ON THE ENTIRE PROJECT	38
TABLE 4.4: COST IMPACT (IN PERCENTAGE) OF THE FIRST CHANGE ON THE ADDITIONAL WORK	38
TABLE 4.5: COST IMPACT (IN PERCENTAGE) OF THE SECOND MAJOR CHANGE ON THE ENTIRE PROJECT	38
TABLE 4.6: COST IMPACT (IN PERCENTAGE) OF THE SECOND MAJOR CHANGE ON THE ADDITIONAL WORK	39
TABLE 4.7: COST IMPACT (IN PERCENTAGE) OF THE THIRD MAJOR CHANGE ON THE ENTIRE PROJECT	39
TABLE 4.8: COST IMPACT (IN PERCENTAGE) OF THE THIRD MAJOR CHANGE ON THE ADDITIONAL WORK	39
TABLE 4.9: COMMON EFFECTS AMONG DIFFERENT CHANGE COMBINATION FOR PROJECT 1	42
TABLE 4.10: LIST OF TOP 10 CHANGE ORDERS BASED ON THEIR COST VALUE (DECREASING ORDER OF VALUE)	46
TABLE 4.11: LIST OF MULTIPLE IMPACTFUL CHANGES IN THEIR CHANGE ORDER FORMAT	47
TABLE 4.12: REFERENCE TABLE FOR THE GANTT CHART OF SDA WS3 PROJECT	47
TABLE 4.13: PERCENTAGE IMPACT OF THE CHANGE ORDER ON OVERALL COST OF THE PROJECT	49
TABLE 4.14: PERCENTAGE IMPACT OF THE CHANGE ORDER ON ADDITIONAL WORK	49
TABLE 4.15: PERCENTAGE IMPACT OF THE CHANGE ORDER ON OVERALL COST OF THE PROJECT	50
TABLE 4.16 - PERCENTAGE IMPACT OF THE CHANGE ORDER ON ADDITIONAL WORK	50
TABLE 4.17: PERCENTAGE IMPACT OF THE CHANGE ORDER ON OVERALL COST OF THE PROJECT	50
TABLE 4.18: PERCENTAGE IMPACT OF THE CHANGE ORDER ON ADDITIONAL WORK	51
TABLE 4.19: COMMON EFFECTS AMONG DIFFERENT CHANGE COMBINATIONS OF THE IMPACTFUL CHANGES	53
TABLE 4.20: LIST OF TOP 10 CHANGE ORDERS BASED ON THEIR COST VALUE (DECREASING ORDER OF VALUE)	57
TABLE 4.21: LIST OF MULTIPLE IMPACTFUL CHANGES IN THEIR CHANGE ORDER FORMAT	58
TABLE 4.22: PERCENTAGE IMPACT OF THE CHANGE ORDER ON OVERALL COST OF THE PROJECT	62
TABLE 4.23: PERCENTAGE IMPACT OF THE CHANGE ORDER ON THE ADDITIONAL WORK	62
TABLE 4.24: PERCENTAGE IMPACT OF THE CHANGE ORDER ON OVERALL COST OF THE PROJECT	62
TABLE 4.25: PERCENTAGE IMPACT OF THE CHANGE ORDER ON THE ADDITIONAL WORK	62
TABLE 4.26: COMMON EFFECTS AMONG DIFFERENT CHANGE COMBINATIONS OF THE IMPACTFUL CHANGES	65

1. INTRODUCTION

1.1 BACKGROUND

The construction industry is a giant industry with over 8 trillion in world market value. The McKinsey Global Institute reports: *‘every year, there is roughly about \$10 trillion globally spent on construction related activities, which amounts to about 13 percent of world’s GDP (Gross Domestic Product). This makes construction one of the largest sectors of the world economy’*. The sector employs around 7 percent of the world’s working population and has a major impact in our day-to-day lives through its various goods and services. However, construction has suffered for decades from remarkably poor productivity relative to other sectors. While the construction sector seems to have been caught in a productivity issue, other sectors have transformed themselves (Taylor, 2017).

In the last 20 years, productivity in the construction industry has grown at 1% annually, which is around one-third the rate of the world economy and only around one-quarter of the rate in manufacturing. If construction labour productivity were to catch up with the progress made by other sectors over the past 20 years or with the total economy, it is estimated that the construction industry’s value added could increase by \$1.6 trillion a year.

Below is a graph showing the construction industry’s real gross value added per hour (A) and the labour-productivity average growth (B) from 1995 to 2014, compared to that of total world economy and manufacturing industry. As seen in fig (A), the Construction sector has a much lower gross value added per hour over the years, with the value added just rising to about 110 compared to that of around 170 of the world economies and 190 of the manufacturing industries by 2014. Fig (B) shows that Globally, construction sector labour-productivity growth averaged 1 percent a year over the past two decades, compared with 2.7 percent for the total world economy and 3.6 percent for manufacturing, 2.6 % higher than construction sector (McKinsey & co, 2017).

(The findings are based on a sample of 41 countries that generate 96% of global GDP.)

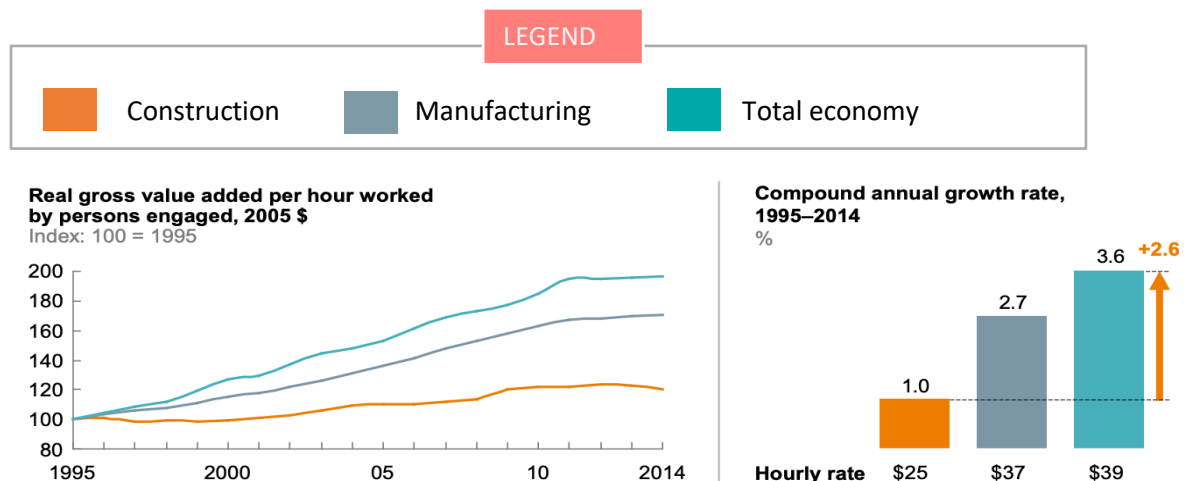


Figure 1.1- (A)- Real gross value added per hour worked by persons engaged, 1995-2014
 (B)- Compound annual growth rate, 1995-2014 (McKinsey Global Institute analysis)

1.2 PROBLEM DEFINITION

1.2.1 CURRENT SITUATION

Poor productivity in construction today is the result of a number of different factors. Changes are one of the most important concerns related to labour productivity. Previous research has reported that changes are among the major factors that cause a decreased labour productivity (Hanna et al. 1999 a, b; Hanna 2001; Ibbs 2005). Quite often, these changes occur individually and can be managed in terms of safety, quality and time. Unfortunately, large projects more often than not suffer from a number of multiple changes. Multiple changes occurring in a project are fairly hard to manage and often lead to damaging outcomes (Rodrigo,2016).

Contractors frequently end up bearing extra costs resulting from consuming additional resources and spending extra work hours as a result of the cumulative impact of changes. Contractors encounter a lot of difficulties and resistance from owners in proving these extra costs and work hours, which often leads to unresolved disputes and lengthy litigations. The interconnected factors that control a project's outcome make it very challenging to isolate and measure the cumulative impact of changes. There are quite a few research studies and methods to quantify the cumulative changes, however, these methods are yet to be accepted completely by the court (acceptance with various limitations) and are only applicable after the project is completed.

1.2.2 THEROTICAL BACKGROUND

In a research conducted by Leonard (1988), it was concluded that, as the number of changes in a project increased, its impact on overall productivity increased more than the sum of the individual changes. This shows that increase in the number of changes have an impact on the productivity of the project, however, the understanding behind this theory is not elaborated. A graph to illustrate the impact of changes on mechanical/electrical and architectural/civil works is shown below.

The lowest curve is a linear regression for those projects in his database that were substantially affected by change orders only. The other two curves represent projects that were substantially impacted by change orders and one or more major causes of productivity loss such as inadequate scheduling and coordination, acceleration, change in work sequence, late supply of information, equipment or materials and increased complexity of work (Ibbs, McEniry,2008):

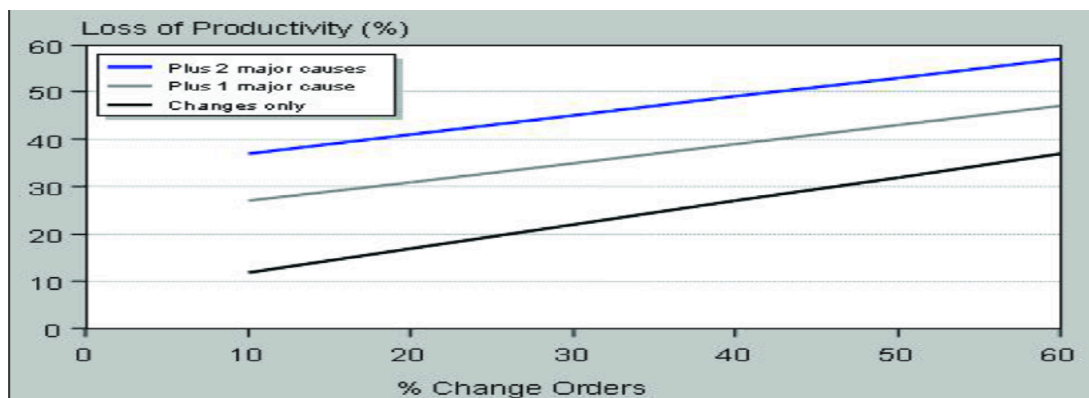


Figure 1.2: Impact of Changes on Mechanical/Electrical Work and civil/architectural works (Ibbs, McEniry,2008)

There are generally two categories of this effect (Ibbs, McEniry,2008):

- The actual direct cost and time of performing the change (additional labour, materials, equipment). And,
- The impact the change may have on other unchanged or contractual work because of delay, disruption, change of sequence, lack of resources, etc.

There are scope change management techniques to deal with changes in projects. Change management seeks to forecast possible changes; identify changes that have already occurred; plan preventive measures; and coordinate changes across the entire project. However, these methods are only applicable for a specific change at a time or for changes one after the other. In reality, more than one change occurs at a single time during realization of the project and tend to interact with one another and their surrounding environment, making it certainly very difficult to isolate the changes and manage it (Ibbs, 2005). Hence, the problem lies in understanding and showing how the effects from multiple changes may result in a larger impact than estimated. The problem statement is as follows:

‘Currently, there is no method to determine and show the interactions among multiple changes, occurring in construction projects’

1.3. RESEARCH CONTEXT

The main **Objective** of the research is to find a solution to the problem of determining and showing interactions among changes in an attempt to provide an understanding for the larger cumulative change impacts. The **goal** of the research is to deliver a method to determine and show interactions among multiple changes by gathering information from research papers and literature, focussed on the cumulative impacts of changes. Only by accepting and considering the cumulative impact of the effects of the multiple changes, can there be a reasonable understanding of the accumulated costs and delays at the end of the project, a crucial aspect for the construction companies. This should provide a basis for future research to prove the cumulative impacts of changes in a project.

1.3.1 RESEARCH FRAMEWORK

This research aims at proposing a procedure on the basis of past research and theories of cumulative impacts of multiple changes, that elaborate on the interaction and the interconnectedness among multiple changes. The procedure will be applied in real projects undertaken by ENGIE service West Industry, ROTTERDAM, The Netherlands, in order to test and validate the applicability of the procedure. The results obtained from the case studies of the projects will be analysed and discussed upon.

1.3.2. RESEARCH QUESTION

This research will focus on answering the main research question: ***“How can the interactions among significant multiple changes in construction projects be illustrated?”***

In order to answer the main research question, a set of sub-questions will have to be answered. The sub-questions are part of the research framework, which serves as a route to answering the main research question. The sub-questions are as follows:

Sub questions:

1. What can be found in literature regarding project changes and how can this information support to draft a new procedure that could determine interactions among changes?
2. How can the proposed procedure determine interactions among multiple changes?
3. Can the procedure be validated by applying it in real projects?
4. What conclusions can be made from the final results?

1.3.3 RESEARCH METHODOLOGY

In order to answer the main research question, the sub-questions will have to be answered. The methodology, as shown in Fig.1.3, will serve as a guide to answer the sub-questions. A literature review will be conducted to learn and obtain valuable information regarding changes, their causes, impacts and controls in the construction sector. This information is crucial to understand the nature of the changes followed by gaining knowledge on the cumulative impact of multiple changes from research papers and articles to get an insight into the theories that support the understanding and the working behind the cumulative impacts of multiple changes on project outcome. The theories combined with general information regarding the changes shall provide a path into developing a new procedure to determine interactions.

The proposed procedure has to be validated in order to be applicable in real projects, so developing of a new procedure is followed by applying the procedure in real projects. This will be done by acquiring data from ENGIE Services West Industry, The Netherlands. The Projects shall be selected based on the following criteria: availability of data, access to the available data and availability of their project managers for interviews in limited time. The interviews will be a crucial element in this research as they shall not only provide information on project data but shall also be used to verify the significant changes obtained from the data on changes. A set of questions will be prepared beforehand to interview the main project managers of the selected projects. This would allow for their expert judgements, opinions and importantly, their detailed analysis on the significant changes and their effects.

The data obtained along with the interviews will be analysed as per the proposed procedure. The results obtained from the case study analysis shall provide information regarding the applicability of the procedure in real projects to determine interactions among the significant changes. Based on the results, a disucssion will be done on the learnings from the case studies, combined with literature. A conclusion will be made on the findings followed by answers to the research questions (sub-questions and the main research question). Finally, limitations and recommendations on using the procedure and scope for future research will be elaborated upon to conclude this research. The methodology for this research is presented below:

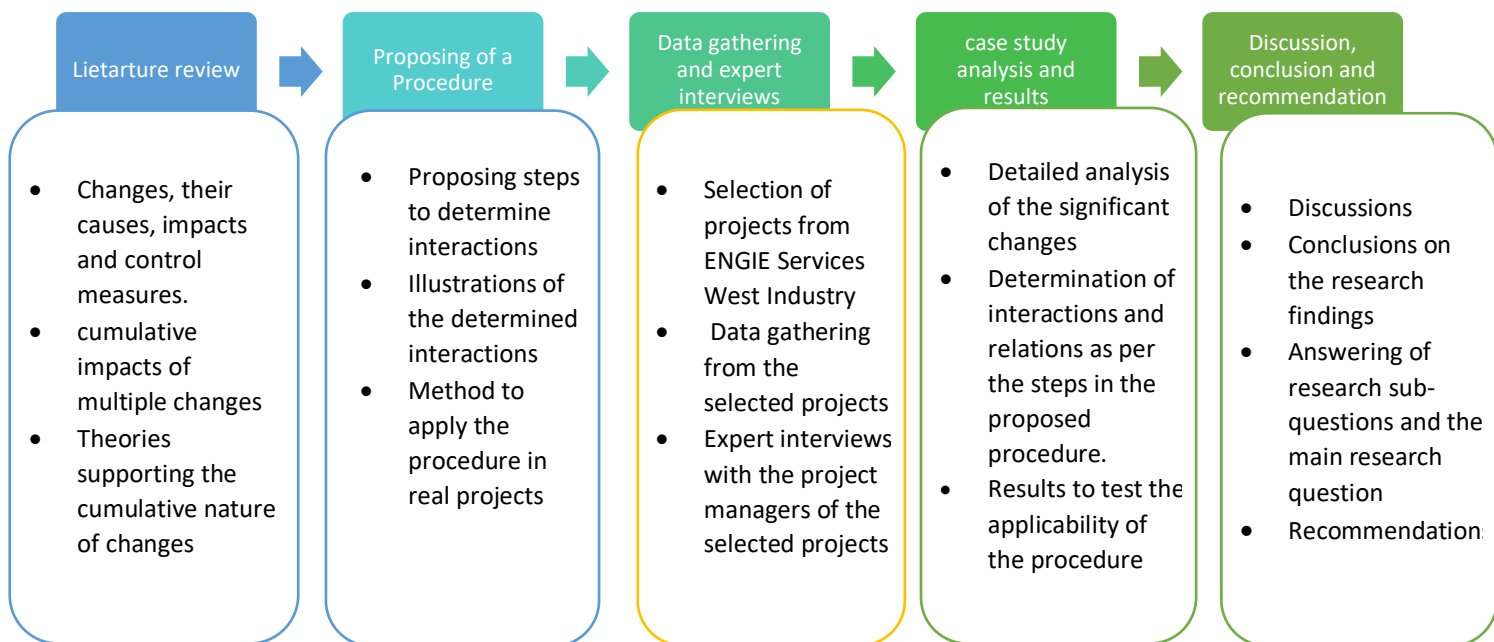


Figure 1.3: Research methodology

2. LITERATURE REVIEW

In this chapter, a theoretical overview is given in order to create a framework for the main research objective as described in chapter 1, section 1.3. Fig.2.1 shows the subjects in the theoretical framework and how to arrive at the creation of a new procedure to determine and show interactions among changes. Firstly, a general description of changes is studied followed by thorough understanding of their causes, impacts and control thus providing new insight into understanding the contributing factors of changes in projects. The methodology and application of change management techniques will be looked into to get better understanding regarding the nature of the changes. Finally, theoretical evidence to support the idea of the procedure will be studied in the final section of the literature, 'cumulative impact of multiple changes'. In chapter 3, the application of the theories to form a new change interaction model, resulting from the procedure, will be researched. The resulting procedure will be tested for its applicability in real projects in chapter 4.

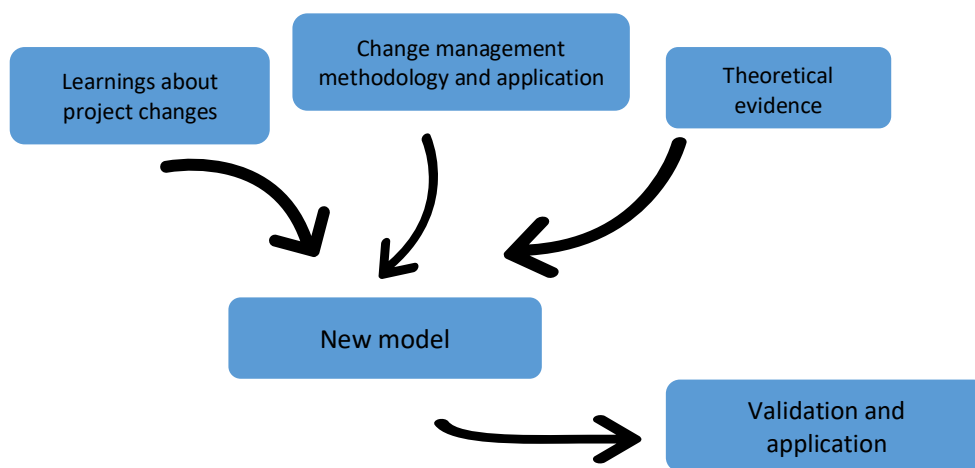


Figure 2.1: Theoretical framework

2.1. PROJECT CHANGES

“Change is any addition, deletion, or revision to the general scope of a contract that causes an adjustment to the contract price or contract time” (Ibbs 1994) and one of the most common reasons for intervention at site. Revay (2003) defined project change to be “any event that results in a modification of the original scope, execution time, cost of work, or quality of work”. Lee (2007) defined project change to be “any action, incidence, or condition that makes differences to an original plan or what the original plan is reasonably based on”. Ibbs et al. (2001) indicated that any additions or deletions to project goals or scope are considered to be changes, whether they increase or decrease the project cost, schedule or quality.

The construction industry is highly prone to changes at indefinite time intervals. The changes all have something in common, namely additions or deletions to the scope of work, which consequently create rework and possibly schedule resequencing, acceleration, delay, or suspension. (Vandenberg, Paul,1996). They occur from different sources (Motawa et al, 2007) and by various causes related to external, organizational and project environments (Sun and Meng 2009).

Change can be categorized in many different ways. Ibbs (1994) claimed that changes comprise of beneficial change (proactive) and detrimental change. Sun and Meng (2009) stated that some projects may benefit from proactive changes. Ibbs et al. (2001) stated the importance of encouraging beneficial changes and discouraging detrimental changes. Exploring beneficial changes further, Ibbs et al. (2001) claimed that beneficial changes resulting from value engineering exercises

can help to reduce cost, schedule, or degree of difficulty, are welcomed by the management team, since these changes benefit the project. Ibbs (2001) further stated that “*these beneficial changes not only give an immediate and proactive impact, but they also can provide the platform and environment for managers to seek further beneficial change*”. However, none of these studies reveals further details of their beneficial changes, or their long-term impact to the project. Before going in detail regarding types and cause/ effect of change, it is important to understand the typical cause effect relationships of change. Fig.2.2 shows the typical relationship between project characteristics, causes of change, and change effects. Where,

- Project characteristics are factors or aspects that have an influence on the project and may lead to change. Project characteristics, which represent the amount of information available at the early stages of a project, are often the original source of change. Therefore, these characteristics are important to show cause and effect relationship.
- Change causes are the reasons for the occurrence of changes and are result of project characteristics.
- Change effects are the consequences of the changes in projects.

A visual representation of a typical cause-effect relationship of change is illustrated in the figure.

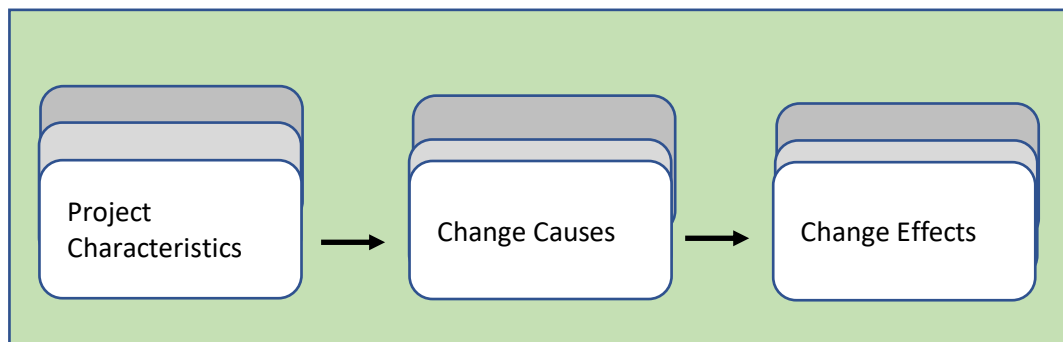


Figure 2.2: Typical Cause and Effect Relationship of change (Source: Motawa I.A., 2005)

Changes in a construction project are commonplace, despite the fact that contractors often sign fixed price contracts. Changes can be avoidable or unavoidable. Avoidable changes are preventable, an example of this being the substitution of a type of material with another type to improve quality. Unavoidable changes cannot be foreseen, such as doing rework due to new regulations in a certain work area. The management team should save time and energy by expeditiously agreeing on unavoidable change items and should direct their effort to resolving issues related to avoidable change items (Hester et al. 1991) and plan an intervention accordingly.

2.1.1. CLASSIFICATION OF CONSTRUCTION PROJECT CHANGES

Changes in construction projects are a very common occurrence and more often than not lead to negative impacts. A critical change may cause consequential delays in project schedule, re-estimation of work statement, and increased demands of resources like equipment, materials, labour, and overtime. Changes, if not resolved through the change management process, can become a major source of contract disputes, and therefore a risk of project failure. However, since the construction industry is project-based, it is best to discuss changes in the context of the typical stages/phases of a construction project. (Hao, Shen, Neelamkavil, 2008)

Changes can be classified to occur into three stages; pre- design specification, design and construction stage. Each stage asserts different stakeholders, impacts and controlling measures. The pre-design specification stage has the owner or the client as the stakeholder impacting the design and construction processes. A design or an engineering consultant oversees the design phase and any change occurring results in rework of design and drawing. Finally, the construction stage sees a

contractor or sub-contractors overseeing the work. Any change here leads to additional work, reworks, delays and cost increases.

As for the controlling measures, changes in pre-design stage may be controlled by avoiding it and carefully providing detailed specification documents before biddings. For the design stage, changes can be controlled by using better designs and considering buildability in design. Finally, for the construction stage, there must be quality control, site operational control and keeping daily logs of the works. Control of changes is further elaborated in section (4.5). Change classification is summarized in the table below.

STAGE	STAKEHOLDER	IMPACTS	Controlling measure(s)
Pre- design	Owner or Client	Changes in design processes	Carefully provide detailed specification documents before bidding.
Design	Design/engineering Consultant	Rework of design and drawing	Better control of design versions and consider buildability in design
Construction	Contractor/sub- contractors	Rework, additional works, delays and cost increases	Quality control, site operational control and keeping daily logs

Table 2.1: Summary of construction changes

2.2. REWORK, CHANGE ORDER AND CONSTRUCTION CHANGE DIRECTIVE (CCD)

The process of a flow of changes in a project, from initiation of a change to finalization and formalization of a change can be understood by learning more about change orders, construction change directive (CCD) and reworks in projects.

2.2.1. CHANGE ORDER

It is important to understand that to formalize a change during a project, a change order must be filed. Project change should not be confused with project change order, which is defined as *“any formal contract modification with the purpose of incorporating a change into the contract”* (Schwartzkopf, 1995; Lee, 2007; Anastasopoulos et al., 2010). Change orders are the means to accommodate only the changes that are officially recognized by management through the contract modification. Hence, it is important to note that change and change order are two different concepts, and the approved project changes include project change orders. When the owner is responsible for a change, the cost and schedule impacts of change are incorporated into the original contract by way of change orders (William Ibbs, 2012).

Means Illustrated Construction Dictionary defines a change order as *“a written authorization provided to a contractor approving a change from the original plans, specifications, or other contract documents, as well as a change in the cost. With the proper signatures, a change order is considered a legal document”*. According to Mokbel (2003), a change order is defined as *“an action that specifies and justifies a change to the scope of a construction contract that alters the original time of completion or the project total cost, or both”* (Mokbel. H, 2003). A simpler definition of a change order by Caltrans (2014) states that change order is a *“legally binding document used to make changes to the contract”* (Caltrans, 2014).

A research conducted on cause and effects of change orders by Elshahat and Dawood (2014) states that the words “Change Order” conjure strong feelings of negativity for all involved in construction projects. Owners do not like them because they generally feel they are paying for other’s mistakes, although most of the changes are usually caused by the owners. Change orders tend to disrupt workflow since they require additional paperwork, which costs. Not only do they disrupt workflow but also strain the relationships of the owners, engineer, contractors, subcontractors, and others involved in the construction process as well as add cost and schedule delay’. Changes on one project can also affect other unrelated projects by tying up resources that are committed elsewhere.

Not only is workflow disrupted, but also trying to get quick response quotes, shop drawings, and many other things required to get back schedule causes a strain on working relationships (Rashid, et al. 2012).

Change orders can be classified into different types depending on the basis and purpose classification. According to the procedure used to introduce them, there exist three main types of change orders (Hanna, 2002).

- Formal changes, otherwise called as directed change, is the type of the change order which arises as a result of the direct order for changing the plan and specification and/or acknowledge that changes are being made directed by the owner or owner’s representative.
- Constructive change is the type of change which arises in the circumstances when the owner by his action and/or inaction changes the scope of work but does not recognize a change. This type includes changes as a result of design problems, interface with the contractor’s responsibilities, clarifications and failure to provide owner furnished items.
- Cardinal changes are changes that arise as a result of the long-time recognition in the federal sector of contracting and changes that are beyond the scope of work, in other words, scope change that can be caused by differing site conditions

Each change order can be further classified into four types based on their nature (Hanna, 2002).

- Additive changes are changes that are added to the original scope of work.
- Deductive changes are changes that deleted from the original scope of work.
- Reworks are changes done due to quality deficiencies.
- Force Majeure changes are changes done as a result of the weather conditions which can impact the schedule and cost of the project.

The management of change orders can mean survival or failure to a contractor. Therefore, it is essential that contractors establish company procedures for handling change orders. 'Few items in a project manager's or cost engineer's busy schedule cause disproportionately more work and anxiety than do change orders. Because of their nature, they are often perceived to reflect flaws in the planning, design, or execution of the project. They almost always increase the capital cost of the project; they also result in a heavy administrative load because they require much review, discussion, and tracking" (Ehrenreich-Hansen 1994)

2.2.2. CONSTRUCTION CHANGE DIRECTIVE (CCD)

A Construction Change Directive (CCD) is issued by an owner or its designate requesting a change in the contract scope when there has been no agreement on cost. CCDs originate from disputed change orders and can become change orders again once the dispute is settled. The process of handling a CCD is simpler than that of change orders in that it directly starts from the implementation stage once the CCD is issued. (Hao, Shen, Neelamkavil, 2008)

2.2.3. REWORK

Rework refers to re-doing a process or activity that was incorrectly implemented in the first place and is generally caused by quality defects, variance, negligence, and poor design and on-site management. “Rework is usually pure waste and should be avoided in most cases” (Hao, Shen,

Neelamkavil, 2008). A change, if determined by authorized parties as rework, must be done without condition by the party at fault. The overspending of rework cannot be claimed, and moreover, subsequent costs caused by the rework might be charged as well, such as costs to the owner for late occupancy.

Rework at the design stage is caused by incomplete or errors in drawings and the lack of consideration of the “buildability” and site conditions. Since the design and construction processes are not changed, the only requirement for handling rework is to perform whatever correction activities are necessary to guarantee that the required activities are completed as per design. Although the process of reworks is simpler than that of change orders, the decision of rework is a difficult one since rework is normally accompanied by the demolition of what has already built. (Hao, Shen, Neelamkavil, 2008). The relationships between Change order, CCD and rework is shown in the figure below.

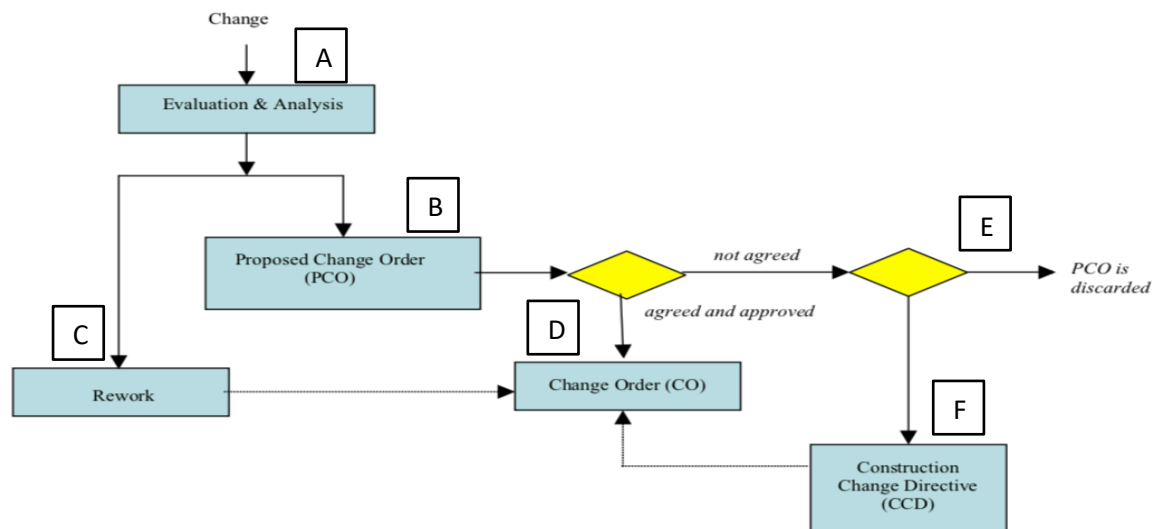


Figure 2.3: Relationship between Change orders, reworks, and CCDs (Hao, Shen, Neelamkavil, 2008)

In a typical change process, the change is first evaluated and analysed (represented by ‘A’, as shown in Fig 4.3). It is then either proposed as a change order (B) or the work is ordered to be redone again (rework, C). Reworks also have to formalized as change orders to have a formal record of the extra work done. The proposed change order can be approved to become a formal change order (D) and if the proposed change order is not approved as a formal change order, it is either discarded (E) or can be issued as a CCD (F), by solving any disputes that may have led to non-agreement in the first place. The CCD can be then formalized as a change order.

Changes require various influential factors to be issued. These are the causes for initiating a change. The owner or the contractor cannot issue a change without reason. The causes for the occurrence of changes in construction projects are talked about in the next section.

2.3. MAJOR CAUSES INFLUENCING THE OCCURRENCES OF CHANGES

The change causes occurring in various countries and different forms of constructions were collected from many previous studies. A total of 23 research papers have been analysed to determine the general causes for the occurrence of change orders in projects. (Please refer Appendix A to get insight into the entire list of causes). However, this research is focussed on significant change causes that occur on a more regular basis in the construction industry. The list was narrowed down to **15 significant causes** obtained from the results of ten research papers, all focussed on determining and ranking the causes for the occurrence of change orders along with their impacts in the construction industry. The results from the research papers show similarities in

terms of ranking the causes.

Table 2.2 lists down the significant causes for issuing of changes in the construction industry in order of their most common occurrences (from top to bottom). Changes in plans and design specifications by owner has been ranked highest in terms of their occurrence among the majority of research papers followed by change in project scope and schedule by owner very closely behind.

SIGNIFICANT CAUSES

1. Change in plans and design specifications by owner
2. Change of project scope and schedule by owner
3. Owner's financial problems
4. Ambiguities and errors in specifications and design
5. Changes in design by consultant
6. Conflict between contract documents
7. Inadequate planning by contractor or consultant
8. Poor planning / knowledge of contractor
9. Contractor's financial difficulties
10. Safety considerations
11. Shortage of materials and equipment
12. Shortage of manpower and skills.
13. Poor procurement process
14. Unforeseen site conditions
15. Extreme weather conditions

Table 2.2: List of significant causes for changes in the construction industry

The significant causes are further described below-

- Changes in plans and design specifications by owner- Change in plans and design specifications by the owner is often the top cause for the occurrence of change orders. These changes come as a result of the owner changing plans mid-way in the project or can occur when the project starts without finalizing the design and the design needs to change during the execution, leading to certain changes. The changes can even come as a result of the revised design by the consultant which can change the opinion of the designer.
- Change of project scope and schedule by owner- Very similar to the first cause, another common cause as a result of the owner is the changes in project scope and schedule. A common complaint among contractors is that "owner instructs additional work" (Assbeihat, Sweis, 2015), which often result in issuing of change orders as the work would not be accounted for in the planning phase. This also causes a change in schedule and delays in projects.
- Owner financial problem- The owner, like the contractor, may have financial difficulties and as a reason of this he will try to reduce the cost. Sometimes even the owner in public construction projects is not paid regularly by the investor causing him difficulties to finish the works on time causing the change orders. This can be eliminated by adequate planning and cash flow.
- Ambiguities and errors in specifications and Design- None of the produced documents are usually 100% error free design. The design originated may have various errors or omissions such as deleted notes, unreferenced designs and other similar errors. The contractor will try to deviate from the extra cost caused by those errors and omissions and delegate those one to the owner.

- Changes in design by consultant – Similar to owner making changes, the consultant can request some changes in design, which leads to a change order to execute the change.
- Conflicts between contract documents- Conflict between contract documents can result in misinterpretation of the actual requirement of a project. This is one of the consultant related causes (Kokel, 2015).
- Inadequate planning by contractor or consultant- Inadequate planning is one of the causes of the change orders. Since the design is inadequate and changes most of the time, a change order may be requested to keep up with the changed design.
- Poor planning/ knowledge of contractor- After the design process an estimation process is done in order to plan effectively the construction. But most of the time this estimation is very poor causing the problem for issuing extra estimation from which is needed an extra change order in order to execute the next estimation.
- Contractor financial difficulties- There are many contractors in the construction industry that are responsible for execution of different activities such as excavations, road layer, bituminous surfacing and other activities. Sometimes the contractors are not being paid regularly causing them financial difficulties which even causes difficulties to finish the works on time without delaying them making this factor a responsible factor for change order.
- Safety consideration- Safety is an essential part of the construction industry and should be taken care of early in design phase. The focus of project delivery without any fatality or injury is of prime importance. Safety considerations sometimes call for changes, which if not agreed upon, could lead to fatalities at workplace.
- Material non-availability- Many of the times the construction project is composed of different materials which cannot be found easily in the region or the entire country. As a result of the material non-availability, a change order may be issued to substitute the material.
- Unavailability of skills- Sometime in construction project the activities require the specialized group of workers which may not be found in the country where the execution is taking place. As a result of this, the owner or consultant is required to change the construction method which causes a change order.
- Poor procurement process- Procurement process is the main process for choosing the best bid offer for the project and acquiring the required materials. If the procurement process is poor, it results into delays for the material delivery or choosing the wrong contractor to execute the work, resulting later in different problem from which arises the problem of change orders.
- Unforeseen Site Conditions- During the design phase, before starting the construction phase, different studies are reported such as geological report, survey report, seismological report. But it is often seen that during realization of the project there could be problems in the survey or geological conditions, causing the interruption of the work. These are unforeseen site conditions which cause change orders.
- Extreme weather Conditions- Weather is an unexpected even that can happen at any moment. Force majeure are part of the weather conditions and as a result of those condition the construction works cannot be executed causing the necessity for issuing the change order for

extra time and cost. This problem may be solved by an adequate planning phase by taking the weather conditions in consideration.

2.4. GENERAL IMPACTS FROM CHANGES IN THE CONSTRUCTION INDUSTRY

The above causes are responsible for the changes having impacts on the project. These impacts or effects vary from small to large depending on the nature of the changes. Changes have an effect on the surroundings or other changes around them. Sometimes, a change in a project can be introduced to bring out a positive result such as increasing the size of the project management team to manage complexities in team structure. But mostly, they bring about a negative result, especially when occurring in multiple numbers. Let us look at the list of negative impacts, obtained from multiple research papers.

Negative impacts of changes

- Increase in project cost- Easily the biggest impact of a change is in cost. Cost includes items such as home-office overhead, increased labor costs, equipment and material costs, financing costs, and overhead which are very difficult to be calculated. The cost impact is calculated as the difference between the end cost and the original budget (Al-Hams, 2010). There exist different models in order to measure the cost impact of the change order (since a change is formally written in a contract as a change order). One of the models is the Ibbs et al, 2003 model which calculated the cost impact based on the equation below (Ibbs, 2003):

$$\text{Change in cost (\%)} = \frac{\text{Final Cost} - \text{Original Budget}}{\text{Original Budget}} \times 100$$

- Delays in completion schedule- Changes mostly result into time extension (or delays), which again brings us to the first point of cost increase. Delays cause the project to be executed later than planned, resulting in extra costs for the extra period taken for completion. In order to avoid these extra costs, the owner is pushing the contractor to follow the original schedule.

Since most activities are connected to one another (directly or indirectly), delays due to changes in one activity can cause an increase in subsequent activities or connecting works. Changes in different work activities can put on hold the upcoming activities. This can be seen especially when the activities are dependent.

- Decrease in productivity – With delays and cost increases in the project, there is inefficiency in work. Inefficiency is loss of productivity, expressed as a percentage of the actual or the optimum productivity. It is the difference between what was actually performed and what “would have been” performed in the absence of the impact (Aghamohammadi, Faraji, N.D). In an extensive research conducted by Ibbs (2012) on ‘change order effects on project productivity’, he mentions that the ratio of final cost to estimated is always higher as the number of changes increase. Also, as the number of changes exceed 10%, productivity begins to decrease.
- Decrease in quality - Changes in activities from time to time may result into mismatch and confusion among workers and since the workers are often affected by the changes, there is a decrease in quality of work and thus, productivity. Also, sometimes due to cost increase resulting from changes, the quality of work and material is reduced to compensate for the extra costs.

- Delay in Payment- The payments may be delayed if they are based on milestones and since changes often delay milestones, there are delays in contractor payments followed by subsequent payments to workers.
- Demolition & Rework - This is an impact of the defective workmanship since their work is not within the requirements (and standards) and as a result of this the demolition of the executed work is done and rework takes place due to change. This effect is mainly in special required works where specialized workmanship cannot be found.
- Dispute between owner and contractor- Changes are the main reason for the claims and disputes between the owner and contractor. The contract conditions are applied but for changes estimation, evaluation and negotiation must be done leading most of the time in problems between parties. These issues can go to arbitration and up the courts and legal aspects from which even the project can be suspended.

2.5. CONTROL OF CHANGES

Having studied the causes and the impacts of changes (in the previous sections), controlling the occurrences of changes and thus, change orders and mitigating (or minimizing to an extent) their negative effects is highly recommended. There are three stages of control, as learnt from multiple research papers. These stages are design stage, design-construction interface stage and construction stage (Al-Hams, 2010). Pre-design stage control is not elaborated here as focus more on controls for post design stages. The three stages of control are specified below.

Design stage (Al-Dubaisi, 2000)

- Proper review of contract documents to improve communication and coordination
- Freezing design in a strong controlled manner by not allowing any changes after design completion
- Taking into consideration value engineering at conceptual phase to decrease design interventions
- Involving of professionals and experts at initial stages of a project reducing changes at later stages
- Involving the owner at planning and design phases to fulfil the owner's desires to perfect the design as per requirement.
- Similar to the owner, involving the contractor early on in design and planning phases
- Thorough detailing of design at early stages helps reduce errors and omissions
- Reducing contingency sum pressurizes the designer to perfect the design and not leave anything for later stages.

Design-construction interface stage (Al-Dubaisi, 2000)

- Prompt approval procedures to reduce the time required to approve a change as a change order, thus reduce time and cost increases.
- Negotiating of change by skilled personnel to the professional team such that its negative impact is reduced
- Calculation of change order considering both the direct and indirect effect of each change to determine the correct cost.
- A good coordination of the main team parties involved such as the owner, consultant and contractor, helps in identifying and managing changes effectively.
- Utilizing work breakdown structure efficiently to add new activities (if changes occur) by reducing the disruption to the flow of work
- Using of knowledge gained from previous projects regarding dealing with changes is very essential in order to maintain the right flow of project.

Construction stage (Al-Dubaisi, 2000)

- Clarifying to all parties involved, the change procedures early on in construction phase.
- Proper scope definition for the project helps reduce changes in unnecessary areas.
- Change logic and justification is one of the principles for effective change management, classifying required and elective changes to better understand their advantages and disadvantages. This helps in applying only the very essential changes.
- Involving the owner during construction helps in the identification of the works that are not as per requirements, approving of the changes and helping him in the decision making.
- Use of project scheduling / management techniques to prepare for a flexible schedule, using CPM/PERT, to include the impacts of changes that might occur in the project.
- Comprehensive documentation of change orders is essential to keep track of the changes.

The above control measures are general measures used universally in construction projects. It is very essential to realize that each project deals with different changes and thus managing them differs from change to change, personnel to personnel and conditions available. For an effective change management there are some management aspects that must be taken in consideration. In its special publication 43-1 (1994), the CII Project Change Management Research Team recognized five principles for effective change management as given in Fig.2.4 (Al-Dubaisi, 2000):

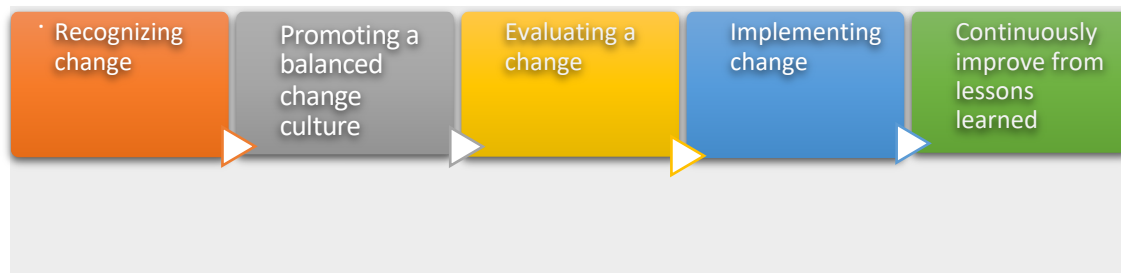


Figure 2.4: Principles of Effective Change Management

However, effectiveness of change management is only valid for changes at a particular time. The effectiveness of change management reduces with the increase in the number of changes since it becomes a lot more difficult to manage multiple changes at a particular instance. (Al-Hams, 2010) Hence, it is essential to focus on multiple changes and their impacts.

2.6. MULTIPLE CHANGES IN A PROJECT

As observed in the previous section, Individual changes impact the project in various ways. However, their individual impacts tend to effect other changes and their impacts when there more than a few changes at the same time in a project. They tend to follow a '*synergistic phenomenon*', as Wikipedia defines it as the "*creation of the whole greater than the sum of its parts*". The cumulative impacts from multiple changes is elaborated in the next section.

2.6.1 CUMULATIVE IMPACTS FROM MULTIPLE CHANGES

When numerous changes occur, there is a compounding and negative effect commonly called "cumulative impact." *Cumulative impact is the unforeseeable disruption of productivity resulting from the "synergistic" effect of an undifferentiated group of changes. Cumulative impact is referred to as the "ripple effect" of changes on unchanged work that causes a decrease in the productivity and is not analyzed in terms of spatial or temporal relationships.* This result is unforeseeable and indirect (Ibbs,2015). This impact is poorly understood, difficult to measure, and seldom reflected in the sum of the estimated costs of individual project changes. This compounding and negative effect often goes unnoticed until it is too late. It generally becomes apparent only in

the later stages of a project when work cannot be completed on time and when labor productivity does not measure up to the anticipated levels. (Ibbs, McEniry ,2008).

Publications by McCally (2006) and Galloway (2007) refer to a “synergistic effect” of changes with respect to cumulative impact. They make reference to the 1990’s definition as set forth in the Construction Industry Institute’s “Quantifying the Cumulative Impact of Change Orders for Electrical and Mechanical Contractors” which offers this definition: “*The theory of cumulative impact claims holds that the contractor fails to foresee the ‘synergistic effect’ of changes on the work as a whole when pricing individual changes, and thereby receives less than full compensation.*” According to this theory of cumulative impact, the issuance of a multitude of change orders creates disruption that exceeds the disruption caused by the individual change orders when viewed independently. In this sense, cumulative impact would be synergistic.

Cumulative impact is not just a theoretical concept but a real occurrence on construction projects suffering numerous changes, the impact of which is difficult to recognize as individual change orders are issued and priced. There are several methods to quantify the cumulative impacts, however, **these methods are only applicable once the project is finished and not during the realization of the project.** Subsequently, they are used to calculate the costs for legal issues and obtaining compensation amounts from the clients. **Important note: these methods are accepted in courts but only with limitations**

An elaborate understanding of these methods shows the limitations that hinder their use in determining the cumulative impacts of changes in projects. Refer to Appendix B for more information on these methods, their limitations and scientific research on this field.

2.6.2 SYNERGISTIC EFFECT

A synergistic design approach is one that is focused on the interaction between the parts or elements within a complex system in order to identify and develop synergies. Here, the combined effects of different types of effects (resulting from individual parts) lead to an interactive environment and moving forward, effects from several developments, which individually might be insignificant, but when considered together could amount to a significant cumulative effect (Corning, 2015). The interactions between the parts can be either **linear or non-linear**. Linear relations are those where the interactions among the parts do not change the overall outcome. In other words, there exists a static relationship, where $1+1=2$. For non- linear relations, the interactions among the parts change the overall outcome, such that overall productivity shows $1+1 >2$ or $1+1 <2$, showing **positive or negative synergies** (complexity labs, n.d.).

The cumulative impact of multiple change theory discusses about the disruption of project productivity due to the “synergistic effects” of changes while the synergy theory discusses about the ‘**self-destructive relationship**’ where interactions among parts in a system lead to a lower productivity. In this type of relationship, there is interaction in a way that each individual part of a system consumes more resources than it generates for the organization. The result is **less productive output** than might be expected if the same individual entities worked independently. Hence, to maintain equilibrium in a system, additional resources must come from outside the system. If there are no resources available to use, the organization suffers a resource deficit and results in lower productivity for the system.

The theories of ‘synergy’ is a general theory that exists in nature and is applicable in several industries. In the mergers and acquisitions literature, synergy usually refers to financial synergy that is gained through the merging of conglomerates (Chang, 1990), while in the industrial economics literature, synergy features in the context of economies of scale that lead to cost savings (Chang, 1990). It is in fact applicable in chemical and biological fields and in medical practices to determine the nature of drug interaction. It is the result of a process whereby better use of physical and invisible resources is made by viewing the total diversified organisation as one system (Jaffe, 2017).

3. INTRODUCING A NEW PROCEDURE

This chapter provides an overview of the learnings from literature in the form of a change flow diagram (3.1) leading to a new proposed procedure to determine interactions among changes. The procedure (3.2) contains various steps leading up to a change interaction model to illustrate the interactions in order to better understand the impacts from substantial changes. Finally, a methodology is prepared to define the steps needed to validate the procedure.

3.1 LEARNINGS FROM LITERATURE

On the basis of knowledge gained from several theories and learnings regarding changes and the limited applicability of change management techniques in dealing with multiple changes at a particular time, a proposed change flow diagram is prepared. The diagram illustrates the possibility of a change in the scope of a project as the number of changes increases. This is based on the theory that as the number of changes increases in a project, the effectiveness of a change management team in dealing with changes decreases, resulting in cost increases and project delays. Fig.3.1 below shows a change flow diagram.

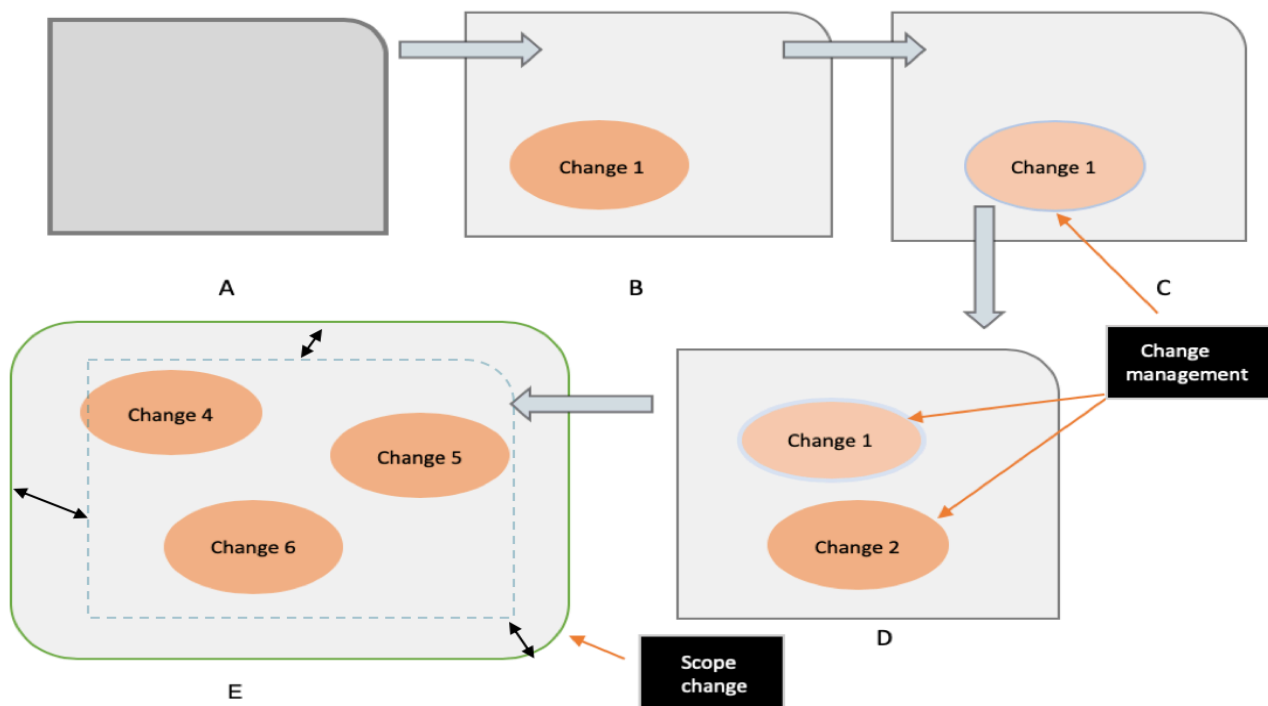


Figure (A) represents a normal project with a proper scope definition. This project now undergoes a change, shown in fig(B), which is dealt with a change management team as illustrated in fig(C). A second change has been introduced in the project as shown in fig(D), however, this change occurs after the first change is dealt with and hence, can be managed by the change management team (after dealing with the initial change). Finally, (E) shows the occurrence of multiple changes at a particular time during a project. As per theory, this is where the actual scope of a project might change as the occurrence of multiple changes allow for interactions among them, leading to a greater demand for resources than the changes would have otherwise required individually. Thus, the project change management team have to prioritize the changes that require immediate management while leaving various changes to interact with other changes without any management

Figure 3.1: Change flow diagram

As learned, the introduction of more changes should demand a lot from the project management team making it certainly difficult to manage multiple changes. Notably, the scope of the project might change due to delays and cost increases resulting from the changes. Ultimately, based on the theories of cumulative impacts of multiple changes, for the project to have undergone scope changes, cost increases and delays, the multiple changes should have an interaction among one another and the environment in the form of direct and indirect effects which should result in consumption of more resources than anticipated, due to their similar effects on the environment. The theories suggest two types of interactions (Corning, 2015)-

- Direct - causal relationship from one part of a system to another.
- Indirect –relationship due to analogous effects from various parts of a system

Following this thought process, a look at the change flow diagram shows figure (E) with an increased scope. Hence, there must be interactions among the changes leading to a greater demand of resources. However, there needs to be a way to determine the interactions to better understand the theory behind it. This gives a sound reasoning to developing a new procedure to determine and illustrate the interactions among changes. A proposed procedure is provided in the next section (3.2).

3.2 PROPOSED PROCEDURE

The procedure to determine and show interactions among changes comprehends the subsequent steps:

Step 1: Identify the significant changes

The first step is to identify the changes that are having or could have had a major influence on the outcome of the project, depending on identifying during or after completion of a project. This is based on the reasoning that interactions among the major changes is more essential to determine as learning from this could show the actual larger resource demand, more than anticipated. In simple terms, learning regarding the larger impact from the changes than estimated.

Step 2: Determine and demonstrate the effects of each significant change

After identifying the significant changes, the effects of each change must be analysed. The changes can have causal effects leading to new changes or have effects on the surrounding environment. These are the direct and indirect effects respectively and are usually responsible for cost increases and project delays. For direct effects, the cumulative theory of changes refers to the term of “ripple effects” or “knock-on effects”, where the occurrence of one change leads to another and so on, causing problems for the project management team. As for the indirect effects, they demand resources from the surrounding and when combined with other changes having similar effects, the demand for resources increases. Hence, the focus of this step is to determine both the direct and the indirect effects of the significant changes.

Following immediately after determining the effects of the significant changes, the effects must be demonstrated. This become vital later when all the changes with their demonstrated effects are compared to isolate the common and the causal effects. The common and specially the causal effects become easier to detect when shown in figures. The next step discusses further on this. As for this step, the effects must be shown as represented in Fig.3.2 below. The figure shows a change (change X) with three effects (effect 1, 2 and 3). The changes have a relationship with the surrounding environment (project environment), hence, they are indirect effects. The dotted arrows represent the relationship with the environment.

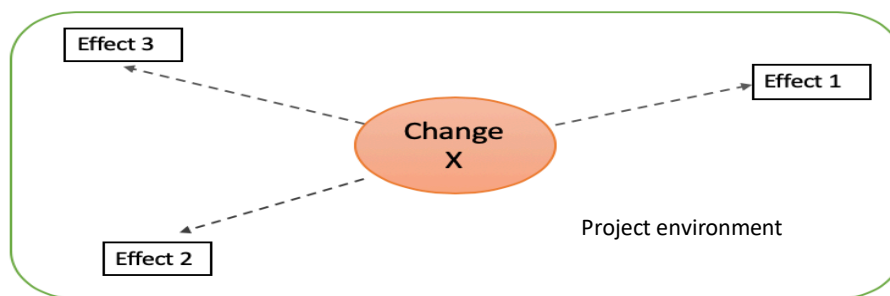


Figure 3.2: demonstrating effects resulting from a change (change X)

Step 3: Compare the figures to isolate the common and causal effects

Following demonstration of the effects from each significant change, the figures are compared. This is done to find out the common and the causal effects among the changes. Common effects are the similar effects occurring among different changes while the causal effects are the effects where one change is caused as a result of another. This is important to determine the interactions in the next step. Once the effects are isolated, it is tabled to as shown in table 3.1 below. The table contains two columns, one for the change combination and the other for the effects from the change combination. The rows depend on the number of change combinations. An example is provided in the figure below for two change combinations (X and Y) and (Y and Z). Change combination X and Y share two common effects (1 and 2) while change Y shows a causal relation with change Z.

Change combination	Effects (common and causal)
Change X and Y	common effect 1, common effect 2
Change Y and Z	Causal effect

Table 3.1: Effects among different change combinations

Step 4: Illustrate the common and the causal effects in the form of a model

Fig.3.3 is a change interaction model that shows the direct and the indirect interactions among different changes. To obtain similar results, the changes are to be illustrated along with their causal or common effects, based on the results obtained from the table of change combinations, discussed earlier. So, once the changes are determined along with their effects, they are to be illustrated. Then, based on the table of combinations, arrows point from a change to their respective effects. The relationships among the changes and the effects are represented by different arrows as shown below. The common and the causal effects illustrated help in determining interactions among the changes



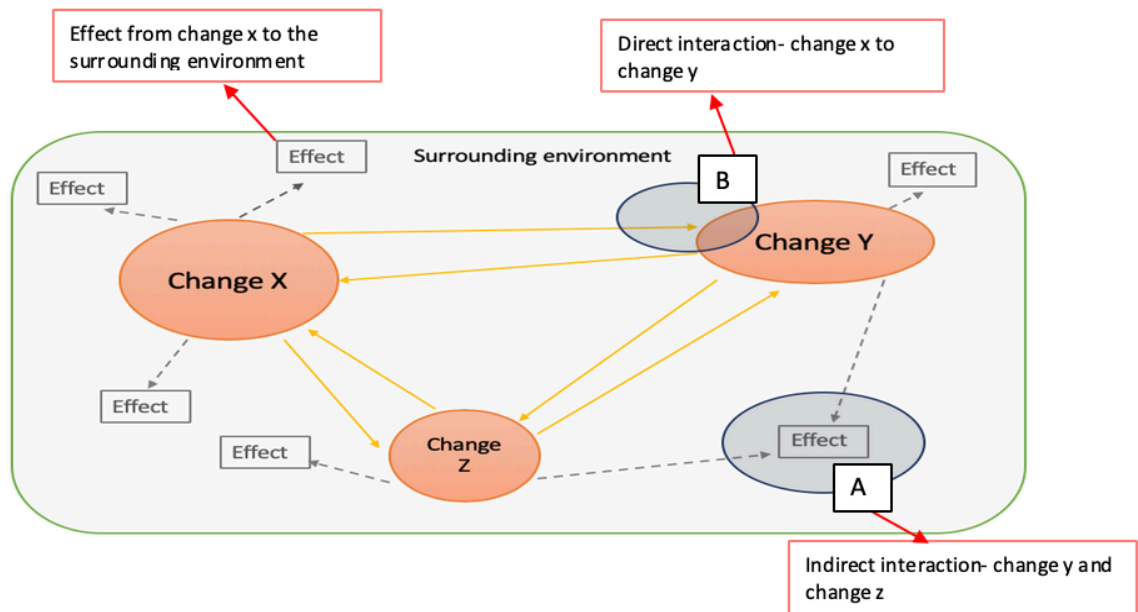


Figure 3.3: Proposed model of change interaction

Step 5: determine the interactions from the illustration

As seen in the model above, the common effects among the changes represent indirect interaction (point A) while the direct effects from one change to the another shows direct interaction among them (point B), as shown in the highlighted sections of the figure (A and B). Hence, to determine the interactions among the changes, certain steps must be followed leading to a change interaction model, where the combination of changes along with their effects help in determining the interactions.

3.3 APPLICATION

Having proposed the steps to determine interactions, the procedure is of no use if it cannot be applied by construction companies in real projects. In order to do so, consider the procedure as a framework with the steps as a guiding method to arrive at the final results. Construction companies must be able to use the framework after or during construction to determine interactions.

In order to determine interactions among the significant changes, the procedure must be applied after the completion of the construction. This will help better determine the significant changes. Now, using the steps of the procedure one by one, the companies should be able to identify the significant changes, considering they would already have all the information regarding the project. After identifying the changes, they deem most impactful, the significant changes must be separated from the other changes and their effects determined. These can be causal effects (one change causing another) or general effects (resource requirement). After this, the effects must of each significant change must be compared and the common/causal effects isolated. Following this, based on the change interaction model, both the effects must be illustrated. This will give the points of interactions among the changes.

Importantly, this shall serve as a guide for companies to show the clients points of interactions among the changes and the resulting resourced demand from the points. In short, this could serve as a reasoning for the extra costs resulting from multiple changes.

In conclusion, following the steps below in table 3.2, should help in determining interactions among changes.

Steps to determine interactions among changes
1. Identify the significant changes
2. Determine and demonstrate the effects of each significant change
3. Compare the figures to isolate causal and common effects
4. Illustrate the causal and the common effects in the form of a change interaction model
5. Determine the interactions from the model

Table 3.2: procedure to determine and illustrate interactions among changes

With a change interaction model proposed to show the interactions among multiple changes in a project, the entire procedure leading up to the model has to be tested in real construction projects for validation. This is done to check if indeed the procedure can aid in determining and illustrating the interactions among major changes to better understand the impacts from the changes.

3.4 METHODOLOGY TO EXAMINE THE PROCEDURE

In order to test the applicability of the procedure, certain steps are generated. These steps are necessary to collect data and apply the procedure using the collected data to obtain results. The results will be key to validate the procedure. The steps include: selection of projects, expert interviews, application of the model and finally results.

3.4.1 Selection of projects

Project selection is based on obtaining information from construction projects that have suffered losses or having compensation issues with extra costs resulting from multiple changes, basically projects with issues. This is important because projects with losses or compensation issues will have undergone multiple changes that might have caused the issues and applying the proposed procedure to this data could help find some valuable results. The company that had undertaken the project should be accessible for gathering of data and interview purposes. This is followed by gathering data from the selected projects. Collection of data from the projects depend on the availability of the entire list of change orders with their cost values and more importantly, accessibility of this data. Most companies have problems sharing their financial data or giving information due to ongoing court cases. Limited data could provide non- conclusive results.

3.4.2 Expert interviews

In order to conduct an interview with a project manager, a set of questions have to prepared beforehand. These questions are based on certain themes of the project. The themes include significant project changes, multiple issues, impacts from the issues, effects of the significant changes, control measures and finally project manager knowledge on interactions. No fixed question should be prepared but a general subject area focusing on the topics must be decided upon. The themes are incorporated in a set of questions which may not asked one by one but a reminder for the interviewer about the topics to focus on. To obtain information from the interview, the entire list of change orders must be narrowed down to a substantial few for the project managers to determine the significant changes. This step is important as the interviews with the project managers involve the use of the list of changes and time is very precious in the interviews. An entire list of change orders can contain up to 350 changes, so to determine the significant changes from a list of 350 change orders could become a tedious task for the project managers. Hence, the list of entire change orders must be narrowed down to ten change orders.

The ten major change orders are to be decided based on their cost value (high to low). This is centered around the idea that an impactful change must have a high cost value and that the higher the cost value of a change, the more impactful it can be. Certainly, the top changes must be significant for the project managers, given their higher cost value compared to the other change orders. The interview session with the project managers is very crucial as not only does it provide information regarding the significant changes and their effects, it also provides information regarding the control measures applied during construction as obtained from their experiences.

Each step will be analyzed using the collected data combined with information from the expert interviews. Lastly, the results from each case study is studied and cross analyzed to give conclusive remarks on the applicability of the model and the procedure. The steps used in this research to validate the procedure is described below in Fig.3.4.

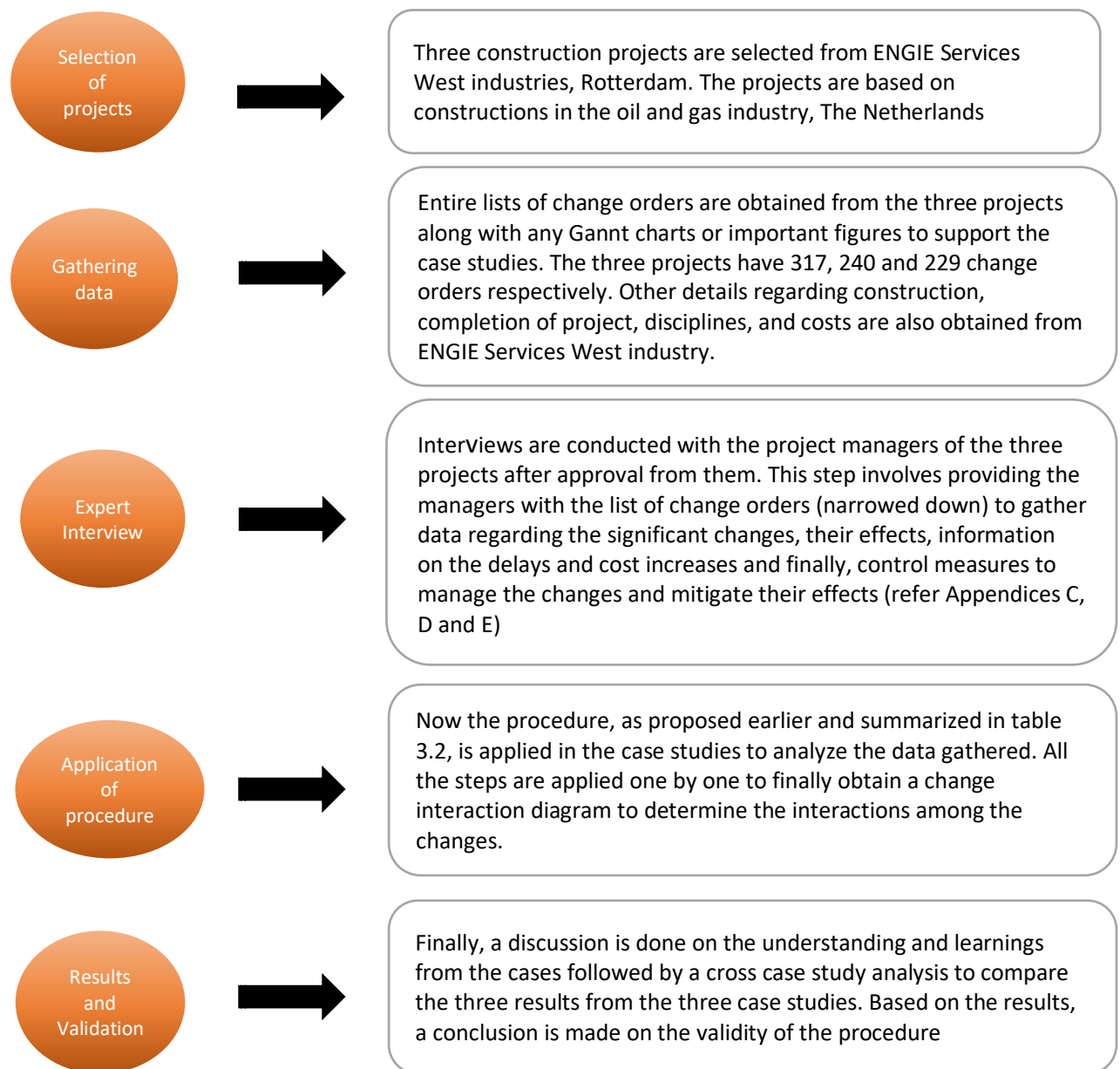


Figure 3.4: methodology to validate the proposed model

4. CASE STUDIES

The following case studies are part of the Engineering and construction industry in the Netherlands and are three projects undertaken by ENGIE Services, Rotterdam, The Netherlands. The projects include the installation of a new gas treatment plant at Maasvlakte, Rotterdam, Construction of tank terminal at Botlek, Rotterdam and the construction of Solvent DeAsphalter (SDA)- work stream 3 (WS3) at Vondelingenplaat, Rotterdam, all in The Netherlands. The proposed procedure, as discussed in section 3.2 (chapter 3), will be applied further into the cases.

4.1. PROJECT 1

This project deals with the construction of a new gas treatment installation at the Oil and gas industry, The Netherlands. The project was undertaken at Rotterdam 2nd Maasvlakte, The Netherlands. The client, **Oranje- Nassau Energie BV**, requested the supplying and installation of the complete piping and electrical & Instrumentation (E&I) system for a new grass-roots onshore gas receiving station and gas reprocessing installation.

General information regarding the application of the project, nature of work involved, actual contract size in terms of cost, ENGIE's role within the project, number of man hours required to finish the work, different disciplines of work involved and the project manager guiding the entire project is provided below.

GENERAL INFORMATION	
Application	Oil and Gas factory (Q16)
Nature of the work	New construction
Estimated cost	9.4 million euros
Final cost	11.4 million euros
Role within the project-	Main contractor
Contract form-	Turnkey EPCM
Disciplines	Design, prefab and construction, P&M, E&I, quality control handover
Project manager	Jacques Slingerland
Commencement of work	July 1, 2013
Planned completion	February, 2014
Actual Completion	April, 2014

The Q16 project had an overall cost of 11.4 million euros, with work in certain disciplines like P&M (Piping and Mechanical) and E&I (Electrical and instrumentation) while also having to look over the design, prefabrication and construction with quality handover of the project. ENGIE, being the main contractor for the project, provided various solutions to the client in order to offer their technical and management expertise in the project. Some of them, obtained from the documents of ENGIE, and have been listed below.

ENGIE SERVICES SOLUTIONS
<ul style="list-style-type: none"> • Supplying and installing scaffolding in order to carry out the work safely • Supplying and installing all piping for the entire installation. • Completing 65% of the detailed engineering for the E&I work that had not been completed at the time of the contract being awarded. • Supplying and installing all electrical & instrumentation materials (and performing the related work) for the entire installation.

Providing solutions and undertaking a project of this size comes with several facets to it. The **positive** aspect of the project was **ENGIE** taking care of all phases for the client, Oranje- Nassau Energie, as they had performed both the E&I and the mechanical activities thus requiring minimal input from the client to manage the interfaces. However, if there was a **negative** aspect, it was the numerous amounts of changes (occurring in various disciplines) throughout the project.

4.1.1. DATA COLLECTION

The project had undertaken a massive 317 change orders throughout the duration of construction. ENGIE Services West Industry estimates the value of scope change to be about € 2.532 million. This would make the final cost € 11.932 million. However, ENGIE was compensated an amount of € 2 million for the additional work, bringing the final cost to € 11.4 million, suffering a loss of € 532,000. By definition, change has an impact on the project, whether positive or negative. However, not every change will have a big impact on the project. The research focusses on the significant changes that may have impacted the project in a way that there were cost increases and delays. Hence, as discussed in section 3.3, the list was narrowed down to 10 changes (formalized as ten change orders), having substantial impact on the project (see table 4.1).

An extensive interview was conducted with the project manager to determine the most significant changes among the top 10 along with verifying the causes of the changes and the multiple issues delaying the project. The causes for the issues were determined by the project manager, from the list derived from literature (Table 2.2)

The changes have been listed down as change orders to keep a record of them. The Change order numbers keep track of the change orders in the project and are numbered from 1 to 317. The change orders have their issue date which may not always be similar with the date of issue of the changes as the change orders are records of the entire change along with its impacts, which takes time to generate. The changes have their own individual causes along with their cost value. Their discipline provides information on the area in which the changes were operated in. The impactful changes along with their change order numbers, description, date of issue, discipline, causes and cost value are listed in the table below.

#	CHANGE ORDER NO.	DESCRIPTION OF CHANGE ORDER	DATE OF ISSUE	DISCIPLINE	CAUSES	COST VALUE
1	COF092	Supple, pull and connect multicores cables above ground	March 6, 2014	E&I	Changes in plans and design specifications by owner	€ 265,017.87
2	COF090	Fire and gas BID AFG	March 6, 2014	E&I	Change of project scope and schedule by owner	€ 141,624.95
3	COF014.2	Delivery DUPLEX material rounding 14-2-2014	March 6, 2014	Mechanical	Ambiguities and errors in specifications and drawings	€ 84,508.37
4	COF148	Additional work (BID AFC) I cable singles and smaller diameters above ground, deliver, pull and connect	April 2, 2014	E&I	Change of project scope and schedule by owner	€ 83,153.38

5	COF021	Insulation BID AFC	March 6, 2014	P&M	Change of project scope and schedule by owner	€ 79,000.00
6	COF004	Newly received Piping specs REV.16	February 18,2014	P&M	Ambiguities and errors in specifications and drawings	€ 64,739.39
7	COF072	E & I by Preciamolen	April 2, 2014	E&I	Change of project scope and schedule by owner	€ 47,747.03
8	COF028	Laying / pulling underground cable work - E & I Part 1	February 18, 2014	E&I	Change of project scope and schedule by owner	€ 36,242.25
9	COF001	Laying / pulling underground cable work - E & I Part 1	Dec 5, 2013	E&I	Change of project scope and schedule by owner	€ 35,407.24
10	COF042	New pipes between T9901 & FW Pump	March 6, 2014	P&M	Change of project scope and schedule by owner	€ 34,935.13
TOTAL						€ 872,375.37

Table 4.1: List of top 10 change orders based on their cost value (decreasing order of value)

The top changes add up to € 872,375.37 which is around 35% of the additional work of €2.5 million, with remaining 307 change orders contributing to 65% of the remaining additional cost. ‘Change of project scope and schedule by owner’ cause is the dominant reason for the changes occurring in seven of the ten changes followed by ‘ambiguities and errors in design,’ in two of the remaining changes. ‘Change in plans and design specifications by owner’ occurs in the change with the highest cost value.

As the data gathering process is complete, an interview is conducted with the project manager to determine the significant changes. This step also coincides with the first step of the proposed procedure, discussed before in section 3.2, to determine interactions among changes. Hence, based on table 3.2, the following steps are taken in order to test the procedure.

4.1.2. ANALYSIS

In order to test the proposed procedure and obtain interactions among the significant changes, the steps of the procedure leading up to the creation of a change interaction diagram are followed in this section.

Step 1: Identify the significant changes

In the interview session (refer Appendix C), the list of change orders was further narrowed down to 3 significant change orders that the project manager felt were most impactful in the project (table 4.2). **Surprisingly, the changes were not the top three but rather three of the top ten, thus signifying the impacts of the three to be larger than estimated.** It is important to note that the interviews were conducted after the completion of the project, hence information regarding the significant changes was straightforward. The change orders along with their change order numbers, description, date of issue, discipline, causes and impacts are listed in the table below

#	CHANGE ORDER NO.	DESCRIPTION OF CHANGE ORDER	DATE OF ISSUE	DISCIPLINE	CAUSE	COST IMPACT
1	COF092	Supply, pull and connect multicores cables above ground	Wed, March 6, 2014	E&I	Changes in plans and design specifications by owner	€ 265,000.00
2	COF014.2	Delivery DUPLEX material rounding 14-2-2014	Wed, March 6, 2014	Mechanical	Ambiguities and errors in specifications and drawings	€ 84,508.37
3	COF004	Newly received Piping specs REV.16	Tue, February 18, 2014	P&M	Ambiguities and errors in specifications and drawings	€ 64,739.39
TOTAL						€ 414247.76

Table 4.2: List of multiple impactful change orders

The above changes, chosen by the project manager as the most impactful changes from the list of top ten changes, added a sum of € 414247.76 to the additional cost with ‘ambiguities and errors in design’ being the reason dominating the changes. The changes are further analysed in the next section.

This section goes in depth into the three changes and their effects on the project contributing to a better understanding of the nature of cumulative multiple change impacts. Commencement of work for the project started on the 1st of July 2013. The turnaround of the project was estimated to be around 33 weeks with completion to take place on Feb 14, 2014. However, there was 7 weeks delay in the project, thus actual completion taking place around mid-April. The Gantt chart below (Fig.4.1) shows the working period of the project along with various key events within the time frame. The project had a piping scope of ± 30,000 hours and E / I scope of ± 40,000 hours.

Prefabrication work started on week 1 of the project up to 14 weeks, when the work preparation took place. The prefabricated components of piping system, called spools, first arrived around 4 weeks into the project. Prefabrication works for the spools speeded up by week 10 of the project, commencing on to week 17. Piping work started week 6, which was assembled on week 28, working simultaneously with the work on spools. E&I work, simultaneously with the piping and spools began week 11, commencing up to week 40. The mechanical and E&I work was supposed to be completed by week 33 but extended to week 40.

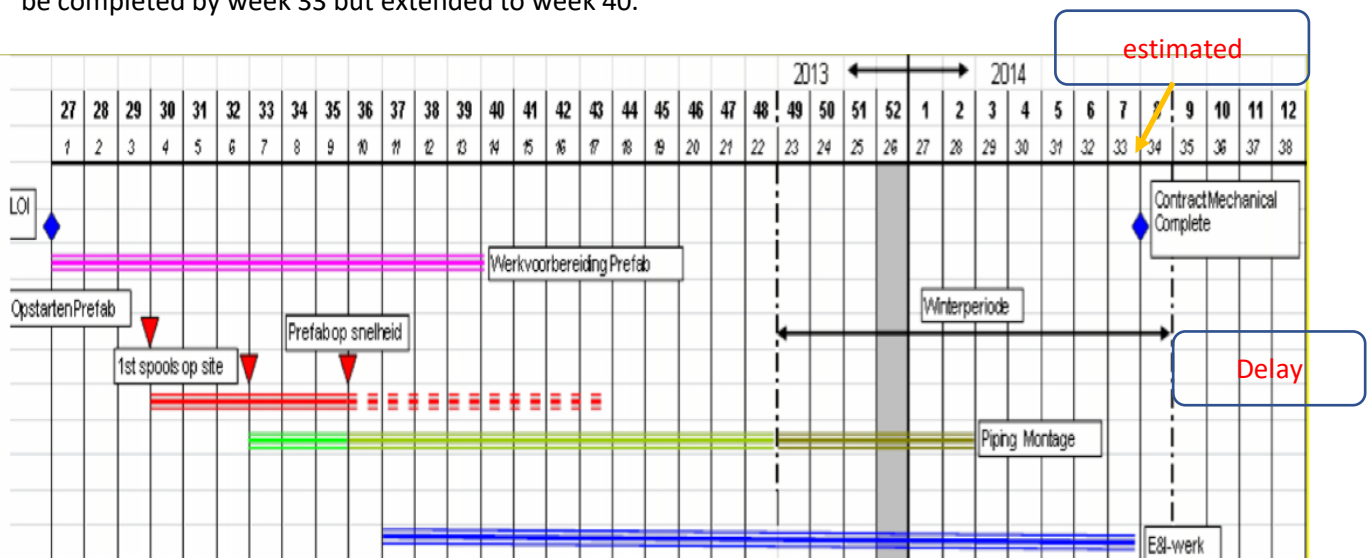


Figure 4.1: Gantt chart for project 1

The **first** significant change was a change in pipe Spec (Specifications) which was issued on 21st August 2013. A New Pipe spec was issued by the client and the client requested to review the impact on the isometrics for this item. Isometrics here are drawings for a pipeline. The project had over a thousand isometrics. The Client had done the engineering (isometrics) and prepared the Bill of Material (BOM) per ISO (Isometric) and ordered most of the materials. Regarding the change of scope, the project manager discussed that “we have 1000 isometrics and around 330 were affected. This meant 33% of the isometrics were affected by this change of scope. Importantly, if it affects 33% of the isometrics, it also affects 33% of the piping scope, since isometrics contain instrumentation as well. Therefore 33% of the E&I scope “.

This change impacted 33% of the E&I scope and mechanical scope as per ENGIE Services West Industry, the isometrics comprising of electronic valves and instruments along with mechanical components to be installed in the pipes. The value of the Change order was € 64,739.00 (as seen in the table below) and later partly approved in an overall deal. The cost value of the change itself contributed 0.56% to the overall cost value and just about 2.6% to the additional work. But the nature of change allows for interactions with the surrounding environment. As learnt from literature, changes have a “ripple effect” or “Knock-on” effect on its surroundings, in this case resources. The tables below provide the details of the change order along with its cost percentage impact.

CHANGE ORDER DESCRIPTION (change 1)	CAUSE	COST VALUE	CONTRACT VALUE	PERCENTAGE IMPACT
Newly received Piping specs REV.16	Ambiguities and errors in specifications and drawings	€ 64,739.39	€ 11,400,000.00	0.56 %

Table 4.3: Cost impact (in percentage) of the first change on the entire project

CHANGE ORDER DESCRIPTION	CAUSE	COST VALUE	ADDITIONAL WORK	PERCENTAGE IMPACT
Newly received Piping specs REV.16	Ambiguities and errors in specifications and drawings	€ 64,739.39	€ 2,500,000.00	2.58 %

Table 4.4: Cost impact (in percentage) of the first change on the additional work

The **second** major change took place on October 3rd, 2013, around 13 weeks into the project. The client did not order enough duplex piping materials and requested ENGIE to supply the duplex materials, which ENGIE found out during the work preparation process, (which was not something discussed before realization of the project). Hence, there was change in the scope since ENGIE Services West industry had no choice but to request the order of this material to fulfil the requirements of piping materials. As per the project manager, this change had an effect on around 100 isometrics (out of the 1000) containing piping scope, thus affecting 10% mechanical and 10 % E&I scope.

The value of the Change order was € 84,508.37. The change itself contributed just 0.7% increase in overall project cost and 3.3% to the additional work resulting from changes. The tables below provide the details of the change order along with its cost percentage impact.

CHANGE ORDER DESCRIPTION (Change 2)	CAUSE	COST VALUE	CONTRACT VALUE	PERCENTAGE IMPACT
Delivery DUPLEX material rounding 14-2-2014	Ambiguities and errors in specifications and drawings	€ 84,508.37	€ 11,400,000.00	0.7 %

Table 4.5: Cost impact (in percentage) of the second major change on the entire project

CHANGE ORDER DESCRIPTION	CAUSE	COST VALUE	ADDITIONAL WORK	PERCENTAGE IMPACT
Delivery DUPLEX material rounding 14-2-2014	Ambiguities and errors in specifications and drawings	€ 84,508.37	€ 2,500,000.00	3.3%

Table 4.6: Cost impact (in percentage) of the second major change on the additional work

The Last major (**third**) change was due to a delay caused by the client in the supply of cabinets in the control room along with design changes in the electrical cables. The connecting cables were supposed to arrive by week 42, instead arriving on week 48 (around end of November 2013), with design changes along with it. The change affected around 32.5% of the E&I scope as around 325 of the Electrical and Instrumentation isometrics were impacted by the change and had to be changed. As per the project manager, the cables were a crucial part of the electrical and instrumentation package and the change had implications on final project delivery.

The change order recorded a cost value of € 265,017 resulting from the change, contributing 2.32% to the overall cost and around 10.6% to the additional cost. The tables below provide information on percentage of cost impact from the change.

CHANGE ORDER DESCRIPTION (Change 3)	CAUSE	COST VALUE	CONTRACT VALUE	PERCENTAGE IMPACT
Supply, pull and connect multicores cables above ground	Changes in plans and design specifications by owner	€ 265,017.00	€ 11,400,000.00	2.32 %

Table 4.7: Cost impact (in percentage) of the third major change on the entire project

CHANGE ORDER DESCRIPTION	CAUSE	COST VALUE	ADDITIONAL WORK	PERCENTAGE IMPACT
Supply, pull and connect multicores cables above ground	Changes in plans and design specifications by owner	€ 265,017.87	€ 2,500,000.00	10.6%

Table 4.8: Cost impact (in percentage) of the third major change on the additional work

Step 2: Determine and demonstrate the effects of each significant change

After identification of the significant changes, the second step focuses on determining the effects from each significant change.

For the **first** major change, not only did the change have cost and time impacts, it had other “knock-on” effects on the surrounding, resulting largely in inefficiencies in work preparation and prefabrication and hence the installation of the piping. As the change is introduced, the previous works have to be managed and re-done again. This means that the prefabrication work comes to a halt until the new isometrics are ready. There was Bill of material (BOM) revision by ISO and also re-ordering of materials. All these minor effects also cause an increase in cost, which is very hard to calculate. When talked to Jacques about this, he commented “it is very hard to isolate the effects from the changes as there are so many changes taking place at a single time, with so many effects per change.”

Hence, it is necessary to try to isolate the effects from the particular change in order to have a better understanding of the effects. The effects from this change include:

- Working overtime in prefabrication shop

- Managing works connected to the work affected by the change
- Ordering of new piping materials as a result of changes in previous piping specifications
- Demobilization in prefabrication shop at times due to delays in certain sections of work phase
- Bill of material revision by Isometrics (ISO)
- Modified installation sequence to cope with alterations in work phases due to the changes

To demonstrate the determined effects, Fig.3.2 of the proposed procedure (section 3.2) is taken into consideration. Based on the figure, the effects of each significant change are shown in the Fig.4.2 below.

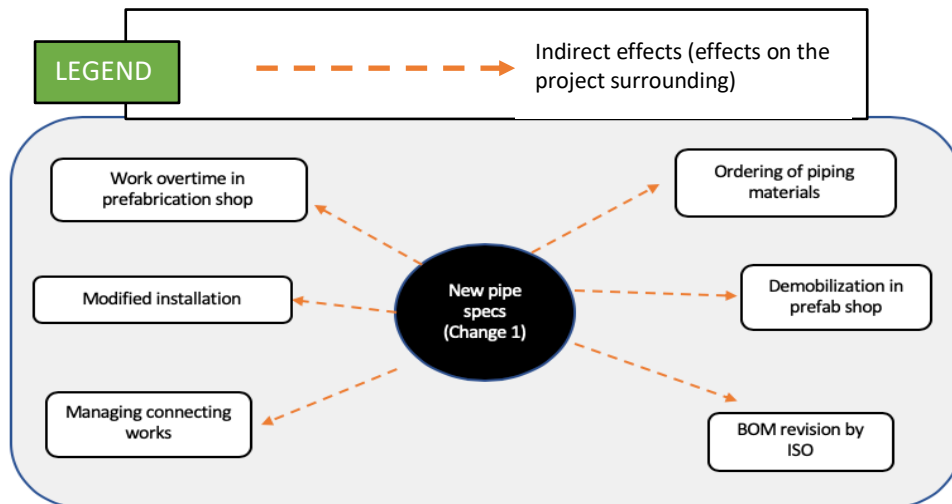


Figure 4.2: Effects resulting from first change on project 1

For the **second** major change, the work preparation was stopped again and hence the prefabrication as well, as there were not enough Duplex piping materials. The materials had to be ordered which meant time delay, since work had to be stopped on the pipes. This also meant hiring equipment and tools longer on account of the resulting delay. Overtime work had to be conducted in shop to keep up with the change and prevent any further delay. Thus, the effects from the change include:

- Working overtime in prefabrication shop
- Ordering of duplex piping materials to fulfil requirements
- Hiring extra tools and equipment for the delayed period
- Temporary stoppage of prefabrication work at times due to not enough piping materials

The effects are shown below in Fig 4.3

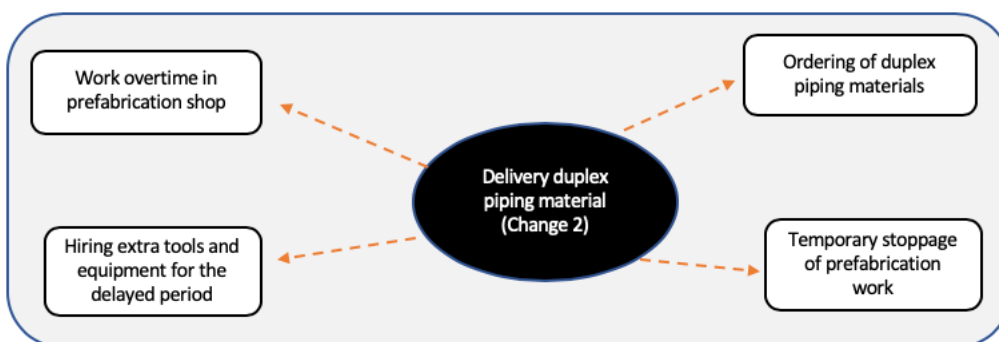


Figure 4.3: Effects resulting from second major change on project 1

Finally, for the **third** major change, there was delays and inefficiencies in work preparation. This change had its own effects, mainly stoppage of work in the period (week 42 to 48, where it was supposed to be executed). This also meant equipment and tools required for this work were not being used in that particular time, however they were available on site. The design changes had to be rectified which meant re-designing of the E&I specs for the cables. There was also *bow wave* caused in execution, which according to the project manager is a Dutch saying meaning ‘the front of a ship’, representing a lot of work occurring at the same time as a result of which the project managers add an extra cost to the estimate due to not having enough information regarding efforts needed to be taken in order to perform the specified work. Thus, the effects from the change include:

- Implementation and *bow wave* caused in execution
- Temporary stoppage of work in the control room
- Equipment and tools not used per planned, due to delayed arrival and design changes in the electrical cables

The effects are demonstrated in the figure below

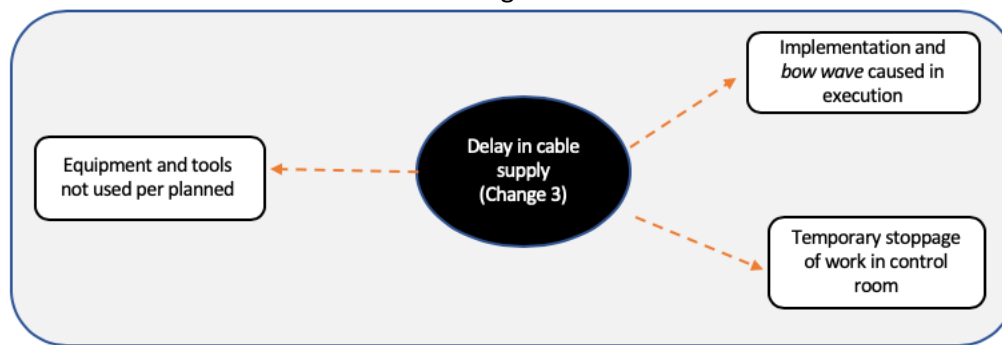


Figure 4.4: Effects resulting from the third major change on project 1

Step 3: Compare the figures to isolate the common and causal effects

Applying steps 1 and 2 of the proposed procedure, the effects from the significant changes are determined and demonstrated. Following this, the next step requires the comparison among the three changes to find out the causal or common effects that may exist among the changes. The changes are marked as change 1, 2 and 3 to give it a more general identity with respect to the other changes in the following case studies.

After careful observation of the three changes, it can be said that the effects in this case are indirect effects, since there is no direct causal relationship among the changes. ‘New Pipe spec’ (change 1) and ‘missing duplex piping materials’ (change 2) both illustrate similar effects in ordering of new materials, stopping of work preparation and prefabrication work temporarily and demobilization in prefabrication shop. This is problematic for the project management team as both the changes demand new resources along with slowing down work. Similar scenario can be observed with change 1 and ‘late delivery of cables with design changes’ (change 3) with similar effects demanding overtime working in prefabrication shop to overcome the time lost due to earlier changes, hence showing an interaction among the changes. Interactions can be seen among change 2 and 3 as both requiring similar resources in tools and equipment. Finally, all the three changes can be observed to have a common interaction in managing of works connected to the work in which change is introduced. The table below shows the change combinations along with their causal or common effects.

CHANGE COMBINATION	EFFECTS
Change 1& 2	Ordering of new materials, work preparation and prefabrication work stopped temporarily, demobilization in prefab shop
Change 1& 3	Work overtime in shop
Change 2&3	Requiring extra tools and equipment for the delayed period
Change 1,2 and 3	Equipment and tools not used as per planned, managing connecting works

Table 4.9: common effects among different change combination for project 1

Step 4: Illustrate the common and the causal effects in the form of a model

Based on figure 3.3 of the proposed procedure (section 3.2), common effects among the changes are illustrated below-

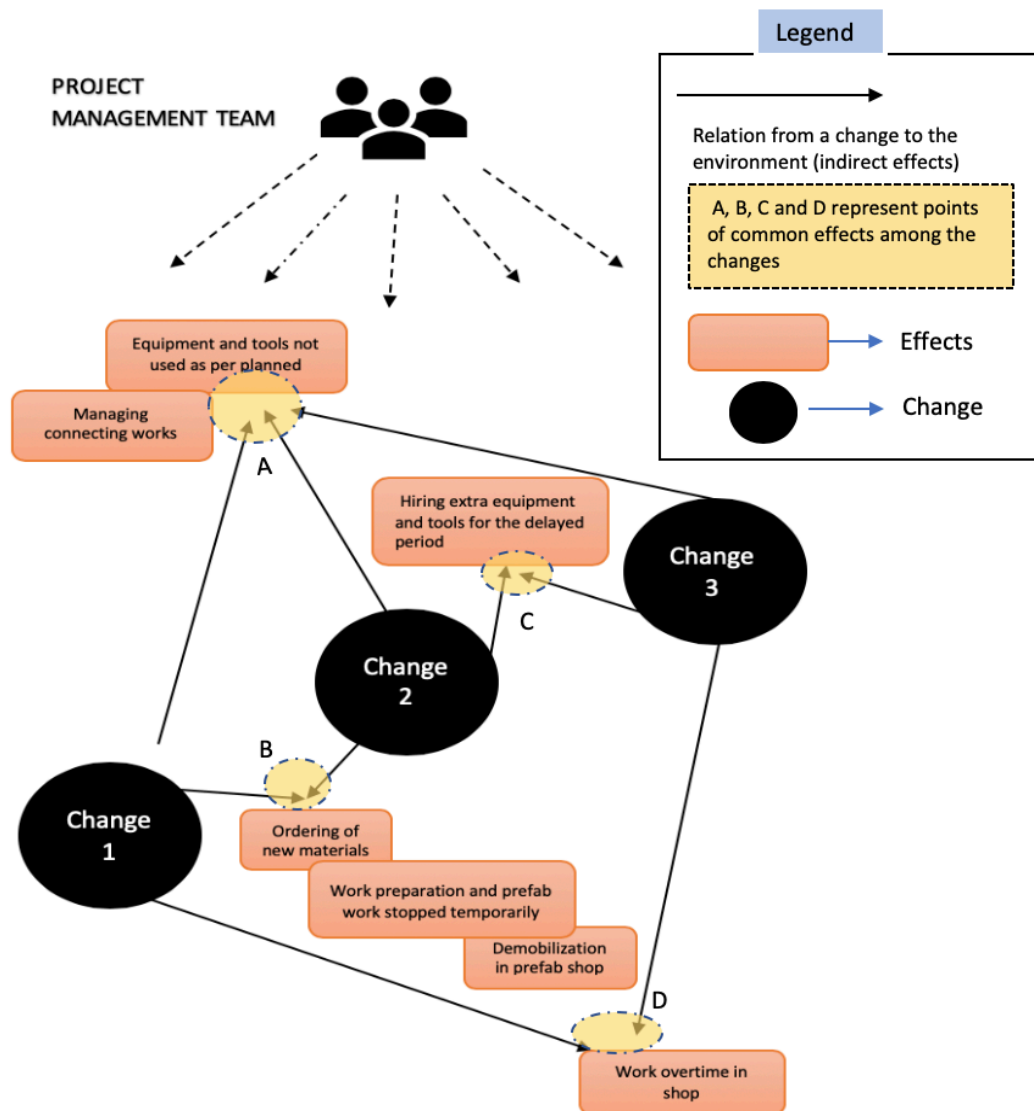


Figure 4.5: Change interaction diagram showing common effects among the changes

Step 5: determine the interactions from the illustration

Figure 4.5 shows the common effects among the changes. The points of common effects contribute to interactions. These are indirect interactions among the changes. Hence, A, B, C and D in the figure show points of indirect interactions among the significant changes.

As previously elaborated, the points of indirect interactions are obtained by connecting changes with similar effects on to the project environment. Let us take the example of point B, where changes 1 and 2 share similar effects of ordering new materials, stoppage and demobilization of prefab work. Here, the project management team has to look after the effects at B while also having to consider the effects at points A, C and D, since they all occur close to one another (in terms of time). In the interview, the project manager expressed that, in projects, major changes occurring within months or a few months of one another is considered “occurrence in the same time frame”, since the major changes have larger influence on the project, lasting longer and their effects overlap with subsequent major changes.

This follows for points of interactions at A, C and D. Point A shows indirect interaction among all the three changes due to similar effects of delaying connecting works and not using of equipment and tools as per planned. At point C, there is indirect interaction among changes 2 and 3 for showing similar effect of hiring extra tools and equipment for the delayed period. Finally, point D shows indirect interaction among changes 1 and 3 due to similar effect of working overtime in prefabrication shop.

4.1.3 Control measures

This case study shows interaction (indirect effects from changes) among the major changes that the project managers deemed impactful in his interview. Interestingly, the project did not suffer the delays or extensive cost increases that were initially expected as a consequence of the large number of changes that were introduced throughout the project. This suggests the use of certain controlling measures to keep the impacts of the changes within manageable levels. Earlier in the literature section (2.5), several controlling measures were discussed for the changes depending on the phase they were introduced into. Keeping that in mind and also the fact that the projects dealt with multiple changes at a time, the project managers were asked to discuss the measures used in their respective projects as a control mechanism.

For the first project, there were several controlling measures directed to the changes in order to mitigate its effects to the point where the delays were reduced from the expected 12 weeks to 7. They include adapting to change in the form of working in double shifts, doubling the amount of resources to speed up work, working on Saturdays and double handling of the E- cables. One can only adapt to a situation if they accept it, as the project manager comments “*you must accept change, you must allow for changes, deal with it and implement it as efficiently as possible. What usually happens is we do the change without proper work preparation and engineering. What could help is having a change management team only to deal with the engineering side*”. What that does is, having a management team just to deal with the engineering issues and changes while keeping other teams focussed on changes in other disciplines. Thus, even if the changes overlap in time, different teams, managing changes in different disciplines, can mitigate some of the effects better without putting pressure on a single project management team.

The project manager also reveals the importance of communication with team members, involving only the people essential to handle the change thus reducing pressure throughout, allowing other team members to concentrate on their work. Thus, **adaptability** and **communication** are very essential in order to handle changes during the project. He further emphasized that there should also be a level of **trust** among the client and the contractor to be able to handle periods of change while keeping progress of the project.

4.2. PROJECT 2

The project was the construction of SDA (Solvent DeAsphalter)-WS3 (workflow 3) in the oil and gas industry, The Netherlands. The project was undertaken in Vondelingenplaat, 3196 KK, Rotterdam. The client for the project, Shell Nederland Raffinaderij B.V, requested piping works in a new plant called SDA, built by Shell Pernis. The plant is subdivided into three workflows (known as 'WSs'). WS1 is the SDA plant itself. WS2 is the conversion of the HYCON plant and WS3 is the works in between. This included both the piping in between and the conversion of OSBL systems.

GENERAL INFORMATION	
Application	Industrial site
Nature of the work	New Build
Estimated cost	No estimate
Final cost	9 million euros
Role within the project	Main contractor
Contract form	Unit rate
Specializations	Tie-ins
Disciplines	Mechanical, piping, E&I
Project manager	Norbert Lardinois
Commencement of work	Mid-June, 2016
Planned completion (in weeks)	34 weeks
Actual Completion (in weeks)	40 weeks

The SDA-WS3 project had an overall cost of 9 million euros, with maximum work in the mechanical engineering section (€8 million). E&I had work costing €1 million. The project also had some additional work due to changes worth €1.4 million, included in the overall cost. ENGIE Services West Industry, being the main contractor for the project, provided various solutions to the client in order to offer their technical and management expertise in the project. Some of them were obtained from the documents of ENGIE and have been listed below.

ENGIE SERVICE SOLUTIONS
<ul style="list-style-type: none"> • WS3 was a total solution for mechanical Engineering (WTK) and E&I, during the process of which ENGIE worked closely with Engineers (Jacobs) with one ENGIE man in the Jacobs team. ENGIE was the driving force for Shell. • Aided with fine tuning the Engineering and propagating the project philosophy (AWP-area based Engineering, preparation, prefabrication and construction). • Along with Shell, the ENGIE team took on a share of the burden, optimizing performance to get the desired result

Although solutions were provided to the client, like every project there were some positive and negative aspects to it. Team members were already involved in the leading (SDA early) works, hence had knowledge of the project. This was a major **POSITIVE** for ENGIE. Also, the team was young and motivated with cooperation and trust among one another. There was a general understanding achieved through mutual communication.

However, this was a rolling project. There was no pre-defined scope but only work packages giving a general idea of the scope for the project as ENGIE had a general agreement with Shell for doing projects for the next five years, irrespective of the type of project. There was an agreement for

the number of work-hours. This was a certain **NEGATIVE** aspect for the project combined with certain issues that led to delays in the project. The issues were multiple changes.

4.2.1. DATA COLLECTION

The project had undertaken 240 change orders. the contract size at the start of the project was 0, as the scope was not pre-defined. ENGIE anticipated 25 to 35 work packages to come in. That was considered scope work, but the amount and value of it was not determined before the project started. Instead each time a new package arrived, the amount and the value would be decided. Anything done outside of these packages is considered additional work. As discussed earlier, almost every change introduced during the project has some effect on the project’s cost and schedule (Ibbs, McEniry, 2008). However, the effects of every single change may vary from very low to high. This is why it is essential to single out the changes that may have interacted with other changes and the surrounding to cause a much larger combined impact, than their individual effects, on the overall project. The effects of these changes are very difficult to establish and prove, hence an expert interview was conducted with the project manager Norbert Lardinois, to understand the effects of the changes and determine the impacts from the significant changes.

The list of 240 change orders were narrowed down to 10 change orders with high impact on project cost increase. The change orders were listed from high to low in terms of their cost value (as seen in table 4.10). The causes for the changes were provided by the project manager from the list of significant change causes obtained from Table 2.2, in the literature section (Chapter 2). The impacts of the changes along with other information for the change order were found in the change order document with 240 listed change orders. The change orders along with their change order numbers, description, date of issue, discipline, causes and impacts are listed in the table below.

S.NO	CHANGE ORDER NUMBER	CHANGE ORDER DESCRIPTION	DATE OF ISSUE	DISCIPLINE	CAUSE	COST VALUE
1	ESWI 0187	Staff changes	-	Piping	Change of project scope and schedule by owner	€ 128,436.00
2	ESWI 0140	Contingency hours week 17	May 11, 2017	Piping	Ambiguities and errors in specifications and drawings	€ 98,009.00
3	ESWI 0201	Requisites supports vs. Final accounts	-	Piping	Financial reason	€ 52,631.99
4	ESWI-0122	Workfront gap	April 25, 2017	Piping	Lack of strategic planning by contractor	€ 52,460.00
5	ESWI-0084	Extra scope SGHP from ITC / Rosemarijn Dekker / Nico van Genderen	Nov 26, 2016	E&I	Change of project scope and schedule by owner	€ 48,241.00
6	ESWI 0141	Contingency hours week 18	May 11, 2017	Piping	Ambiguities and errors in specifications and drawings	€ 44,162.00

7	ESWI 0123	Extra supervisor	April 25, 2017	Piping	Change of project scope and schedule by owner	€ 41,580.00
8	ESWI 0001	2nd planner	May 11, 2016	Piping	Change of project scope and schedule by owner	€ 40,242.40
9	ESWI 0005	Extra Atlas costs	Aug 12, 2016	Piping	Financial reason	€ 38,955.00
10	ESWI-0115	FCN Road 8	April 25, 2017	Piping	Lack of strategic planning by contractor	€ 34,361.30
TOTAL						€ 579078.39

Table 4.10: List of top 10 change orders based on their cost value (decreasing order of value)

The changes add up to € 579078.39, which is around 41% of the additional cost of the project of € 1.4 million, with remaining 230 change orders contributing to 60% of the remaining additional cost. ‘Change of project scope and schedule by owner’ cause occurs in four of the ten changes followed by ‘ambiguities and errors in design’ and ‘lack of strategic planning by contractor’.

4.2.2. ANALYSIS

Following collection of data, an expert interview is conducted with the project manager so as to determine the significant changes. This is also the first step of the proposed procedure (section 3.2), being tested in the case study. Hence, to test the application of the procedure and the proposed model, the following steps are followed:

Step 1: Identify the significant changes

In the interview session (Appendix D), the list of change orders was further narrowed down to 3 significant change orders that the project manager felt were most impactful in the project (table 4.11). As mentioned before, the interviews were conducted after the completion of the project, hence the significant changes were easier to obtain. Interestingly, the significant changes were not the top three changes but rather three of the top ten, showing the larger influence of interactions among the changes. The change orders along with their change order numbers, description, date of issue, discipline, causes and impacts are listed in the table below.

#	CHANGE ORDER NO.	DESCRIPTION OF CHANGE ORDER	DATE OF ISSUE	DISCIPLINE	CAUSE	COST IMPACT
1	ESWI 0187	Staff changes	-	Piping	Change of project scope and schedule by owner	Increase in project cost, €128,436.00
2	ESWI-0122	Workfront gap	April 25, 2017	Piping	Lack of strategic planning by contractor	Increase in project cost, € 52,460.00

3	ESWI 0123	Extra supervisor	April 25, 2017	Piping	Change of project scope and schedule by owner	Increase in project cost- € 41,580.00
TOTAL						€ 222,476.78

Table 4.11: List of multiple impactful changes in their change order format

The above changes, chosen by the project manager as the most impactful changes from the list of top ten changes, added a sum of € 222,476.78 to the additional cost with 'Change of project scope and schedule by owner' being the main dominating cause for the occurrence of the major changes. The changes are further analysed in the next section.

This section gives a detailed analysis of a project where a single major change affected the project to an extent that led to the introduction of two other major changes that had a considerable effect on the outcome of the project. Commencement of work for the project began on the 3rd week of June 2016. The turnaround of the project was expected to be around 34 weeks' worth of work, spread over the course of the year, but was extended to 40 weeks due to delays caused by the changes to be discussed in this section. The Gantt chart below, Fig.4.6, shows the turnaround period of the project along with various key events within the time frame.

The Gantt chart uses various key rudiments to show the work done. The table helps in better understanding the chart. Each month is divided into weeks, hence showing the work done per week. There is a 2-week period in December where there was no work scheduled for the Christmas and new year breaks. Further data regarding the Gantt chart is provided in the tables below

Starting Contract	SDA	Starting point AWP		Needed			
				IFF	KNR	Shop material	Field material
0	0		ENGIE actually received documents	I			
1	1		Data preparation	I			
2	2		Data shop	I	K	S	
3	3		Prefab	I	K	S	
4	4		Prefab	I	K	S	
5	5		Prefab	I	K	S	
6	6		Prefab	I	K	S	
7	7		Painting	I	K	S	
8	8		Painting	I	K	S	
9	9		Site preparation	I	K	S	F
10	10		Site preparation	I	K	S	F
11	11		Site preparation	I	K	S	F
12	12		Site preparation	I	K	S	F
13	13		execution	I	K	S	F
14	14		execution	I	K	S	F
15	15		execution	I	K	S	F
16	16		execution	I	K	S	F
	17		presses	I	K	S	F
	18		reinstate	I	K	S	F

H	Hold
	Engineering RFC and IFF targets
IFF	Issue for fabrication
KNR	Documents on how to technically do the welding
HS	Hold at Brabant Group " Shell to set priority "
R	IFF package not in order, revision needed

K	represents inspectors of Shell not being ready with their work. Hence, ENGIE receives the documents at 0 after which there is data preparation at 1 2 followed by inspection from s
----------	---

Shell (KNR) which is essential for the actual work in their shop in Dordrecht, The Netherlands and the field work as well F
--

Table 4.12: Reference table for the Gantt chart of SDA WS3 project

The **main** issue in the project was the work front gap. The change order was issued on April 25, 2017 and is an integral part of the piping and mechanical(P&M) discipline, with main focus on the piping aspects. This change order was a collective response to a lot of gaps in works leading up to this. Let us consider a small section of the project schedule (Fig.4.6.) discussed above.

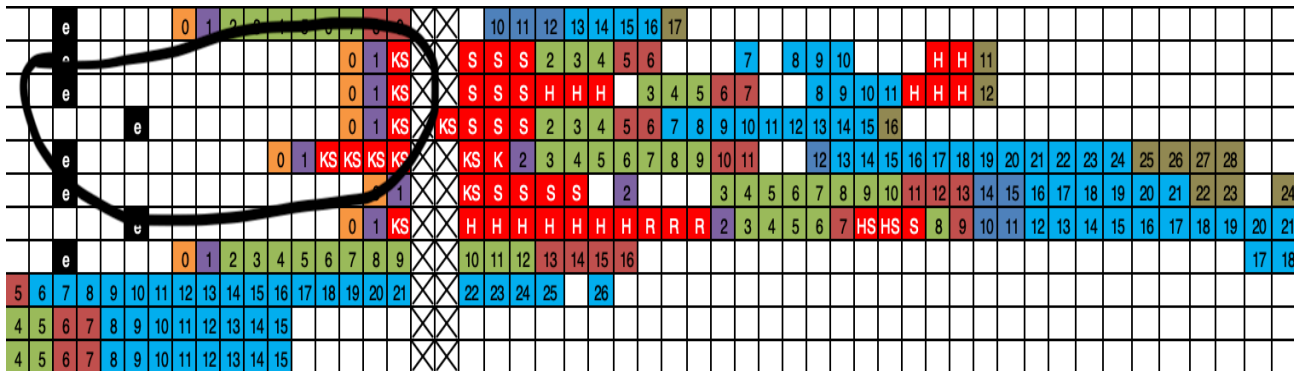


Figure 4.7: Portion of Gantt chart focusing on the work front gap issue

Initially, the engineering targets were required to finish before June’2016, but then they estimated new delivery dates, represented by **e** throughout the schedule. We know **0** represents that the documents are actually received. So, if we take a look at the circled section in the figure above, there was big differences in the estimated delivery date and the actual date of receiving the documents. Hence big delays with consequences with other works and resources, leading to delays in the overall project.

In an interview conducted with the project manager of the project, he says “for this particular incident, 12 weeks after they should have delivered the documents, we could do the data preparation, then wait until the inspectors were done with the KNR’s and we needed them to start the actual work in shop (in Dordrecht) and field work.” He later went on to say, “as you can see, there was big gap in work and a lot of red k’s. Hence, no work could be started up until then to do the actual work. All the projects were delayed. One of them does not make a real impact. The project was supposed to be finished by early July, but adding all the delayed work, then there is a big problem. And all this caused by Engineering not being on time.”

The change order had a cost value of € 52,460.00, which in itself is not much considering its impact on overall cost of only about 0.6%. But the entire cost of the project was initially planned for 9 million euros including an additional cost of 1.4 million euros due to the changes and additional work. This meant it alone contributed to about 3.75 % to the additional cost. The tables below serve as a reference for the cost impact.

CHANGE ORDER DESCRIPTION (Change 1)	CAUSE	COST VALUE	CONTRACT VALUE	PERCENTAGE IMPACT
Workfront gap	Lack of strategic planning by contractor	€ 52,460.00	€ 9,000,000.00	0.58 %

Table 4.13: Percentage impact of the change order on overall cost of the project

CHANGE ORDER DESCRIPTION	CAUSE	COST VALUE	ADDITIONAL WORK	PERCENTAGE IMPACT
Workfront gap	Lack of strategic planning by contractor	€ 52,460.00	€ 1,400,000.00	3.75 %

Table 4.14: Percentage impact of the change order on additional work

This brings us to other issues caused by the work front gap. **Two major changes** caused by the work front gap were staff changes and the involvement of an extra supervisor. The reason the project needed a new supervisor was because of wanting to start a package earlier (which was not fully prepared) due to earlier delays, which would be very challenging and thus required a dedicated supervisor.

It is important to realize that a lot of staff had to be relocated to different disciplines during periods of no work, as they were on payroll. Also, since this was rolling project, changes for staff were not agreed upon up front. Norbert says that “the scope of the project was not set in stone when we calculate our first staff estimate, since it was a rolling project. We thought we were going to have 26 work packages, turns out we had 38.” He goes on to say, “negatively it just had cost impact as a big effect”.

Staff change, one of the effects of the work front gap, was in itself a big change to the project. The change order for this change amounts to a massive € 128,436.00. Which meant that it alone contributed 1.42% to the overall cost of the project. Considering just the additional cost of the project, it had an impact of 9.175% towards cost increase. The tables below serve as a reference for the cost impact.

CHANGE ORDER DESCRIPTION (Change 2)	CAUSES	COST VALUE	CONTRACT VALUE	PERCENTAGE
Staff changes	Change of project scope and schedule by owner	€ 128,436.00	€ 9,000,000.00	1.42 %

Table 4.15: Percentage impact of the change order on overall cost of the project

CHANGE ORDER DESCRIPTION	CAUSE	COST VALUE	ADDITIONAL WORK	PERCENTAGE IMPACT
Staff changes	Change of project scope and schedule by owner	€ 128,436.00	€ 1,400,000.00	9.175 %

Table 4.16 - Percentage impact of the change order on additional work

The next issue as a result of the work front gap was the involvement of an extra supervisor. Norbert discusses that “this was because of the earlier changes, as we were going to do more things simultaneously. If it wasn’t for this change, then the project would have extended more. This was out of choice since it had cost impact, but a necessary one due to the many changes occurring at the same time.”

The change order for the extra supervisor had a cost value € 41,580.00. This had a lesser contribution to the overall cost of just about 0.5% and just about 3.0 % in the additional cost responsible for the cost increase. The tables below serve as a reference for the cost impact.

CHANGE ORDER DESCRIPTION (Change 3)	CAUSES	COST VALUE	CONTRACT VALUE	PERCENTAGE
Extra supervisor	Change of project scope and schedule by owner	€ 41,580.00	€ 9,000,000.00	0.46 %

Table 4.17: Percentage impact of the change order on overall cost of the project

CHANGE ORDER DESCRIPTION	CAUSE	COST VALUE	ADDITIONAL WORK	PERCENTAGE IMPACT
Extra supervisor	Lack of strategic planning by contractor	€ 41,580.00	€ 1,400,000.00	3.0 %

Table 4.18: Percentage impact of the change order on additional work

Step 2: Determine and demonstrate the effects of each significant change

After identification of the significant changes, the next step is to determine the effects of each change and demonstrate it in the form as proposed in figure 3.2

For the main change order ‘work front gap’, there was a lot of activity with the staff around and having situations of idle workforce. This meant managing them when there was no work and also motivating them for more work when there was sudden pressure in work schedule. Minor effects from the change include delayed use of tools and equipment while managing all connecting works due to delays was a major effect. When the project manager was asked about staff changes, Norbert responded “people working in the project work in different teams, answerable to different bosses, thus complicating things when there are changes in staff. This also meant there was an effect on connecting works”. While some resources required for construction are ordered as needed, most are ordered prior to construction to save on cost and prevent further delays. This meant delayed use of equipment and tools would cause for the tools and equipment to be at site longer than intended, hence cost increase.

Also, the Gantt chart is a planning mechanism to keep the flow of work in a continuous sequence which would allow for the project to be finished in the intended time. When the start of a work is delayed, the connecting works are also delayed. Hence, the effects from the work front gap include:

- Inadequate use of tools and equipment due to delayed periods of work
- Major delayed starts for works connected to the initial delayed works
- Idle workforce as a result of gaps in work
- Staff changes as a lot of staff had to be relocated to different disciplines
- Extra supervisor to cope with burden of extra work

The effects from the change are represented in the figure below.

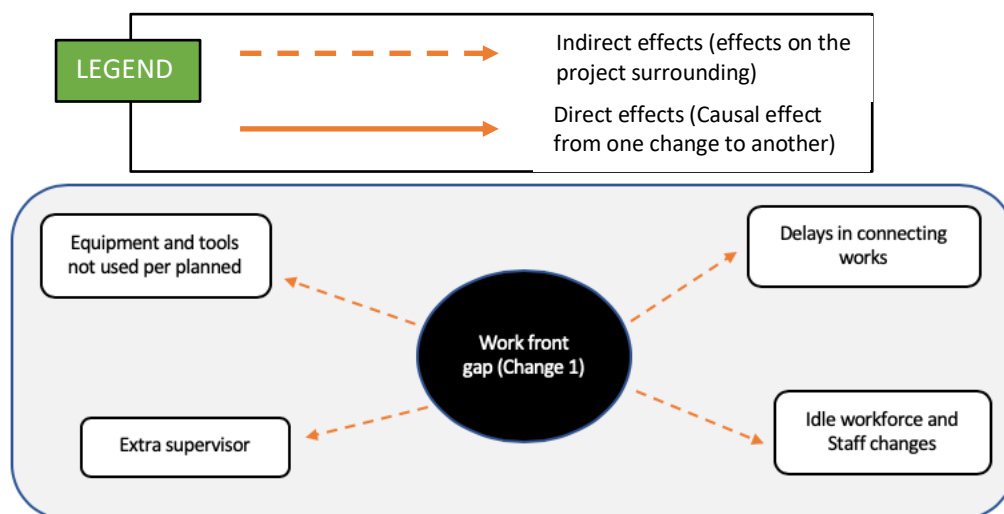


Figure 4.8: Effects of the change order ‘work front gap’

The two changes ‘staff changes’ and ‘extra supervisor’, resulting from one big change at the start ‘work front gap’, have their own impacts on the project environment in terms of resource utilization and changing the scope of work. This meant the project management team had to manage new complexities rising from changes in staff and work force. Changes in staff also had an effect on the use of tools and equipment available at site. Interestingly, the involvement of the new supervisor had a positive impact as the change helping to manage connecting works and manage some of the complexities rising from the changes. Thus, a situation where there is an introduction of a change to counter the negative effects from other changes. Although there was a counter effect of positive and negative impacts, there was causal effect from the work front gap onto the two changes, resulting in utilization of project resource due to the introduction of the changes. The effects from the two changes include:

- Complexities rising from staff changes
- Inadequate use of tools and equipment due to delayed periods of work
- Delays in connecting works due to delays at the start of the project
- Managing of complexities rising from staff changes
- Managing of delays in some of the connecting works

The changes along with their effects are represented in the figure below

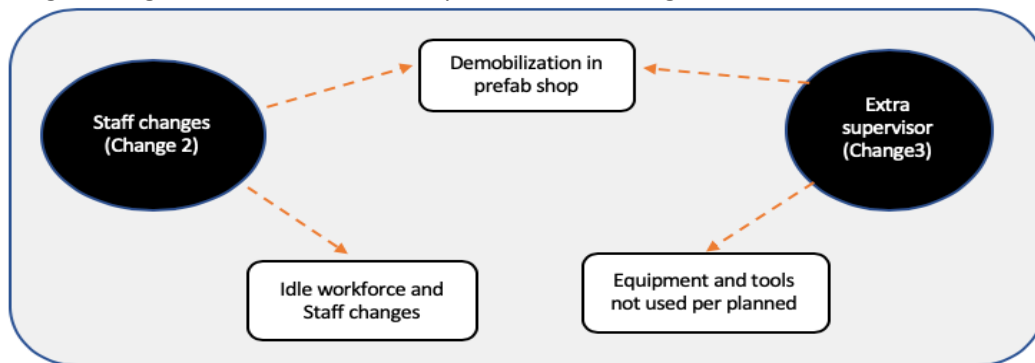


Figure 4.9: Effects of the change orders ‘staff changes’ and ‘new supervisor’

Step 3: Compare the figures to isolate the common and causal effects

After completing the first two steps, the effects are determined from the significant changes. This is followed by the next step where the figures are to be compared to isolate any common or casual effects among them. The changes are numbered 1 to 3, as previously discussed.

A detailed analysis of the effects from the changes show both causal and common effects among them. Change 1 (work front gap) has a causal relationship with change 2 (staff changes) and change 3 (extra supervisor), where one change is causing the other two. Also, change 1 and change 2 have a common effect of ‘inadequate use of tools and equipment’. This follows in the combination of change 2 and 3, which have the common effect ‘Complexities rising from staff changes’ and finally change combination 1 and 3 have the common effect ‘delays in connecting works’. Thus, there is interaction among the three changes as a result of which there is going to be sharing of the resources available, which may lead to cost increases as a result of requirement of more resources at the points of interactions. This would also mean that the project management team has to focus on a particular change at a time which allows for impacts from other changes at the same time. This may also result in changes of the project scope. Table 4.19 below shows the change combinations among the three changes having causal or common effects.

CHANGE COMBINATION	EFFECTS
Change 1& 2	Inadequate use of tools and equipment
Change 1& 3	Delays in connecting works
Change 2&3	Complexities rising from staff changes

Table 4.19: Common effects among different change combinations of the impactful changes

Step 4: Illustrate the common and the causal effects in the form of a model

Following determining of the common and the causal effects among the changes, the effects are illustrated based on the change interaction model (Fig.3.3) proposed in the procedure (section 3.2) to determine interactions. The common and the casual effects are shown below in Fig.4.10.

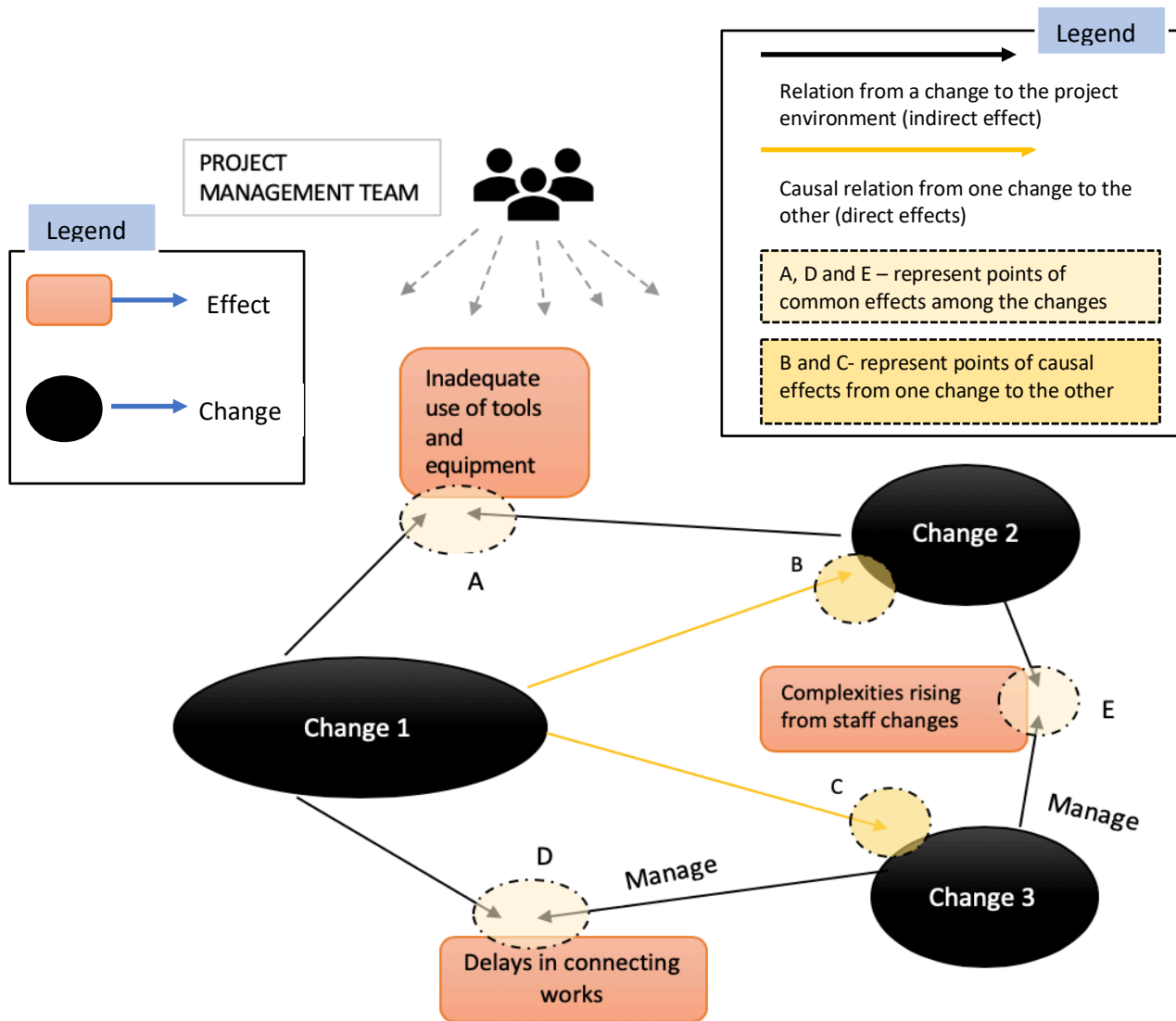


Figure 4.10: Visual representation of the causal and the common effects among the major changes

Step 5: determine the interactions from the illustration

Figure 4.10 shows the common and the causal effects among the changes. As learnt previously, both effects contribute to interactions. The points of common effects among the changes show indirect interactions while points of causal effects show direct interactions among the changes. Hence, A, D and E in the figure above show points of indirect interactions among the significant changes, while points B and C show points of direct interaction among the changes.

Point A shows indirect interaction among changes 1 and 2 due to both showing similar effects of 'Inadequate use of tools and equipment'. The same follows for points D and E. Point D shows indirect interaction among change 1 and 3, where change 1 is causing delays in connecting works while change 3 is managing some of those delayed works. For point E, Changes 2 and 3 show indirect interaction as change 2 causes complexities due to staff changes while change 3 manages some of the complexities. Moving on to the direct interactions, change 1 causes the occurrence of change 2 and 3, thus, showing direct interactions with the two changes, which in turn interact with other effects from other changes, showing indirect interactions.

4.2.3 Control measures

Having determined interactions among significant changes in the project, the occurrence of interactions at several points (A, B, C, D and E) reveal that the significant changes had a big impact on the outcome of the project. However, the project had a 6 weeks delay, although ENGIE Services West Industry expected the delay to be a lot more. In the interview conducted with the project manager, he revealed that the project management team had some controlling measure applied during the project in order to minimize the extent of the impact from the changes, as most of the work started later than estimated. He commented *"we had 3 members in the Quality Control (QC) department, we only needed two. So, if one of the changes occurred, one of those guys could come and help us. Same holds for the work preparator to keep everything on track, **communicating** with people the changes, by **adapting**, and controlling it within a small space. There is never a sure solution and a perfect answer. We must deal with the changes by adapting and communicating with one another and prepare for the change by not involving those not necessary but only communicating with the people necessary."*

The statements from the project manager regarding adaptability and use of communication suggest that adapting to changes along with good communication among the team members is key to deal with changes. However, in terms of the project manager, project success or failure does not have to only depend on change management. Further in the interview he gave an important insight *"in terms of failure or success on the project, it is not the same for all parties involved. For us, if the client was happy, we get paid, it's a success irrespective of the delays or anything else. Hence, if we have three changes at a single time for example, then we talk to our client that we cannot resolve all of them, we can do three in 4 weeks for example, but since they are all occurring at the same time, we need 6-7 weeks in total"*, hence showing the importance of communication. He further commented *"If you keep your client in touch with everything and informed, then it is not a big problem, thus, create a level of trust with the clients"*. The above statements reveal that a good line of communication and keeping a level of **trust** with the client is very essential. Keeping the client up to date with good reasoning for the delays would allow for focus on the right problem.

4.3 PROJECT 3

This project dealt with the construction of a new tank terminal in the Oil and gas industry, the Netherlands. The project was undertaken at Rubis Terminal, Welplaatweg 26, Botlek Rotterdam, The Netherlands. The client, **Rubis**, requested the installation of piping and electrical cables and cabinets for the equipment for 14 tanks along with the installation of the general automation. The main goal was to deliver a working plant for better work performance, supplying and manufacturing of pipes based on the design produced by third party along with the operational handover for shipment of client’s product.

General information regarding the application of the project, nature of work involved, actual contract size in terms of cost, ENGIE’s role within the project, number of man hours required to finish the work, different disciplines of work involved and the project manager guiding the entire project is provided in the table below.

GENERAL INFORMATION	
Application	Industrial site
Nature of the work	new construction
Estimated Contract Size	11.7 million euros
Additional work	1.42 million euros (estimate)
Final cost	13.6 million euros
Role within the project	main contractor
Contract form	Construction
Man hours	115,000
Disciplines	Detail design, prefab and construction, P&M, E&I, quality control handover including automation installation
Project manager	Alex Söntgerath

The project had a massive contract size of **11.7 million euros**, which meant ENGIE had to perform a lot of work in in various disciplines and provide solutions to the client in order to share their expertise in the field. The works in different disciplines and solutions are listed below as provided by ENGIE.

ENGIE SERVICE’S SOLUTIONS
<ul style="list-style-type: none"> • Setting up Scaffolding activities for the purposes of the work to be done • Supplying, assembling and manufacturing, piping works • Supplying, installing and connecting cable works • Assembling and connecting the instrumentation and fittings such as pumps • Testing and commissioning the installation • Preparing documentation handover and assisting client obtaining authority approval

As comprehended from previous two project cases, this one is no different to any other project with positive and negative aspects to it. The **POSITIVE** aspect was that ENGIE and the client, RUBIS, had very strong partnership. Hence, ENGIE took care of everything for RUBIS through ENGIE’s multidisciplinary approach. Also, thanks to the partnership between RUBIS and ENGIE, a cooperative relationship between the two emerged, resulting in successful completion of the project. ENGIE was also able to perform the necessary detailed engineering and able to change gear when necessary in

terms of extra manpower through their partners.

However, they had very short time to construct and install the pipes at site with major problems in the engineering documents containing the drawing for the pipes which, according to ENGIE, were not up to standards. This was the fault of the engineering company providing the drawings thus contributing to a big **NEGATIVE** aspect of the project.

4.3.1. DATA COLLECTION

The project had undertaken 229 change orders. ENGIE estimated the change orders to amount to a sum of 1.42 million euros. The estimated cost of the project was 11.75 million euros and the final cost amounting to 13.6 million euros. This shows that there was around 430,000 euros of impacts or more not accounted for. This means that the changes should amount to a cost of 1.85 million euros. However, it is not possible to analyse each and every change and determine for sure the impacts from a combination of changes in a very limited time frame. Hence, analysis must be done for the changes that had the most impact on the project and determine their interactions. As discussed earlier, the effects of every single change may vary from very low to high. This is why it is essential to single out the changes that may have interacted with other changes and the surrounding to cause a much larger combined impact on the overall project. The effects of these changes are very difficult to establish and prove, hence an expert interview was conducted with the project manager **Alex Söntgerath**, to understand the effects of the changes and determine the impacts from the significant changes.

The list of 229 change orders were narrowed down to 10 change orders based on their cost value. The change orders were listed from high to low in terms of their cost value (as seen in table 4.20). The causes for the changes were provided by the project manager from the list of significant change causes obtained from table 4.2 in the literature section (chapter 4). The impacts of the changes along with other information for the change order were found in the change order document with 229 listed change orders. The top change orders along with their change order numbers, description, date of issue, discipline, causes and impacts are listed in the table below.

#	CHANGE ORDER NO.	DESCRIPTION OF CHANGE ORDER	DATE OF ISSUE	DISCIPLINE	CAUSE	COST VALUE
1	ENGIE-VOR-063	Extension of time Rubis	Oct 19,2016	General	Change of project scope and schedule by owner	€ 235,369.50
2	ENGIE-VOR-002	TM-RUBIS-CWI-0001 VOR Heat tracing vapor lines.xls - Tracing & insulation vapor return line	June 21, 2016	E&I	Change of project scope and schedule by owner	€ 217,187.93
3	ENGIE-VOR-198	Expiration costs WTK; week 21 to week 42	Oct 21, 2016	General	Ambiguities and errors in specifications and drawings	€ 195,500.00
4	ENGIE-VOR-098, Rev. 2	Extension of time Rubis Vapor tracing- week 38 until week 42	Oct 21, 2016	General	Ambiguities and errors in specifications and drawings	€ 195,500.00
5	ENGIE-VOR-003, Rev. 1	TM-RUBIS-CWI-0002 Electrical cable lists	May 30, 2016	E&I	Ambiguities and errors in specifications and drawings	€ 190,844.70

6	ENGIE-VOR-007, Rev. 1	38 ISOS do not match the line list (insulation)	May 20, 2016	P&M	Replacement of materials or procedures	€ 95,455.00
7	ENGIE-VOR-121	Excavation works to solves blocked cable conduit	Oct 4, 2016	E&I	Different site conditions	€ 83,515.21
8	ENGIE-VOR-059	Add isometrics Vapor in TLS and TTLS, and Tie-ins	Oct 11, 2016	P&M	Ambiguities and errors in specifications and drawings	€ 75,322.17
9	ENGIE-VOR-004	TM-RUBIS-CWI-0002 Instrument cable lists	April 26, 2016	E&I	Ambiguities and errors in specifications and drawings	€ 66,030.53
10	ENGIE-VOR-191	Adjustments vapor Return piping	Oct 18, 2016	P&M	Ambiguities and errors in specifications and drawings	€ 59,534.45
TOTAL						€ 1,414,256.0

Table 4.20: List of top 10 change orders based on their cost value (decreasing order of value)

The changes already add up to € 1,414,256, which is 78% of the additional cost of the project of €1.8million, with remaining 219 change orders contributing to 22% of the remaining additional cost. ‘ambiguities and errors in design’ is the dominant cause of the top changes occurring in 6 of the 10 changes. ‘Change of project scope and schedule by owner’ occurs in the top two changes followed by ‘replacement of materials’ and ‘different site conditions’ occurring once each

4.3.2. ANALYSIS

Keeping in line with the proposed procedure (section 3.2) to determine interactions among significant changes, following collection of data, an expert interview is conducted with the project manager. Hence, to test the application of the procedure and the proposed model, the following steps are followed:

Step 1: Identify the significant changes

In the interview session (Appendix E), the list was further narrowed down to 6 significant change orders that the project manager felt were most impactful in the project (table 4.21). Again, as seen in the other two case studies, the significant changes are not the top 6 but rather 6 of the top 10, emphasizing the nature of combined change impacts. The change orders along with their change order numbers, description, date of issue, discipline, causes and impacts are listed in the table below.

#	CHANGE ORDER NO.	DESCRIPTION OF CHANGE ORDER	DATE OF ISSUE	DISCIPLINE	CAUSE	COST VALUE
1	ENGIE-VOR-063	Extension of time Rubis	Oct 19, 2016	General	Change of project scope	€ 235,369.50

					and schedule by owner	
2	ENGIE-VOR-198	Expiration costs WTK; week 21 to week 42	Oct 21, 2016	General	Ambiguities and errors in specifications and drawings	€ 195,500.00
3	ENGIE-VOR-003, Rev. 1	TM-RUBIS-CWI-0002 Electrical cable lists	May 30, 2016	E&I	Ambiguities and errors in specifications and drawings	€ 190,844.70
4	ENGIE-VOR-059	Add isometrics Vapor in TLS and TTLS, and Tie-ins	Oct 11, 2016	P&M	Ambiguities and errors in specifications and drawings	€ 75,322.17
5	ENGIE-VOR-004	TM-RUBIS-CWI-0002 Instrument cable lists	April 26, 2016	E&I	Ambiguities and errors in specifications and drawings	€ 66,030.53
6	ENGIE-VOR-191	Adjustments vapor Return piping	Oct 18, 2016	P&M	Ambiguities and errors in specifications and drawings	€ 59,534.45
TOTAL						€ 822601.35

Table 4.21: List of multiple impactful changes in their change order format

The above changes, chosen by the project manager as the most impactful changes from the list of top ten changes, added a sum of €822601.35 to the additional cost with ‘ambiguities and errors in design’ being the dominant cause for the occurrences of the changes. The changes are further analysed in the next section.

This following section analyses the nature of multiple changes that occurred in the project, with focus on the major changes obtained from the interview with the project manager involved in the project. Here four changes affected the project such that two more had to be introduced (leading to major delays), with the four changes occurring simultaneously and interacting with one another. Commencement of work for the project began in the 2nd week of January 2016. The turnaround of the project was expected to be around 32 weeks but was extended to 42 weeks. The Gantt chart for the project, obtained from ENGIE (Fig.4.11), shows the turnaround period of the project along with various key events within the time frame.

Contractual work started 11th of January 2016. RFC (reinforced concrete) drawing from the engineering company were received on the 4th of Feb. Planning for prefabrication work took place towards the end of February with actual prefab work starting 3rd of March. This excluded area 8 of the project. Planning and actual prefab work of area 8 took place end of April. Prefabrication work (excluding area 8) were planned to be ready by May 11th with actual date being May 30 with prefabrication for area 8 actually being ready by mid-June. Construction of scaffolding work started mid Feb. Piping erection work started 21st of March with actual work ready by 19th of September. The month of September also had painting and tracing with electrical works following later as per work completion of prior activities. Extension of work, denoted by end week 46 (EW 46) in the month of November, shows the delayed period in the project. Please refer to the figure below.

INTERACTIONS AMONG MULTIPLE PROJECT CHANGES

| MASTER THESIS - ABHISHEK BORPUJARI, 4621654 |

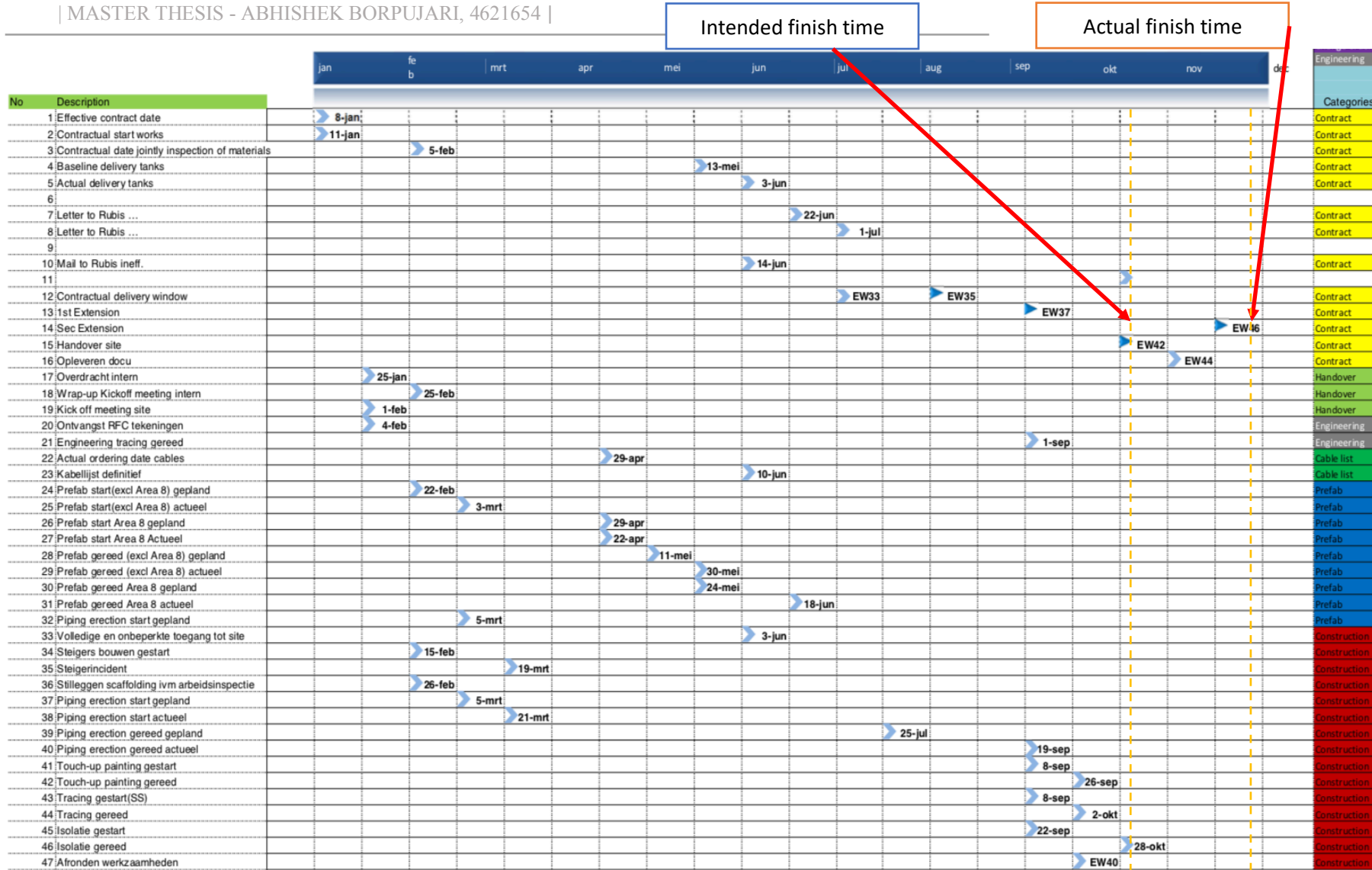


Figure 4.11: Gantt chart of the 'Rubis terminal' project undertaken by ENGIE

With around 20 change order requests coming in week 36 it shows a large number of changes occurred during the construction phase of the project. These changes occur in a particular week and tend to have effects for a longer duration affecting other changes that might take place in the following weeks. As per the project manager, most of them occur at the same time, which make it hard to isolate them and hence manage them. Figure below shows the number of interventions and change orders occurring per week, throughout the project

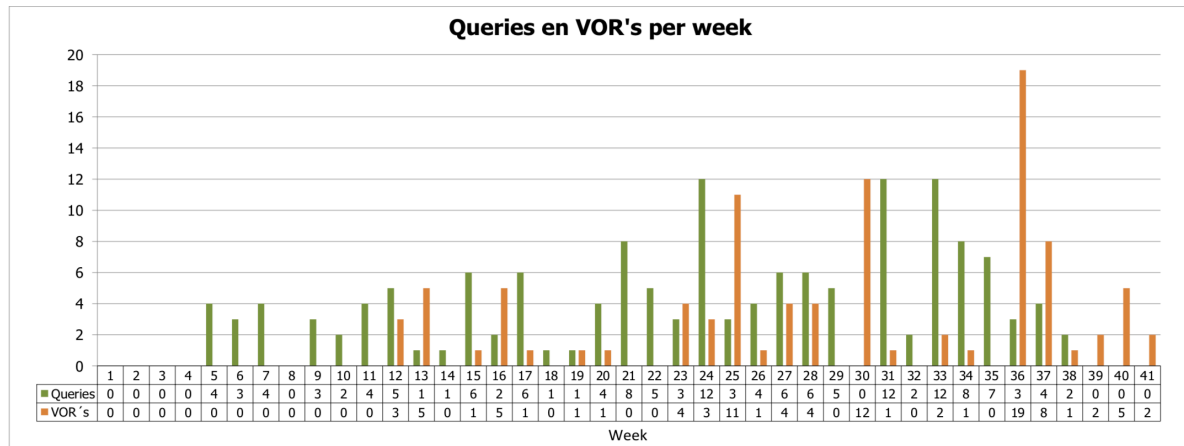
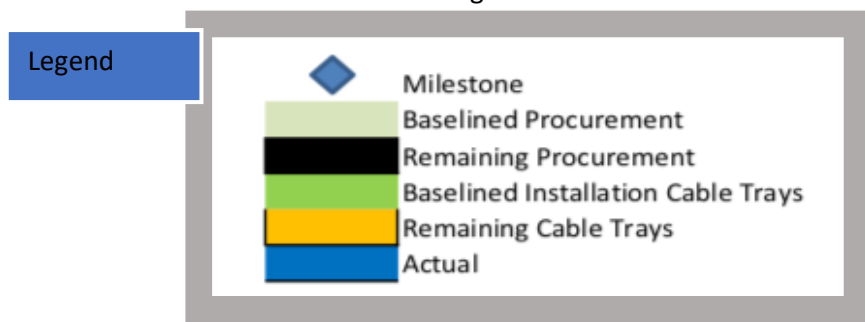


Figure 4.12: Representation of the number of change orders and interventions, per week, for the project

Going in depth with regards to the major issues, “Extension of time Rubis” was caused by the owner changing specific scope and specifications due to design errors in the electrical and instrument cable list and later delivery of the tank bund (‘tankput 6.2’). The change order was issued on October 19th, 2016. It is important to note that the change was mainly imposed as a result of two of earlier changes, “TM-RUBIS-CWI-0002 Instrument cable lists” and “TM-RUBIS-CWI-0002 Electrical cable lists”. The engineering company, responsible for the design of the cables in collaboration with ENGIE, measured the cables in 2-D space and not in 3-D. This meant ENGIE had to order cables during construction phase and redesign the whole cable lists. The extension was also as a result of various other engineering issues and limited or no access to site at times and additional work included up to week 22.

Fig.4.13 shows the actual document obtained from ENGIE regarding ‘Delay by later order of cables and later delivery Tank bund 6.2’. The baseline delivery of tank well 6.2 and 7.1 was set for week 19 but was actually delayed to week 22. Contract planning was set to 33 weeks with delays beyond that due to engineering or cable issues or a combination of both. Limitations to site shows a milestone delay by 20 weeks at BW 22 (beginning of work at week 22). Final documentation was at EW 39 (end of works at week 39). There was also delay with later ordering and delivery of the cables due to design error, with actual cable ordering date set around 16th to week 17th, whereas the actual ordering date was set to be mid-December to 1st week of January. The cables were delivered by week 37, a major delay. Please refer to the box below as a reference to the figure.





Vertraging a.g.v. latere bestelling kabels en latere oplevering Tankput 6.2



Extension of time Rubis Terminal RT-2

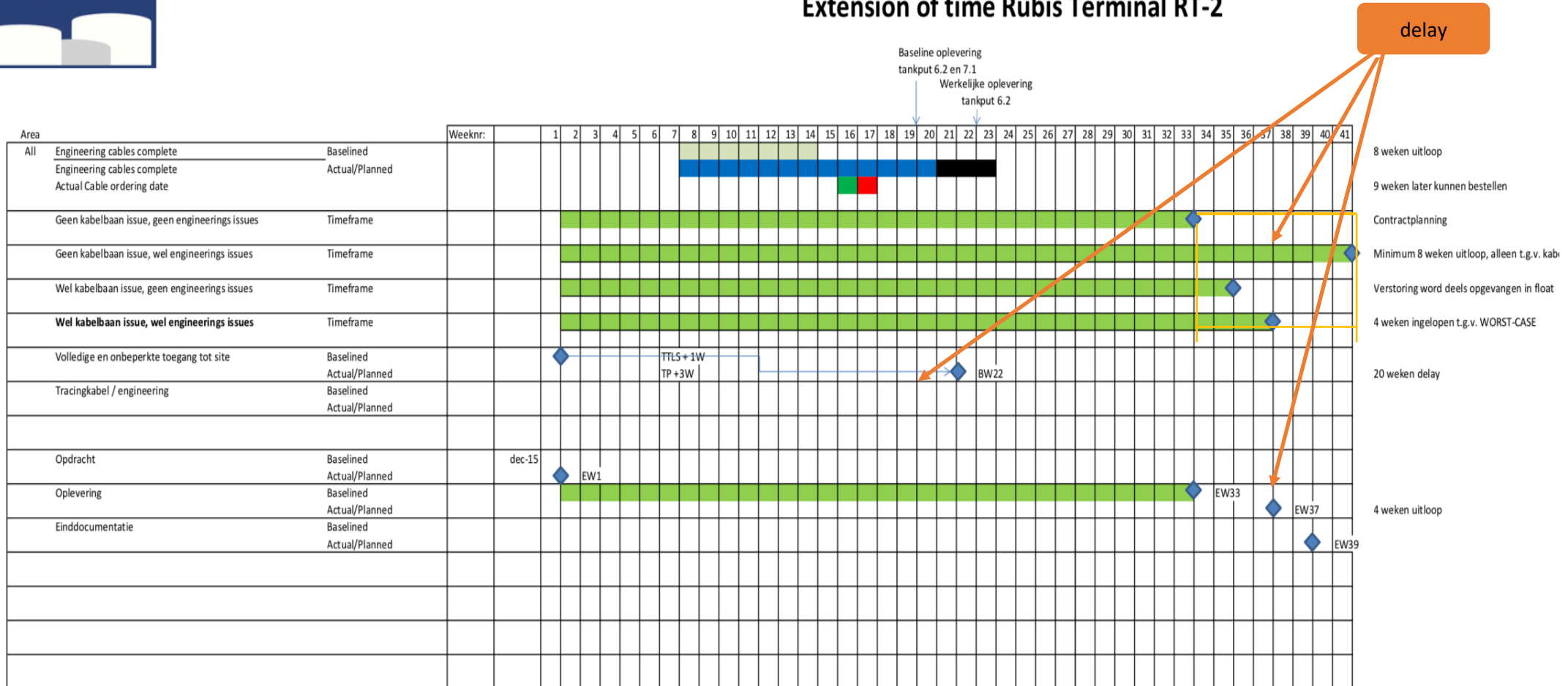


Figure 4.13: Document showing the delay resulting in 'Extension of time Rubis' change order

The change order had a value of € 235,369.50. With € 1.8 million in additional work, the change itself contributed to 13.8 % in additional cost increase and 1.74 % to the whole contract value. The tables below serve as a reference.

CHANGE ORDER DESCRIPTION (Change 3)	CAUSES	COST VALUE	CONTRACT VALUE	PERCENTAGE
Extension of time Rubis	Change of project scope and schedule by owner	€ 235,369.50	€ 13,600,000.0	1.738%

Table 4.22: Percentage impact of the change order on overall cost of the project

CHANGE ORDER DESCRIPTION	CAUSES	COST VALUE	ADDITIONAL WORK	PERCENTAGE
Extension of time Rubis	Change of project scope and schedule by owner	€ 235,369.50	€ 1,800,000.0	13.8 %

Table 4.23: Percentage impact of the change order on the additional work

The next key issue “Expiration costs WTK; week 21 to week 42” was majorly imposed due to two preceding changes. Caused by errors and ambiguities in design, this was mainly the extra staffing cost from week 21 to week 42 due to extra work and a desperate attempt of reducing any delays, hence speeding up work to keep the project on track. The two changes preceding this change “Add isometrics Vapor in TLS and TTLS, and Tie-ins “and “Adjustments vapour Return piping” were caused due to errors and ambiguities to design specifications in the Piping and mechanical (P&M) disciple. There were design errors in piping specifications for vapour returning pipes which eventually lead to additional work resulting in schedule extensions and extra staffing costs.

The change order had a value of € 195,500.0. With € 1.8 million in additional work, the change itself contributed to 10.9 % in additional cost increase and 1.43% to the whole contract value. The tables below serve as a reference.

CHANGE ORDER DESCRIPTION (Change 6)	CAUSES	COST VALUE	FINAL CONTRACT VALUE	PERCENTAGE
Expiration costs WTK; week 21 to week 42	Ambiguities and errors in specifications and drawings	€ 195,500.00	€ 13,600,000.00	1.43 %

Table 4.24: Percentage impact of the change order on overall cost of the project

CHANGE ORDER DESCRIPTION	CAUSES	COST VALUE	ADDITIONAL WORK	PERCENTAGE
Expiration costs WTK; week 21 to week 42	Ambiguities and errors in specifications and drawings	€ 195,500.00	€ 1,800,000.00	10.9 %

Table 4.25: Percentage impact of the change order on the additional work

After identification of the significant changes, the next step is to determine the effects of each change and demonstrate it in the form as proposed in figure 3.2

Step 2: Determine and demonstrate the effects of each significant change

The two issues responsible for ‘Extension of time Rubis’ were caused as a result of ambiguities and errors in design by the engineering company (responsible for the designing of the cables). According to ENGIE, ‘Extension of time Rubis’ resulted in a 10-week delay for the entire project. However, as per the project manager, the delay was not only as a result of the two prior changes but due to minor effects that resulted from ‘Extension of time Rubis’. **Alex** commented, “As the designs by the Engineering firm were faulty, we had to order cables and redesign it ourselves, which had cost and time impact along with additional work, meaning gathering resources from other disciplines and areas of the project.” He further commented, “It is crucial to remember that these changes were all being carried out at the same time as other changes, thus working on a specific change meant stalling other works connected to this work, which meant further delays.” He later also revealed that there were extra staffing costs also due to additional works. Also, limited accessibility to site at times led to further delays. Hence, the effects from the change include:

- Design issues with cables leading to ordering of materials and redesigning the cable
- Delays in connecting works due to later delivery of cables, design issues and limited accessibility to site at times
- Additional work resulting in extra staffing costs and schedule extensions

The effects from the change are represented in the figure below. Please refer to the legend as a reference to the figure.

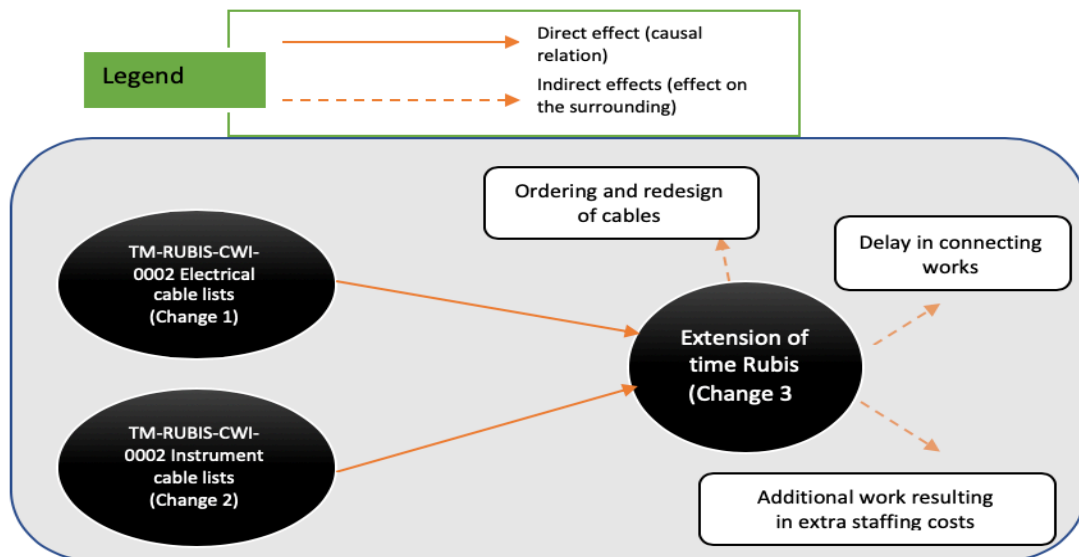


Figure 4.14: Causal relationship of two changes on change order ‘Extension of time Rubis’ and its effects

For the next major change order ‘Expiration costs WTK; week 21 to week 42’, the two changes responsible for its occurrence ‘Add isometrics Vapor in TLS and TTLS, and Tie-ins’ and ‘Adjustments vapour Return piping’ were design errors in P&M discipline and together added € 134,856.0 to the project. The specific delay from the combined changes is not known to the project manager as he reasons “it is very difficult to isolate and give information about the changes among a large number of changes. There are so many changes occurring at a single time, determining a single impact is very difficult.” However, there were few effects resulting from the major change ‘Expiration costs WTK; week 21 to week 42’.

The project manager elaborated on it, saying that “due to errors in design of the pipes, there was additional work of redesigning and re-ordering of piping materials. This meant ENGIE had to order new materials and re-design the pipes as per required specifications. This is very similar to the last change”, referring to ‘Extension of time Rubis’, where ENGIE had to order and redesign the cables due to design errors. He continued, saying “there was stalling of other works connected to this discipline. This meant having to add extra resources to one discipline while limiting them in other disciplines, as they were all occurring at the same time and finally additional costs in hiring more people resulting in extra staffing costs and schedule expenses “. Hence, the effects from this change include:

- Ordering and redesigning of piping materials due to later delivery of materials and design errors
- Additional work resulting in extra staffing costs and schedule extensions
- Delays in connecting works due to errors with the piping materials.

The effects from the change are represented in the figure below.

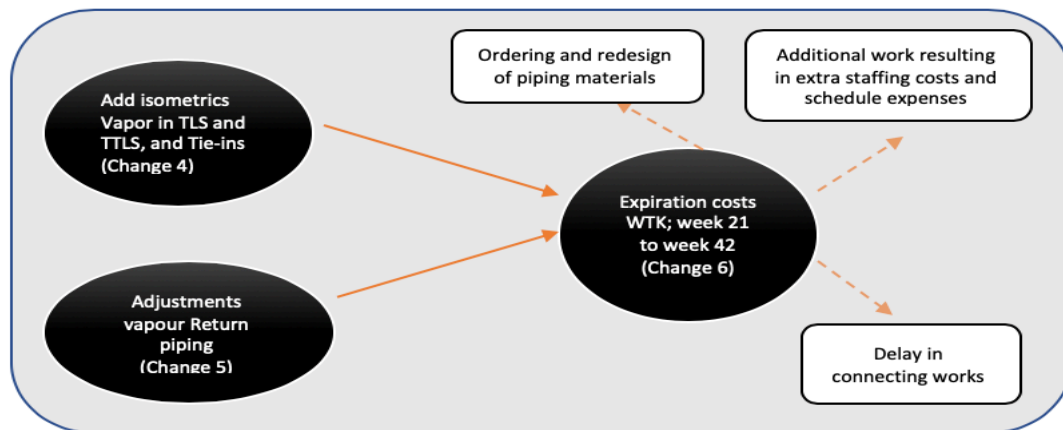


Figure 4.15: causal relationship and effects of two changes on change order ‘Expiration costs WTK’

Step 3: Compare the figures to isolate the common and causal effects

The first two steps of the procedure are followed by the third step, where the figures are to be compared to isolate any common or casual effects among them. The changes are numbered 1 to 6, for reasons as previously discussed.

The case study shows the major changes interacting with one another due to similar effects and resulting dependence on resources, while also showing a direct causal relation with other changes. Here Change 1 (TM-RUBIS-CWI-0002 Electrical cable lists) and change 2 (TM-RUBIS-CWI-0002 Instrument cable lists) have a direct causal relation to major change 3 (Extension of time Rubis). This follows for change 4 (Add isometrics Vapor in TLS and TTLS, and Tie-ins) and change 5 (Adjustments vapour Return piping) having a direct causal relation to major change 6 (Expiration costs WTK). Also, change 3 and change 6 commonly share the effects of ‘Delay in connecting works’ and ‘Additional work resulting in extra staffing costs and schedule expenses’, thus showing a direct effect on the surrounding while interacting with one another.

Thus, there is common and causal effects among the three changes as a result of which there is going to be sharing of the resources available, which would mean the greater demand for resources among the changes showing the effects. Table (4.26) shows the change combinations among the changes having causal or common effects.

CHANGE COMBINATION	EFFECTS
Change 1 & 2	Extension of time Rubis
Change 4 & 5	Expiration costs WTK; week 21 to week 42
Change 3 & 6	Delay in connecting works, Additional work resulting in extra staffing costs and schedule expenses

Table 4.26: Common effects among different change combinations of the impactful changes

Step 4: Illustrate the common and the causal effects in the form of a model

Now that the common and the causal effects have been determined, the effects are illustrated based on the change interaction model (Fig.3.3) proposed in the procedure (section 3.2) to determine interactions. The common and the casual effects are shown below in Fig.4.1

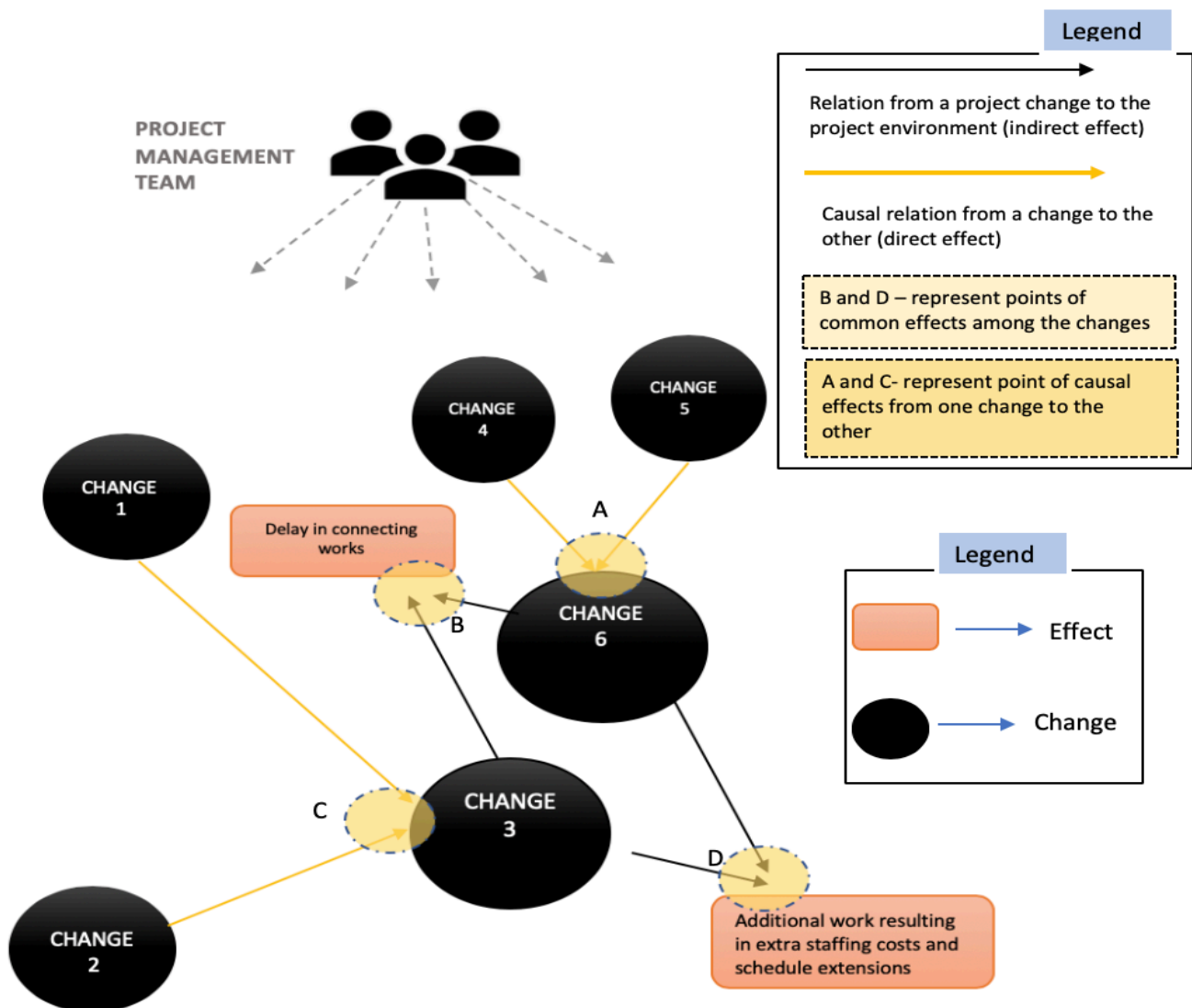


Figure 4.16: Visual representation of the common and the causal effects among the major changes

Step 5: determine the interactions from the illustration

Fig.4.16 shows the common and the causal effects among the changes. By now, we know that the points of common effects among the changes show indirect interactions while points of causal effects show direct interactions among the changes. Hence, B and D in the figure show points of indirect interactions among the significant changes, while points A and C show points of direct interaction among the changes.

Point A shows direct interaction to change 6 from two changes, 4 and 5, due to a causal relationship. This follows for point C, where changes 1 and 2 cause change 3, thus showing direct interaction. There is indirect interaction at points B and C, where changes 3 and 6 have similar effects of causing delays to connecting works and extra staffing costs and schedule extensions as a result of additional work respectively.

4.3.3 CONTROL MEASURES

It is hardly a surprise that there were control techniques applied throughout the project, considering the number of changes that occurred. The project had 10 weeks delay, however, as per ENGIE Services West Industry, the delay could have been much more had there been no intervention from the management side to mitigate the effects of the changes.

In the interview, the project manager was adamant regarding the aspects of **communication** and **adaptability** with the team, the managers involved and certainly the client. He suggested that there must be an openness and transparency within the system to allow for developing a level of **trust**, which eventually leads to efficient communication among the team. This helps to manage complex situations much more competently. When asked about specific control techniques used in the project, he replied " *that depend on the type of answer you are looking for. This project was undertaken almost 3 years ago, so it is not possible to remember any technical control measure or method. There were so many changes happening in so little time that is not possible to remember managing each and every change or the techniques used. But yes, if you want a general answer (with regards to multiple changes), we have to adapt to changes. It is very essential to adapt. We have to be ready to accept that there will be changes and think what we can do now. This is also why communication matters, as you can then involve your team members and staff along with the change by communicating with them, developing a level of trust within the team, with the clients.*

His responses suggest the need to accept when there are changes and communicate with the team and the clients about what can be done regarding the change. A level of trust develops when the team and the client(s) are involved in big decisions, which will help to manage situations of multiple changes.

5. RESULTS OF THE CASE STUDIES

In order to validate the applicability of the proposed procedure (section 3.2), it had been subjected to three case studies, three projects undertaken by ENGIE. This was done to test the procedure to determine if real project changes can show interactions following the steps in the proposed procedure. The results of the case studies have shown to be able to illustrate the interactions among the major changes and have been summarized below.

5.1 CASE STUDY 1

The **first** case study was on a project that dealt with the construction of a new gas treatment installation at the oil and gas industry, The Netherlands. Applying the steps of the proposed procedure resulted in determining three significant changes. Outlining the effects of the three changes and finally combining the changes with similar effects show four change combinations with common effects at four points, represented by points A, B, C and D. The points of common effects show indirect interactions among the changes as illustrated below.

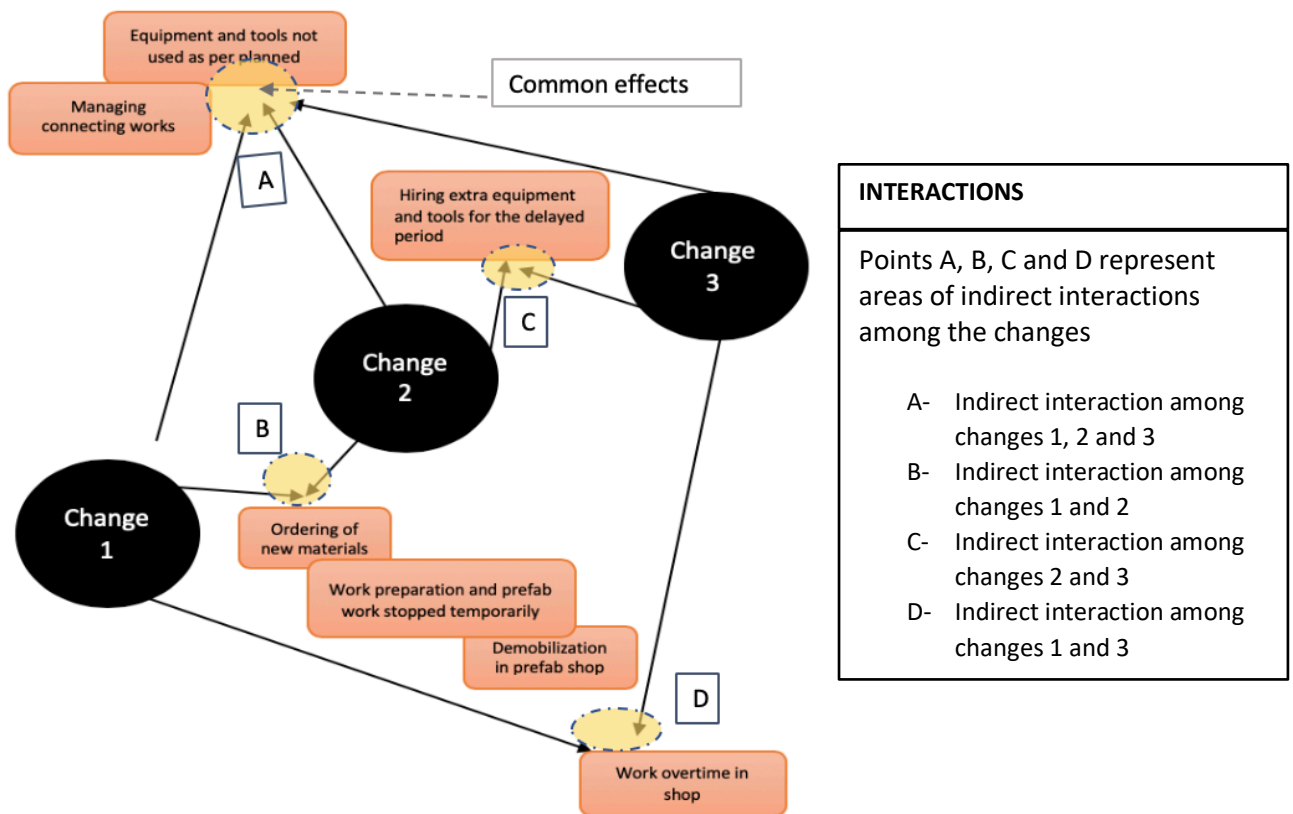


Figure 5.1: Illustration of common effects among the changes (project 1)

5.2 CASE STUDY 2

The **second** case study was on a project that dealt with the construction of SDA-WS3 in the oil and gas industry, The Netherlands. Like the first project, applying the steps of the proposed procedure resulted in determining three significant changes. Determining the effects of the three changes and finally analysing the changes show similar and causal effects among the changes. The points of the effects among the changes are represented by A, B, C, D and E which also represent points of direct and indirect effects among the changes. Fig.5.2 illustrates the interactions.

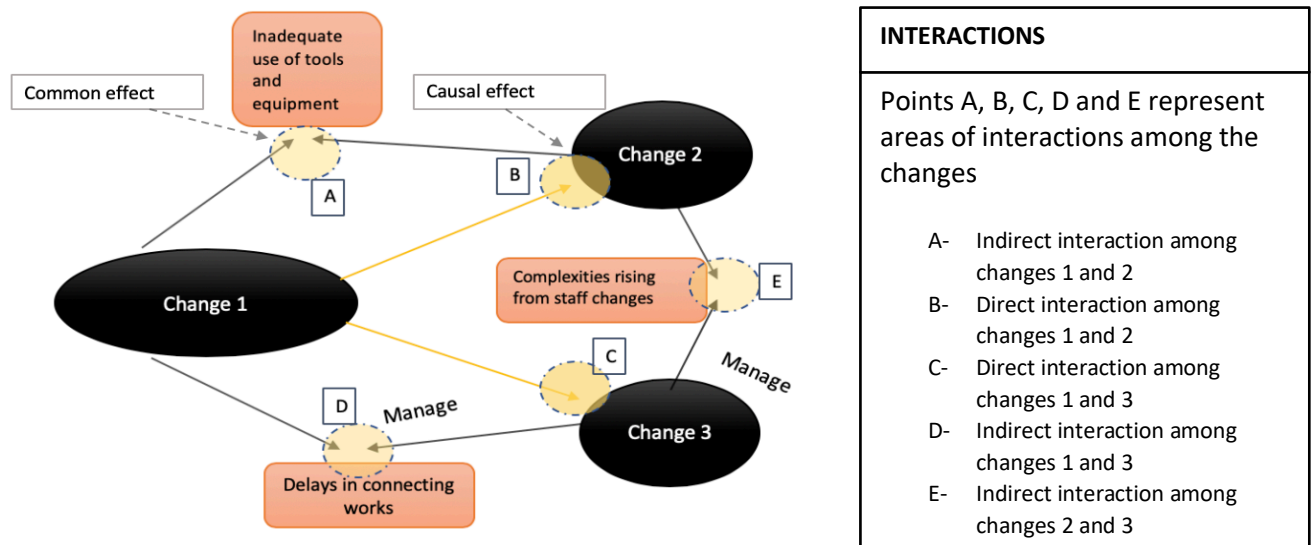


Figure 5.2: Illustration of common and causal effects among the changes (project 2)

5.3 CASE STUDY 3

The **third** and the final case study was on the project that dealt with the construction of a new tank terminal in the Oil and gas industry, the Netherlands. There were six significant changes, with four of them causing two major changes. The changes share common and causal effects among one another and are marked by points A, B, C and D. These points represent direct and indirect interactions among the changes and are represented below.

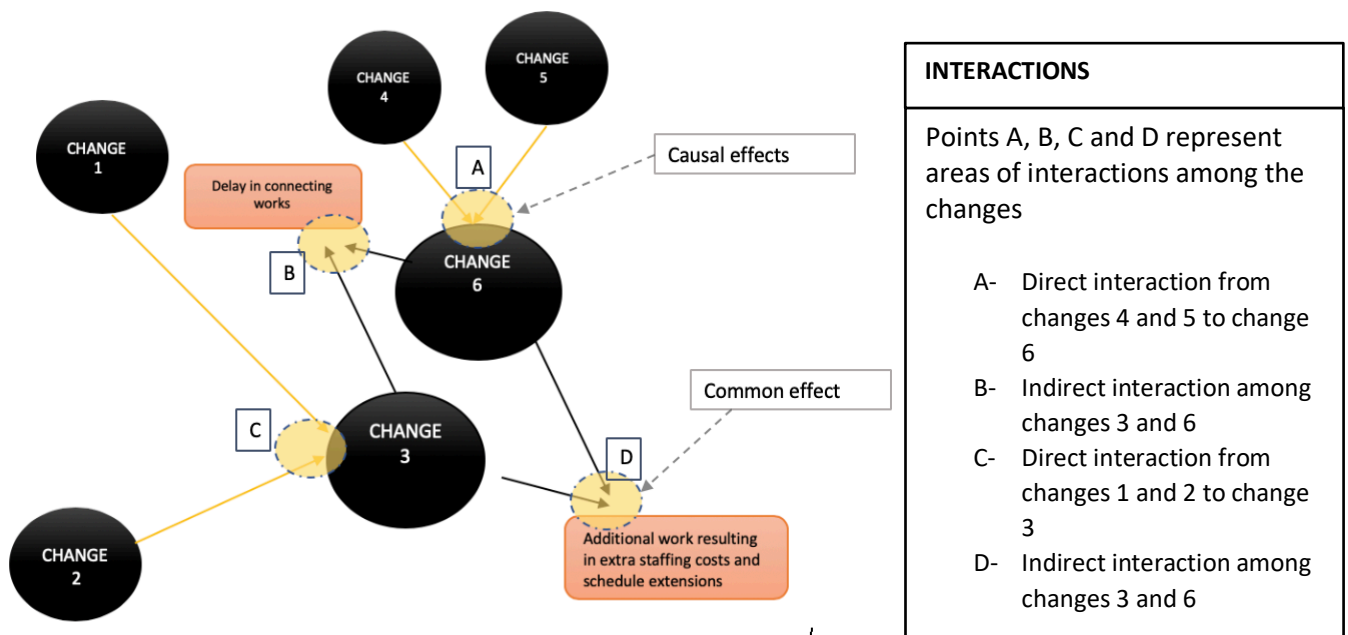


Figure 5.3: Illustration of common and causal effects among the changes (project 3)

The three cases show positive results with regards to the use of the proposed procedure to determine interactions among changes in real projects. The steps of the procedure leading up to the change interaction model were thoroughly scrutinized to get the best possible results out of them. All the three projects show interactions among their significant changes, which rightly suggest that the procedure works (with various limitations, to be elaborated in chapter 7). The first project shows indirect interactions among all their significant changes while the second and the third project show both the direct and indirect interactions among their significant changes.

6. DISCUSSIONS

The research focussed on finding a method that determines and shows the interactions among multiple project changes which may lead to their cumulative impacts on projects. After a detailed literature review on several subjects that deal with multiple changes and their cumulative impacts, an understanding on the behaviour of the considerable multiple changes was developed. This understanding provided the basis for the development of a new procedure leading to a change interaction model that shows the direct and the indirect interactions among the changes. The procedure had been applied step by step in the case studies to examine its applicability in real projects. The results show that it is very much applicable, but with several limitations.

Going back to the start of this research and highlighting the problems of determining and showing interactions among changes, the focus of the research points to exactly solving this problem. However, in the interview sessions with the project managers of the three projects, there was an indication that the project managers have quite an idea regarding the occurrence of interactions among the changes. Not exactly where, how or why, but an idea that there were interactions among the changes, leading to consumption of resources. When the project manager of the first project was asked to comment on interactions, he said *“when multiple changes occur in the same time frame (or close to one another), there is sharing of the available resources, tools or equipment. This is regardless of any similarity between the changes and is due to having a common project management team. Hence, you could say this is a form of an interaction”*. This was followed by similar replies in the other two interviews. Norbert replied *“obviously there is interaction among the changes when they are many occurring together. Changes depend on common resources and to manage them there is usually one project management team with the task of handling all the changes. You can see the problem’*.

Interestingly, the general idea among the project managers is that the occurrence of multiple changes in a similar time frame (or close to one another) lead to their interaction as they share common resources, regardless of the discipline or any similarities among them, and the problem lies in having a common project management team. **There is a general understanding regarding the problems faced by the project management team without a clarity towards the reason for the interactions** or how exactly do they impact the project or why indeed should interactions matter. The results of the cases clarify the above problems. Yes, the project management team has a lot of problems when multiple changes occur as they not only have to manage these changes, they also have to continue their own day-to-day activities as required initially by the project. The team has various tasks to execute other than just to manage the changes. But moving on, the interactions among the changes occurring regardless of any similarities among them or due to having a common project management team is not entirely true as the case studies show that they occur due to two reasons; causal effects from one change to the other and similar effects among the changes, leading to two types of interactions; direct and indirect. **The changes interact first due to similar or causal effects and then there is sharing of the resources at points of interactions.**

To further understand the concept of interactions, the cumulative theory of multiple changes follows a synergistic design approach which focuses on the interactions between the parts within a system leading to developing synergies, in other words, the combined impacts from the changes turn out to be more than estimated, resulting in a lower productivity. The interactions lead to consumption of additional resources and follow different types of relationships within the parts as learnt in the literature section (Chapter 2, section 2.6.2).

To elaborate further on this, consider a project with various works in two sections (A and B) with a few major and minor changes. Suddenly, there is an issue in section B in one of their project deliverables or works (parts in a system), which cannot be solved and hence there has to be a change. The new change has its effects onto other changes and the project environment. If in any

case the effects of this new change are similar with effects of any other change, there is an interaction, as a result of which the amount of resources has to be increased to fulfil the requirements of both the parts. Thus, a possibility of cost increases or delays. Figure 1 below shows an initial project with a few changes. Figure 2 shows the same project with a change introduction having common effects with another change. Hence, changes 1 and 3 of section B and A, respectively, have common effects leading to their interactions.

The example can be backed by the results obtained from the cases. Similar to the example which show common effects leading to interactions among changes, the results from the case studies show both direct and indirect interactions among changes, resulting from common or causal effects. A comparison between the example and the interactions obtained from case study 3 (section 4.3) is shown below.

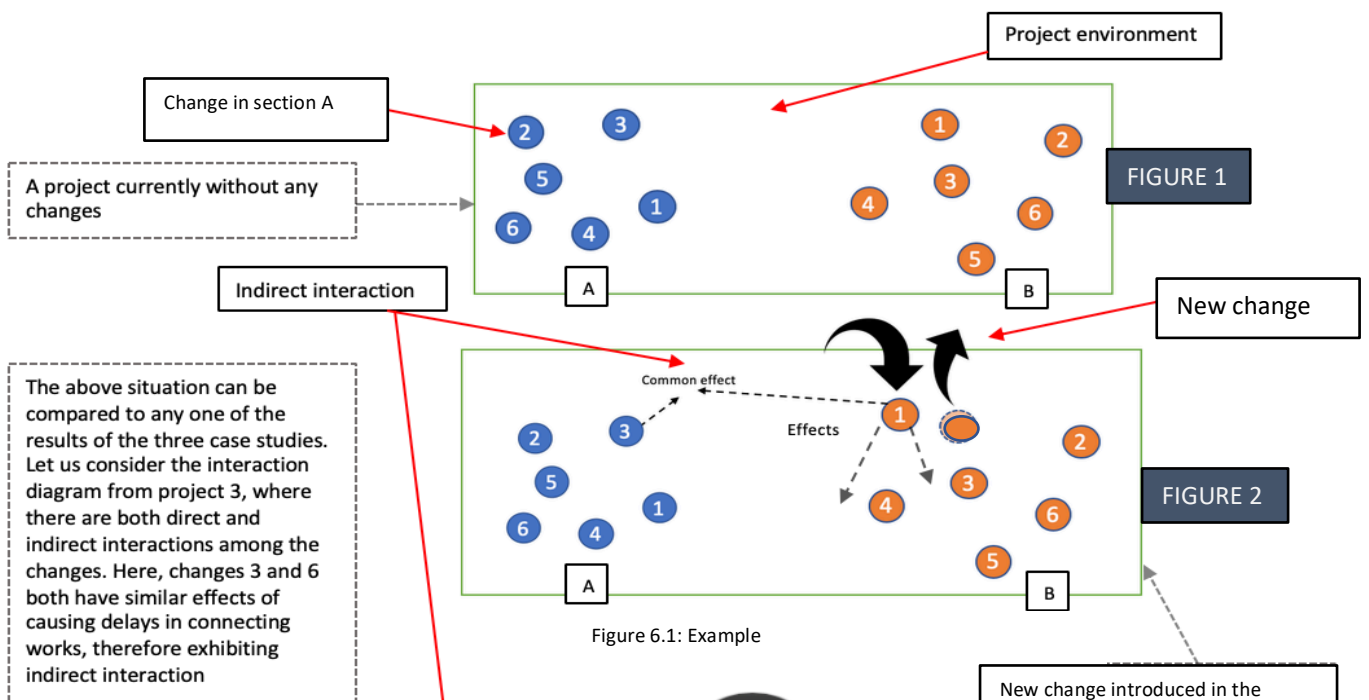


Figure 6.1: Example

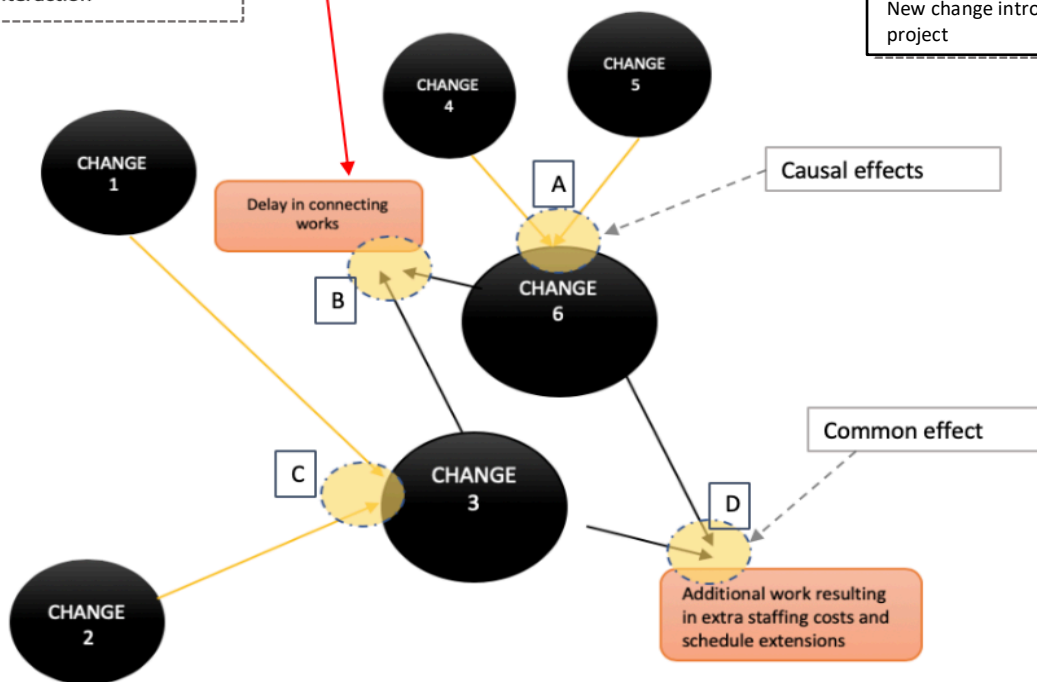
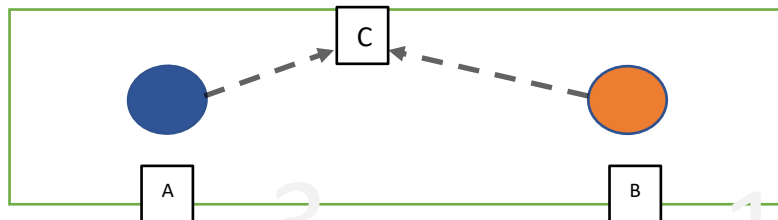
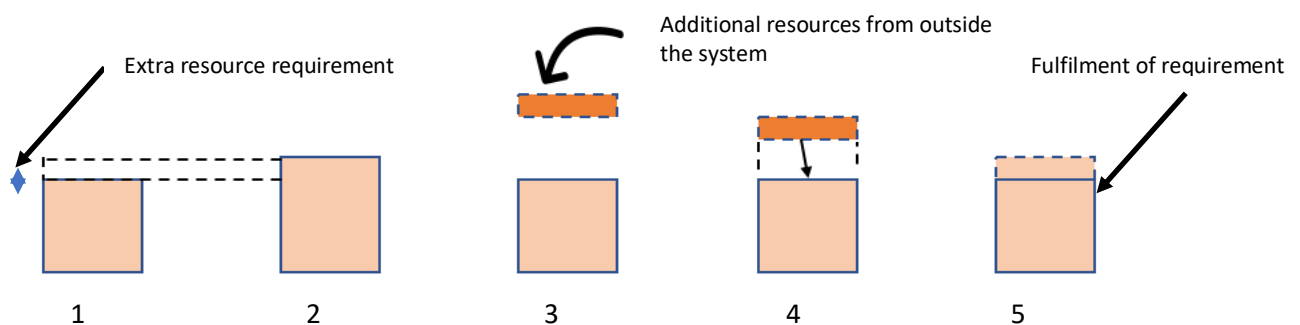


Figure 6.2: Results obtained from case study 3

Therefore, the comparison between the figures (Fig.6.1 and Fig.6.2) depict that at points of common effects, there is interactions among the changes. Having established that and referring back to the theory of cumulative effects of changes, at the points of interactions the amount of resources that would be required initially by the changes would increase since now both the parts would require the same amount of resources to fulfil its demand, due to the similar effect. Consider the same example (Fig.6.1), where changes 1 and 3 of section B and A have a common effect. Let 'C' be the common effect of requiring 6 long pipes.



Change 3 already had its effect of requiring 6 long pipes, prior to the introduction of change 1 in section B. Now, let's say, if in the planning phase of the project, the total amount of resources required for the entire project had considered 10 long pipes (including risks), so initially the effect of change 3 would be managed. However, due to the introduction of the new change having similar effect of requiring 6 long pipes, the combined requirement of long pipes is 12. This means that the project management team has to get two more long pipes to fulfil the combined requirement. Below is a representation of the same.



Numbers 1-5 represent the following,

1. Initial resource requirement of the project
2. New requirement due to interaction among the changes
3. Getting the required additional resources from outside the system (increase in project costs and delays)
4. Adding additional resources to the initial requirement
5. Fulfilment of required amount of resources

The illustration above shows that the combined effect from changes can demand more resources than estimated. Yes, it is very much a possibility that in real projects, the estimated is more than the combined requirement from a single interaction, but as the number of interactions increases, the requirement will increase and after a certain point, the amount of resource required will be more than estimated. Regarding the larger impact from an interaction, a requirement of 6 long pipes by one change and 6 long pipes by the other change would only mean a total requirement of 12 pipes and not 13. The requirement for an individual change cannot increase suddenly that it interacts with another change. Hence, the combined effects do not necessarily follow $1+1=3$, but rather **experience** a similar result as that of $1+1=3$, as suggested by Hester et al (1993). The only major impact it does is that the combined impacts could turn out to be more than what was estimated at the start of the project, since the number of changes and interactions per changes cannot be predicted up front. So, a project can only estimate considering the project deliverables and certain risks and as the number of interactions increases, demand for resources increases and as

a result there is more cost increases and delays.

In terms of productivity, we know, productivity = output/input and a project is less productive if its output is less than its input. Hence, if the input (which is resources- cost, time, people) increases and the output goes lower than estimated, productivity of a project will decrease eventually. So, as the number of changes in a project increases, the chances of interactions among the changes increases, as a result of which the demand for resources will increase at the points of interactions, which may eventually lead to lower project productivity as suggested by the self-destructive theory, where $1+1 < 2$.

Another important aspect covered in the case studies was the control measures applied by the project managers in their respective projects. The three project managers share their experience on the control methods applied to manage the changes. They share a similar view on the **adaptability, communication** and **trust** aspects of management. Managers must accept and adapt to changes, communicate with the team members and the clients and finally build trust among the team to handle changes. This is crucial to maintain a fine balance between the client requirements and project delivery. What this also suggests is that it may not always be necessary to try solving all the issues, but rather to keep the client informed of the issues and the delays that might occur as a result of the issues and changes.

7. CONCLUSIONS AND RECOMMENDATIONS

In this chapter, the conclusions of this research are presented along with answers to the main research question and sub- questions, followed by recommendations.

7.1 CONCLUSIONS

The **main objective** of this research was to find a solution to the problem currently occurring in the construction industry regarding the cumulative impact of changes. The theory on the cumulative impact of changes insinuate that the combined impacts of the changes are more than their individual impacts. Construction companies commonly face this issue and they **cannot** find a method to show these cumulative impacts in order to get compensated. Past research suggest that cumulative nature of changes follow a synergistic theory where **interactions** among the changes lead to their larger combined impacts (Ibbs, 2005), but there is need for determining and showing these interactions. Hence, the **goal** of the research was to develop a method to **determine and show interactions** among significant multiple changes in construction projects with the main focus to illustrate the effects and the relationships that originate from the changes. In order to do that, a procedure was developed from literature and research papers focussed on the cumulative impacts of multiple changes. To test its applicability in real projects, it was applied in three projects undertaken by ENGIE Services West Industry. The results show that the procedure **can only determine interactions** among changes, not the synergy resulting from it.

The procedure to determine and show interactions among changes was developed based on scientific theories regarding the cumulative impacts of changes. "Cumulative impact is the unforeseeable disruption of project productivity resulting from a 'synergistic effect' of a group of changes (Ibbs, 2015). Focusing on the synergistic effect, it suggests that a negative synergy results from the interactions amongst parts in a system which leads to lower productivity in a system, following a 'self-destructive relationship' where productivity expresses $1+1 < 2$. The self-destructive theory implies two types of relationships for interactions leading to direct and indirect interactions. The procedure, applied in three real projects, follows this theory to generate five steps to determine and show interactions, these are: **1) identify the significant changes 2) determine and show the**

effects of these changes 3) Isolate the common and the causal effects 4) illustrate the common and causal effects 5) Determine interactions from the illustration.

The **first** case study was on a project that dealt with the construction of a new gas treatment installation at the oil and gas industry, The Netherlands. In the interview conducted with the project manager, three changes were identified as significant. They were; change in pipe spec with a cost value of € 64,739; shortage of duplex materials costing € 84,508; delay in the supply of connecting cables costing € 265,000. The **second** case study was on a project that dealt with the construction of SDA-WS3 in the oil and gas industry, The Netherlands. The project manager discussed that there was an issue with a particular work front gap that led to other major changes like changes in staff, costing € 128,436 and hiring of an extra supervisor, costing € 41,580. The work front gap was the main issue with the change order for this issue costing € 52,460. The **third** and the final case study was on the construction of tank terminal in the oil and gas industry, The Netherlands. The project had undergone six major changes, with two very significant changes leading to delays and losses. 'Extension of time Rubis' and 'Expiration cost WTK' were the significant changes with cost values € 235,369.50 and € 195,500 respectively. 'Change in scope and schedule by owner' and 'ambiguities and errors in design' were the dominant causes for the occurrence of the highest cost value changes in the three projects.

The projects were analysed based on the steps in the proposed procedure (section). Results show interactions among the significant changes in all the three projects. The idea behind this is that there are two of relationship between changes and the project environment, that contribute to interactions leading to a negative synergy (Conner, 2011). A relationship between a change and the system environment show its effects which when shared with other changes lead to indirect interaction among them while a causal relationship between changes lead to their direct interaction (Corning, 2015). The first project shows indirect interaction while the second and the third project show both direct and indirect interactions among their significant changes. The case studies also provide information on the management of the changes during construction. The three project managers share their experience on the control methods applied to manage the changes. The three managers share a similar view on the **adaptability, communication and trust**. Managers must accept and adapt to changes, communicate with the team members and the clients and finally build trust among the team to handle changes.

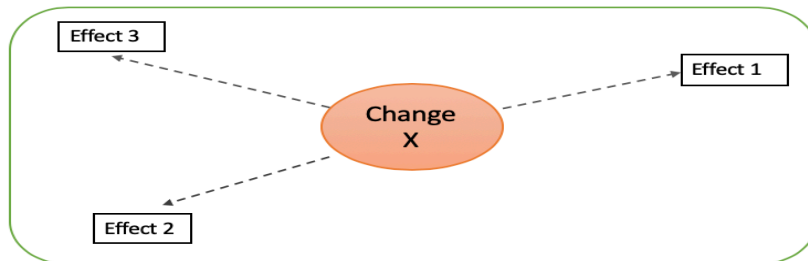
An important learning aspect of this research is that, at points of interactions, there is demand for resources due to changes showing causal or common effects. As the number of changes increases, the possibility of interactions among the changes will increase as a result of which total demand for resources will increase. Based on system theory, the only way to maintain equilibrium in the system is to get resources from outside the system in order to meet demands. This calls for the project management team to make some crucial management decisions. The increase in demand for resources leads to cost increases and delays, which may eventually lead to decrease in productivity as project input will slowly outweigh project output (due to self-destructive relationship: where productivity expresses $1+1<2$). Another important learning aspect was that the project managers already have an understanding regarding interactions among changes commenting that sharing of similar resources among changes lead to their interactions. However, findings from this research show that the changes interact first (due to common or causal effects) and then there is sharing of resources at points of interactions.

Finally, to conclude this research, the procedure applied in the three projects determine and show interactions among their significant changes. However, the resulting synergy cannot be shown due to lack of financial data and limited time. Determining the negative synergy, that may result from the interactions, could provide a way to actually prove the cumulative impacts from the changes. As for now, this procedure only stipulates an understanding for the cumulative nature of changes while providing a way for construction companies to show the extra demand for resources due to change interactions. A framework for construction companies to use the procedure is provided in the next section

7.1.1 Framework

STEPS TO DETERMINE AND SHOW INTERACTIONS AMONG CHANGES:

- 1- Identify the significant changes (or impactful changes)
- 2- Determine and show the effects of the above identified significant changes



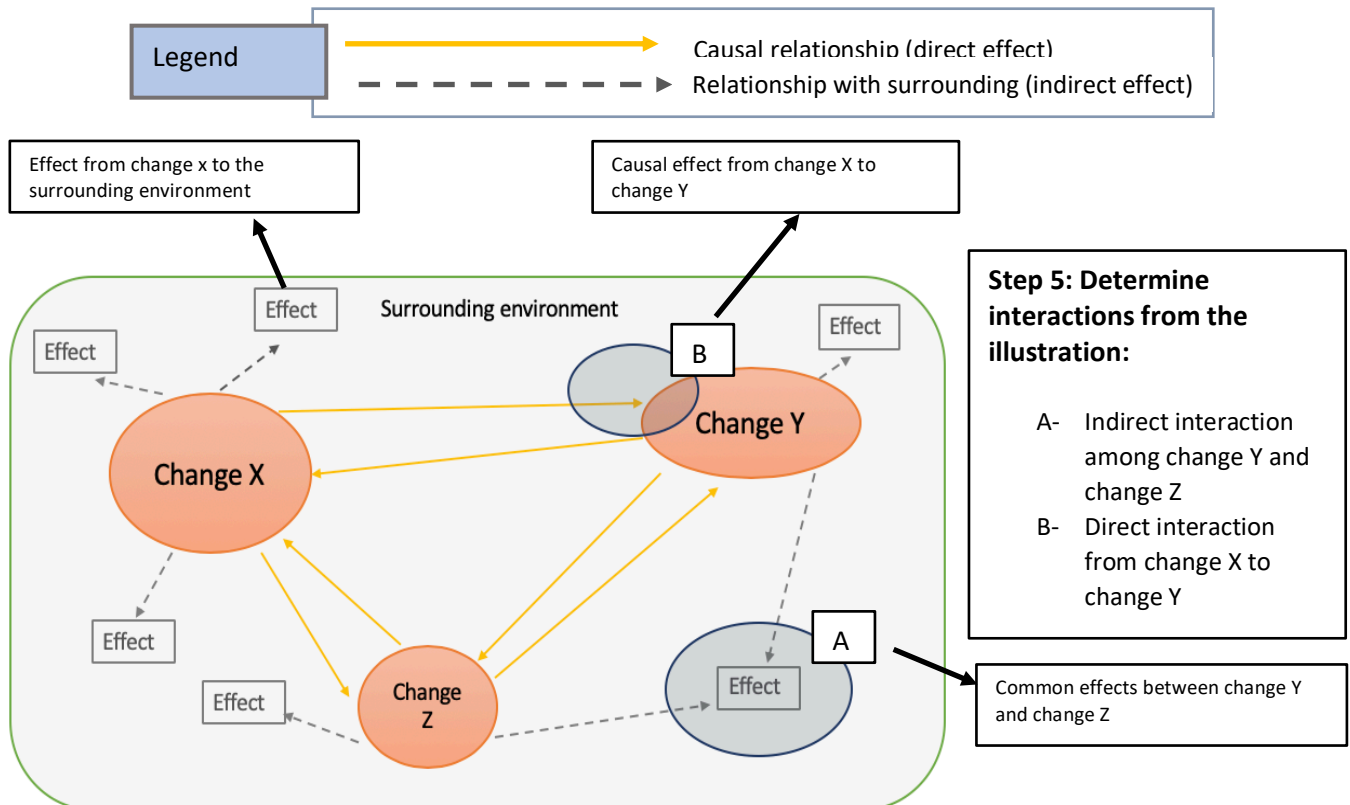
Key control techniques to manage multiple changes

- Communication
- Adaptability
- trust

- 3- Isolate the common and the causal effects

Change combination	Effects (common and causal)
Change X and Y	Common effect, causal effect
Change Y and Z	Common effect, causal effect

- 4- Illustrate the common and the causal effects



Output: The points of interactions show additional resource demand by the changes, which could serve as a reasoning for the extra costs resulting from the changes.

7.2. ANSWERS TO THE SUB-QUESTIONS

As discussed before, in order to answer the main research question, a series of sub-questions have to be answered. The sub-questions were prepared in the introduction chapter (section 1.3) that led to the main research question: *“How can the interactions among significant multiple changes in construction projects be illustrated?”*. The answers are provided below.

1. Sub-question: What can be found in literature regarding project changes and how can this information support to draft a new procedure that could determine interactions among changes?

Change are common interventions that often alter the scope of a project. Project changes occur in three stages; pre-design; design; construction. Agreed changes are formalized as change orders. Over 80 factors, spread out in 9 groups influence the occurrence of changes with ‘changes in plans, design specifications and scope by owner’ and ‘ambiguities and errors in design’, the most common factors. The changes result in cost increases, delays and decrease in project productivity. To manage this, there are several control techniques applicable in different stages of the project with effective change management principles. However, the effectiveness to manage changes decreases as the number of changes in a project increase.

Scientific theories on the cumulative impacts of multiple changes suggest that the decrease in project productivity with increase in multiple changes is due to the larger combined impacts of individual changes that result from a synergistic effect of changes. This synergistic effect is due to the interactions among the changes as synergy theory imply that interactions among parts in a system lead to synergy. The theory also implies that the interactions show a self- destructive type of relationship where productivity shows $1+1 < 2$. This relationship shows two types of interactions: direct and indirect, caused by two types of effects due to two types of relationships. Using this information, a new procedure can be drafted that could show the interactions among the changes using the two types of relationships and showing the effects that lead to interactions among changes.

2. Sub-question: How can the proposed procedure determine interactions among multiple changes?

Applying learnings from literature, a draft model is prepared that show interactions among changes based on the crucial information of the self-destructive type of relationship, where there are two types of interactions:

Indirect interaction: Relation from a part (of a system) to the system environment (sharing of indirect effects)

Direct interaction: Causal relation from one part to the another (direct effect from a change)

Based on this, the steps for the draft model are traced back to the start to prepare an actual procedure to determine interactions among multiple changes. The steps are-

- 1) Identify the significant changes
- 2) Determine and demonstrate the effects of each significant change
- 3) Isolate the common and the causal effects
- 4) Illustrate the common and the causal effects
- 5) Determine interactions from the illustration

3. Sub-question: Can the procedure be validated by applying it in real projects?

Yes, based on the results obtained from applying the procedure in three projects undertaken by ENGIE Services West Industry, the procedure can be validated to determine and illustrate the interactions among multiple changes. The procedure was applied using the methodology as discussed in

Chapter 3, section 3.3. Three projects from ENGIE Services West industry were selected. Gathering of data was followed by expert interviews with three project managers of the company. The interviews helped determine the significant changes along with their effects and control measures. The data was then analyzed by applying the steps of the proposed procedure. The first project showed **indirect interaction** among the major changes while the second and the third project show **both direct and indirect interactions**.

4. Sub-question: What conclusions can be made from the final results?

The results from the cases, following application of the procedure, **successfully show interactions among the major changes**. Interactions occur due to a causal effect from one change to the another or sharing of common effects among changes. At points of interactions, there is a high resource demand due to the changes requiring the same resources, or due to the occurrence of a new change. This creates a problem for the project management team as the number of changes increases. At a certain point, in order to fulfil the requirement, additional resources must be brought from outside the system which results in cost increases and project delays. However, the end results also show the limited amount of financial data and time in the case studies as the resulting synergy from the changes cannot be shown, hence, cannot prove the impacts from the changes. To conclude, it serves two important purposes:

- 1) Provide a reasonable understanding regarding the cumulative impacts of multiple changes
- 2) Provide a framework for construction companies to show points of additional resource demand due to change interactions.

7.3. ANSWER TO THE MAIN RESEARCH QUESTION

Q: How can the interactions among significant multiple changes in construction projects be determined and illustrated?

The concise answer for the above question is that the interactions among significant multiple changes in construction projects can be determined and illustrated with the help of a procedure that leads to a change interactions diagram that show the common and the causal effects among the multiple changes. To elaborate further, the model can be certainly improved upon, but as far as this research is concerned, steps leading to a diagram that shows the major changes in concise circles along with different arrows that represent the type of relationship leading to the change effects, provide a good demonstration for the interactions among major changes, as results from the three case studies show. Two types of effects lead to change interactions. Causal effects are effects from one change to another, thus showing causal relation while common effects are effects similar to other changes, showing a relation from a change to the project environment.

To summarise the answers of the sub-questions that eventually lead to the answer for the main research question, a proposed procedure is developed based on past research papers that theoretically imply on change interactions. Theories on the cumulative nature of changes and synergistic relations combined with understanding of the nature of changes, multiple changes and their management, help to develop a framework. The framework is the proposed procedure containing steps to determine and illustrate interactions among changes. Applying this to real projects validates the framework, provided the results show interactions among changes. In this research, the results from the three case studies show interactions without proving the impacts that

result from the changes. While doing so, it also provides an explanation regarding the impacts that occur due to the increase in the number of changes.

7.4. LIMITATIONS

The research focuses on the case studies by only considering the contracting side and not the clients. The data obtained from ENGIE Services West Industry was just about enough to determine and show the interactions among the major changes. However, this procedure is only limited to showing interactions among the major changes. The application of the model show that it cannot prove the impacts that rise from the interactions but only show interactions among the changes. In order to prove that the interactions lead to bigger impacts or show negative synergy, data on every single change order has to be collected with detailed analysis of the effects from every change. This would require a lot of data from the company as well as time. Most importantly, all the financial documents have to be collected, which the companies are not always willing to share.

Limitations are also on the type of projects selected and type of changes that this model illustrate, as only large projects with scopes of euros 8-14 million were selected and the significant changes are taken into consideration, while large projects on average undergo about 300 changes. The effect from each and every single change is not taken into consideration for this research, however this could be a valuable point of reference for future research on this subject.

7.5. RECOMMENDATIONS

In the following paragraphs, the application of the proposed method for construction companies and recommendations for future research is given.

The proposed procedure can be carefully applied in future projects to determine points of interactions among changes. As construction companies are concerned, determining of change interactions should allow them to share with their clients the increase in costs from the changes. Each change order has their effects, which when combined with other changes show interactions if they share similar effects or show a causal relation. If the significant changes are determined, then their interactions can be determined, which could possibly show the demand in extra cost and time. This can be done to show clients points where resource demand was more than estimated, or at least why collectively the changes led to a bigger cost than estimated. This could be a good reasoning for the extra costs resulting from multiple changes, which may sometimes be difficult to prove just via calculations.

Also, the procedure may be applied during the construction phase to check points of resource demand from the ongoing changes (if there are any), which shall help to plan the use of resources in the future accordingly. This would give an idea of the amount of extra resource demand, at the points of interactions, at that particular time. This could also be a good talking point with the client, requesting them not to make unnecessary changes or unnecessary changes in a particular discipline to fully optimize the use of resources. The research also determines the possibility of using management methods of communication and adaptability to deal with changes. This is achieved by creating a level of trust within the project team and the team with the client.

With limitations comes the possibility to suggest future research that can provide better results by surpassing the limitations this current research faced. The current focus of the research was to determine interactions among changes that could possibly prove the negative synergy resulting from the interactions. However, the procedure can only determine the interactions without proving the resulting synergy. Thus, it does not prove the impacts from the interactions but rather gives a sound reasoning for the impacts. Hence, future research could focus on determining the synergy resulting from the interactions. Also, the interaction determination process can be coded in a software, with inputs such as change order detail and costs to determine interactions,

reducing the time required and increasing the efficiency of the process by providing more accurate results. The software can be programmed to determine resource demand at the points of interactions, which could help complete the entire process of determining interactions along with the resulting synergy, all at faster and more efficient rate.

7.6 PERSONAL REFLECTION ON THIS ASSIGNMENT

The research project was a major learning curve for me. Very similar to real construction projects, where a project has delays and numerous changes throughout its construction phase, my research project had numerous changes throughout (its working phase) with certain issue delaying the project. However, a very positive aspect of this is that you eventually learn to cope with the changes and the sooner you can deal with it, the faster your thesis progress.

Personally, an important learning aspect of this project for me was that I could not keep my thesis committee and the supervisor of the company, I had my internship with, on the same page for the majority of the research period. What I learnt from this was that a good line of communication must exist between the two parties to facilitate a swift flow in the research. There is a different set of requirements from both parties which can only be solved by conducting meetings on a nearly regular basis to share the problems and get suggestions to move forward in the research.

Moving on, this assignment made me realize that writing is an equally essential part of the thesis as much as the research. I started writing my thesis roughly a month and a half before my final submission. If I had to do the thesis again, I would surely start writing a lot sooner. Writing not only focuses your mind on the goal but gives you a proper indication on your progress. This improves the understanding of the problem and the research focus and helps to get a better picture of the entire project rather than just focusing on collecting data and finding results. Finally, working in a company as part of my research internship was crucial to the findings on my thesis. It serves as a stepping stone to a real work experience. It helped me understand the construction industry at a deeper level. I had the luxury of working alongside project managers, engineers and designers, who guided me in my research by providing data and agreeing to be interviewed for the case studies.

REFERENCES

- Abdurahman Ammar, Awad S. Hanna, M., Erik V. Nordheim and Jeffrey S. Russell, M. "Indicator Variables Model of Firm's Size-Profitability Relationship of Electrical Contractors Using Financial and Economic Data". *Journal of Construction Engineering and Management*, 129: 192-197, 2003.
- Al-Dubaisi, A. (2000). Change orders in construction projects in Saudi Arabia. Saudi Arabia: King Fahd university of petroleum and minerals.
- Al-Hams, M. F. (2010). Simulation Model of Change Orders and their Impact on Building Projects Performance in Gaza Strip. Gaza: The Islamic University.
- Anastasopoulos, P. C., Labi, S., Bhargava, A., Bordat, C., and Mannering, F. L. (2010). Frequency of change orders in highway construction using alternate count-data modeling methods. *Journal of Construction Engineering and Management*, 136(8), 886-893.
- Caltrans. (2014). Contract Administration. In C. D. Transportation, Construction Manual. California, USA: Caltrans.
- Chang, Y.M. (1990). Synergy, relatedness, and organization form in the strategic management of diversification. Unpublished doctoral dissertation, University of Illinois at Urbana- Champaign.
- CII. (2000). Quantifying the cumulative impact of change orders for electrical and mechanical contractors. Publication 158-1. Construction industry institute, University of Texas, Austin, TX
- Daryll Conner. (December 6, 2011). "The importance of synergy during transformational change"
- Erjon Sadrija. (2016). "Change order causes, effects, controls and their impact on project cost in albanian infrastructure projects." Master Thesis project.
- El- karim, Nawawy, Abdel- Alim(2015, May 11). Identification and assessment of risk factors affecting construction projects.
- FIDIC. (1999). Conditions of Contract for Construction (Vol. I). Geneva: Engineers, International Federation of Consulting.
- G, McEniry. (2007, May). *The Cumulative Effect of Change Orders on Labor Productivity – the Leonard Study "Reloaded"*. Project Management and Construction Claims Services. Volume 26, Number 1.
- Hanna, A. L. (2002). Statistical-fuzzy approach to quantify cumulative impact of change orders. 16(4).
- Hanna, A. S., Russell, J. S., Gotzion, T. W., and Nordheim, E. V. (1999a). "Impact of change orders on labor efficiency for mechanical construction." *J. Constr. Eng. Manage.*, 125(3), 176–184.
- Hanna, A. S., Russell, J. S., Nordheim, E. V., and Bruggink, M. J. (1999b). "Impact of change orders on labor efficiency for electrical construction." *J. Constr. Eng. Manage.*, 125(4), 224–232.
- Hao, Q., Shen, W.; Neelamkavil, J. (June 2008). "managing changes in construction". National research council Canada. RR-258.

- Hester, W. T., Kuprenas, J. A., and Chang, T. C. (1991). "Construction changes and change orders: Their magnitude and impact." Source Document 66, Construction Industry Institute, Univ. of Texas, Austin, TX.
- Ibbs, C. W. (1994). "Project change management." Construction Industry Institute Special Publication, 43-1, Austin, Tex.
- Ibbs, C. W., and Allen, W. E. (1995). "Quantitative impacts of project change." Construction Industry Institute Source Document 108, Univ. of Texas, Austin, TX.
- Ibbs, C. W. (1997). "Quantitative impacts of project change: Size issues." J. Constr. Eng. Manage., 123(3), 308-311.
- Ibbs, C. W, Wong, C. K, and Kwak, Y. H. (2001). Project change management system. Journal of Management in Engineering,17(3), 159-165.
- Ibbs, C. W, Nguyen, L.D, and Lee, S. (2007). Quantified impacts of project change. Journal of Professional Issues in Engineering Education and Practice,133(1), 45-52.
- Ibbs, C.W. (2012, August). *Construction Change: Likelihood, Severity, and Impact on Productivity*. JOURNAL OF LEGAL AFFAIRS AND DISPUTE RESOLUTION IN ENGINEERING AND CONSTRUCTION © ASCE. Page no. 67-73.
- Ibbs, W. C. (2015). *Thinking about Delay, Disruption, and the Cumulative Impact of Multiple Changes*. Article in Journal of Legal Affairs and Dispute Resolution in Engineering and Construction · August 2013 Pages 109-112. DOI: 10.1061/(ASCE)LA.1943-4170.0000126.
- Karim, A. S. I. (2016). "Modelling the Cumulative Impact of Change Orders". M.S.-thesis, University of Wisconsin, Madison
- Klaus Jaffe. (2017). "The thermodynamic roots of synergy and its impact on society "
- Lee, S. (2007). Understanding and Quantifying the Impact of Changes on Construction Labor Productivity: Integration of Productivity Factors and Quantification Methods. PhD dissertation, UC Berkeley
- Leonard, C. A. (1988). "The effects of change orders on productivity." M.S. thesis, Concordia Univ., Montreal.
- McCally, Bob, *The Cumulative Impact of Change*, 2006 AACE International Transactions, CSC.05.
- McKinsey & Company (Feb 2017). "Reinventing construction: a route to higher productivity ", McKinsey Global Institute.
- Millhollan, C. (2008). *Scope change control: control your projects or your projects will control you*. Paper presented at PMI Global Congress 2008- North America, Denver, CO. Newton Square, PA: Project Management Institute.
- Motawa, Anumba, C, Lee, S and Peña-Mora, F (2007). An integrated system for change management in construction. "Automation in Construction", 16(3), pp. 368-377.
- Mokbel. H. (2003). Assessing the parametric building model capabilities in minimizing change orders. Faculty of the Worcester Polytechnic Institute.

Peter A Corning and Eörs Szathmáry.(2015). “Synergistic selection: A Darwinian frame for the evolution of complexity”. *Journal of Theoretical Biology* 371: 45–58,

Rashid, I., Elmikawi, M. and Saleh, A. (2012), ‘*The Impact of Change Orders on construction projects Sports Facilities Case Study*’. *Journal of American Science*, 8(8), 628-631.

Rodrigo. (2016, August 29). *Issues, Problems and Risks in Construction Projects and Ways of Mitigating them*. The write pass journal.

RS Means ILLUSTRATED CONSTRUCTION DICTIONARY (Student Edition), John Wiley & Sons, Inc.

Schwartzkopf, W. (1995). *Calculating lost labor productivity in construction claims*, Wiley, Somerset, N.J.

Sun, M and Meng, X (2009). Taxonomy for change causes and effects in construction projects. “*International Journal of Project Management*”, 27(6), pp. 560-572.

Vandenberg, Paul J. (1996). *The impact of change orders on mechanical construction labor efficiency* Calhoun: The NPS Institutional Archive.

Yu-Shan Chen, Ke-Chiun Chang, and Mei-Hui Lin. “Exploring the Nonlinear Influences of Size, Profitability and Employee Productivity upon Patent Citations in the US Pharmaceutical Industry by Using Artificial Neural Network”. *National Yunlin University of Science & Technology, Taiwan* 2006.

Appendices

Appendix A- List of general causes of changes

#	Group	Factors
1	Design errors	<ul style="list-style-type: none"> ▪ Errors ▪ Omissions ▪ Ambiguities ▪ Inconsistencies ▪ Impossibilities ▪ Change in design requests (by owners, contractors, consultants) ▪ Design criteria changes ▪ Inadequate design ▪ Design complexity ▪ Inadequate working drawing details ▪ Inadequate shop drawing details ▪ Consultants lack of required data ▪ Noncompliance of design with owner's requirements ▪ Change in specifications by consultants. ▪ Lack of contractor's involvement in design.
2	Changes in market conditions	<ul style="list-style-type: none"> ▪ Specified items become unavailable ▪ Shortage of manpower ▪ New products become available, cheaper and more efficient. Substitution of materials or procedures
3	Scope and quantities of work	<ul style="list-style-type: none"> ▪ Significant changes in the quantities of work ▪ Quantity changes to meet field requirements ▪ Plan errors ▪ Materials plan errors/ Changes in material ▪ Changes of plans or scope by owner ▪ Change in specifications by owner ▪ Change of schedule by owner ▪ Owner's financial problems ▪ Owner fails to maintain hold on project schedule ▪ Change in owner's requirements ▪ Owner, architect or contractor desires to improve their financial conditions ▪ Contractor financial difficulties ▪ Additions or modifications of work

		<ul style="list-style-type: none"> ▪ Inadequate project objectives ▪ Obstinate nature of owner ▪ Change in work sequence
4	Suggestions to initiate better	<ul style="list-style-type: none"> ▪ Suggestions to initiate faster ▪ Suggestions to initiate more faster construction ▪ Value engineering
5	Contract Conditions	<ul style="list-style-type: none"> ▪ Size of project ▪ Magnitude of facility ▪ Type of construction ▪ Previous similar projects between owner and contractor ▪ Types of contract ▪ Owner's project budget ▪ Consultant's lack of judgement and experience ▪ Lack of consultant's knowledge of available materials ▪ Honest wrong beliefs of contractor and consultants ▪ Contractor's desired profitability ▪ Contractor's obstinate nature ▪ Lack of specialized construction manager ▪ Poor planning and scheduling of the project by the contractor ▪ Ineffective quality control by the contractor ▪ Conflict between contract and document ▪ Lack of contractor's judgement and experience ▪ Contractors lack of required technical knowledge ▪ Contractor's financial problems
6	External conditions	<ul style="list-style-type: none"> ▪ Strikes ▪ Extreme weather conditions ▪ Material non-availability ▪ Unforeseen site conditions. ▪ Uncovering disclosed and unknown existing conditions
7	Differing site conditions	<ul style="list-style-type: none"> ▪ Presence of site conditions not mentioned in bid ▪ Differing main site and sub-surface conditions

8	Coordination and management	<ul style="list-style-type: none">▪ Non-performance of a team member▪ Safety considerations▪ Delays in project(sub-projects)▪ Defective workmanship▪ Lack of coordination▪ Technology changes▪ Unavailability of skills▪ Unavailability of equipment▪ Poor procurement process▪ Conflict in site
9	External actions	<ul style="list-style-type: none">▪ New government regulations▪ Emergency▪ Review of the project by proper governmental agency▪ Addition or deletion of work▪ Acceleration▪ Suspension of work▪ Change in economic conditions▪ Socio-cultural factors

Appendix B- Methods to quantify cumulative changes

There are generally two approaches for quantifying the cumulative impact of changes: (karim,2016).

- micro approach
- retroactive approach.

The micro approach is a proactive method where each productivity factor is evaluated separately. It is also called the factor approach. On the other hand, the retroactive approach encompasses methods that evaluate the cumulative impact after the fact. The following methods include both proactive and the retroactive methods

1. Total Cost Method
2. Modified total cost method
3. Industry standards and publications
4. Experts and Consultants
5. Measured Mile

The figure below shows the different methods to quantify the cumulative impacts of changes based on low to high outcome uncertainty (uncertainty curve) and expertise required (effort curve) through various stages of a project

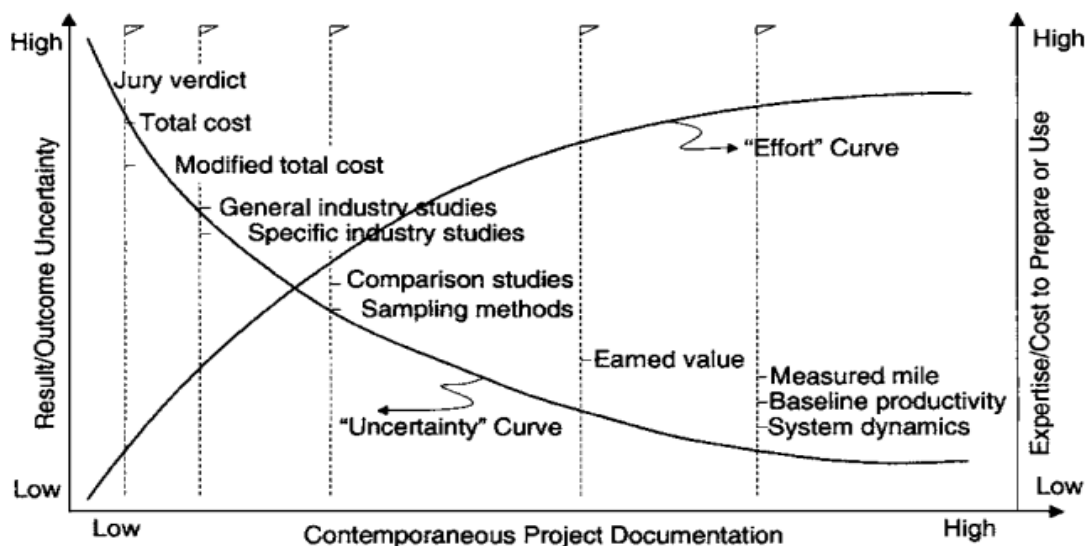


Figure: Comparison of Cumulative Methods adopted from (Ibbs, 2007)

•**Total Cost Method**- This is one of the least favored methods and may be adopted only in limited circumstances. This method relies on subtracting the estimated cost of the project from the actual cost incurred. The resulting difference in that case is assumed to be due to the owner only, which is a skeptical approach that should be used as a last resort. When the contractor's estimate is reasonable and alternative methods are not possible, the contractor's estimate is assumed to be "normal" (Moselhi et al. 1990). Total cost method applies only when: (Schwartzkopf, 1992).

1. The contractor's actual losses are impractical to prove
2. The contractor's bid estimate was reasonable
3. The contractor's actual costs were reasonable
4. The contractor was not responsible for any of the cost increases

•**Modified total cost method**- If the impact of the changes is so much, where the determination of the productivity loss from each is impossible, “Total Cost Method” can be modified (Serag,2006.) The rationale behind this method is that the equation of the total cost method is adjusted so that owners are no longer responsible for contractors’ performance inefficiencies and errors in bid estimates. (Schwartzkopf 1992).

This method calculates normal productivity based on the original estimate for the project. To determine the proper estimate, the contractor's estimate is compared to the next three highest bids when the difference is less than 3 - 5%. The normal number of hours is taken as the contractor's estimate multiplied by a ratio of the average of the next three bids. If the difference is more than 5%, the contractor's estimate is compared to a theoretical estimate based on published estimating tables. When this theoretical estimate is no greater than 3 - 5% more than the contractor's estimate, the theoretical estimate is taken as normal. Any labor amount over the "normal" amount is taken as impacted. (Vandenberg,1996)

•**Industry standards and publications** - Industry publications are often used to prove the productivity loss associated with change orders. Courts and boards sometimes accept many reliable industry publications established by recognized researchers and practitioners (Karim,2016). Some industries used their past project data to form a study on the labor productivity losses due to owner changes. Some of these are the U.S Army Corps of Engineers, National Electrical Contractors Association (NECA), Mechanical Contractor Association of America, Business Round Table and others. The idea behind these studies is to be able to have guidelines of how to quantify the effect of changes on labor productivity inefficiency (Serag,2006)

•**Experts and Consultants**- Consultant and expert testimony are often used to prove lost productivity in construction projects. In that case, opinion of experts is not sufficient. Supportive documents incorporating the analysis of actual circumstances and cost data of the project are needed to prove the actual incurred decreased productivity (Schwartzkopf 1992).

•**Measured Mile**- Of all the quantification methods available, the measured mile is the most widely accepted one, although still has its limitations (Shwartzkopf, 1992). The measured mile approach compares the impacted period with unimpacted period from the same project. Once the contractor has performed a sufficient quantity of work prior to the change and the quantities are recorded, then a productivity baseline can be established by multiplying the physical units of the work installed by the estimated unit rate to determine the earned hours. The earned man-hours are compared with the actual man-hours in the project

A measured mile analysis is performed by the following steps (Gemell, Thomas,2016)

- Step 1: Define the performance measure;
- Step 2: Reconcile the data;
- Step 3: Decide on the scope of analysis;
- Step 4: Partition into periods;
- Step 5: Plot performance (productivity) curve;
- Step 6: Determine unimpacted and impacted periods;
- Step 7: Calculate the date from which damages are measured;
- Step 8: Validate percentage of production;
- Step 9: Calculate inefficient work hours;
- Step 10: Cause–effect analysis; and
- Step 11: Validate the analysis.

Often referred to as the “Gold Standard”, this method compares similar activity impacted and unimpacted segments of the project in order to determine the productivity loss curtailing from the impact. The difference in productivity between the impacted and unimpacted periods is considered to be the lost productivity. A disadvantage of this method is that in highly distressed and

troubled projects, it is hard to isolate unimpacted from impacted periods. It is also difficult to find two different periods where identical activities were being performed (Schwartzkopf 1992).

SCIENTIFIC STUDIES

Hester et al. (1991) stated that the cumulative impact of multiple interventions is essential to study since there is a likelihood that a compounding and negative effect will occur, sometimes resulting in damages greater than the sum of individual parts. This “greater than the sum of the parts” phenomenon occurs because the accumulating effect arising from changes disrupts not only the change work itself, but also the base contract work. Hence, a 1+1=3 experience results. Expressed another way, the change orders prepared and priced during the project tend not to include the full cost caused by the change. The studies by Ibbs (1997,2005), Ibbs and Allen (1995), Thomas and Napolitan (1995), and Hanna et al. (1999) generally corroborate these findings (Ibbs ,2015). Scientific studies on the subject are as follows-

- Leonard study 1988

The ‘Revay Report’ by Gerald McEniry states that ‘the Leonard study was a pioneering attempt to determine the cumulative impact of multiple changes on construction labor productivity. The study was based on 57 different projects from 90 construction disputes involving a variety of commercial and institutional buildings and industrial plants. The results of Leonard’s research are often depicted in two graphs, one for civil and architectural work and the other for electrical and mechanical work (McEniry, 2007).

The graphs show productivity loss attributable to the following three cases: 1) change orders are the only cause of productivity loss; 2) change orders plus one additional major cause is the source of additional productivity loss; 3) change orders plus two additional major causes are the source of more additional productivity loss (Iskander, 2016).

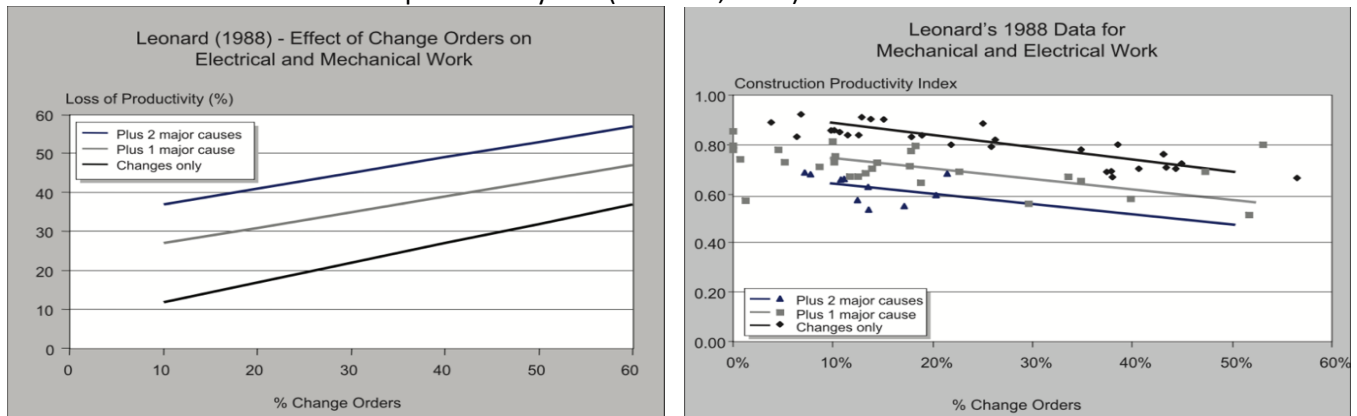


Figure: Leonard’s graphs on effects of change orders on productivity loss

In the Leonard study, the term “additional major cause” refers to the use of an acceleration technique, adverse weather conditions, or poor site management and logistics (Moselhi et al. 1991 and Leonard 1988). Leonard calculated the loss of productivity using the differential method of calculation (“measured mile”) whenever possible as written in an article by the ‘Revay report’.

1. He first determined the “normal” hours from which the lost hours could then be established. In cases where the normal hours could not be determined, “earned” hours (which could be equated to normal hours) were used to calculate the lost hours.
2. If the contractor’s estimate was considered reasonable, then earned hours were the estimated (budgeted) hours.
3. If the contractor’s estimate was not reasonable, the earned hours were modified to put them in line with other bids.

Leonard then calculated the productivity index (“PI”) as the ratio of earned hours vs actual base contract hours. Loss of productivity (“LOP”) was calculated as follows:

$$\text{LOP} = (1 - \text{PI}) \times 100\%$$

The main advantage of his study is that it does not rely on the contractor’s original estimate. It is based entirely on the actual labor hours. However, his study is based on a biased sample where the data used were collected from projects that reached the dispute stage. He did not compare impacted and unimpacted projects (Serag, 2006). In addition, the study combined the data for electrical and mechanical trades, where there might be a chance that the loss of efficiency between the two trades may be different. The study considered the amount of change as the only factor that caused loss of efficiency. He did not consider other factors such as timing of change and/or project percent complete (Hanna, 1999b)

Although it was the first effort to investigate the cumulative impact of changes, the Leonard method had some drawbacks in that it only considered small and building projects that were already troubled at the dispute stage (Jones 2001; Revay 2002).

- Construction Industry Institute Studies (CII)

In a CII study, Hester collected field data in order to investigate the impact of changes on various productivity factors, including cost and schedule, while also providing the industry with techniques for effectively managing changes (Hester et al. 1991). Although the study did not provide a quantitative assessment of the impact of changes, several conclusions were reported. Among the conclusions is that it is unpractical to assume that the regular change in the work will only affect the work in the changed area. The effects can extend beyond that area and encompass other work areas (Hester et al. 1991).

The Revay report states that in 1995, Ibbs and Allen, working under the auspices of the Construction Industry Institute, CII, studied some 104 projects from 35 different companies (15 contractors and 20 owners) representing both disputed and undisputed projects, foreign and domestic work, industrial, commercial and heavy civil work, and various delivery systems. The Ibbs and Allen (1995) study presented a significantly more optimistic, or less severe, estimate of lost productivity than Leonard study, for example ‘The Leonard curves do not extend into the area where changes are less than 10% whereas the Ibbs and Allen results indicate that, in cases where changes on a project are less than 10%, productivity could in fact be even better than estimated.’ Another significant change was in relation to percent change order measurement- ‘The “percent change” is defined as the number of work-hours expended on authorized changes that originated during the construction phase divided by the total number of work-hours expended for construction.’

They also conducted the following hypothesis (Serag,2006):

1. Changes at the later stage of the project are carried out less efficiently than 52 those early ones.
2. The greater the change, the greater the negative effect on the productivity.
3. The hidden or unanticipated cost of change increase with more project change.

According to Hanna, 1999a, such study revealed several limitations and they are follows-

- In their study to relate independent variables affecting productivity to the changes, low coefficient of determination, R², values were recorded.
- In the study, it was assumed that the ratio between the installed material cost and the total cost is an indication of efficiency for changes that occur late in the project are carried out less efficiently. Such an assumption can lead to difficulties when there is a change in scope, or when changes do not affect the material consumption.
- The study couldn’t prove the fact that changes that occur late in the project are implemented in a less efficient way than those occur at earlier stages in the project

APPENDIX C- INTERVIEW PROJECT 1

Case: construction of a new gas treatment plant

Interviewed: Jacques Slingerland, project manager, ENGIE

Date: October 3, 2018

Location: ENGIE services, Rotterdam, The Netherlands

Purpose of the interview

The purpose of the interview was to determine the significant changes from the list of top change orders in order to focus on the main issues that may have led to delays and cost increases in the project. Substantial information was to be obtained regarding the significant changes, their causes, effects and control methods in order to determine the interactions among them. Further data was collected to obtain Gantt charts, tables or graphs that could help in the demonstration of the changes and their impacts and finally the interactions.

Results of the interview

Considerable data was collected from the interview. The session was recorded with consent from the project manager. The causes for the significant changes, followed by obtaining of several graphs, Gantt charts, figures to show change impacts, information regarding the effects from the individual changes, controls of the changes from the point of view of project management and finally, expert comments on the nature of multiple change impacts on project outcome.

Questions and Answers

The following questions were answered by the project manager after determining the significant changes, their causes and discipline of operation, from the list of top changes.

Q: What was the intended finish time and what time did you actually deliver the project?

A: *Well, as you can see (pointing to his PowerPoint presentation), we intended to finish the project in 33 weeks, but was delayed to 40 weeks. So, we had 7 weeks of delay.*

Q: Which issues were crucial to the delay of the project?

A: *There were primarily three issues that we estimate to be the reason for the delays. There was change in pipe specifications, delay of delivery of the duplex materials by the client and finally was the short supply of cabinets in the control room, again by the client.*

Q: Could you elaborate on the first major change?

A: *The change in pipe spec was actually the client issuing a new pipe spec. The client requested to review the impact on the isometrics for this item. Do you know what isometrics are? Isometrics are drawings for a pipeline. The project had over a thousand isometrics. The Client had done the engineering (isometrics) and prepared the Bill of Material per ISO and ordered most of the materials. we have 1000 isometrics for the project and around 330 were affected. This meant 33% of the isometrics were affected by this change of scope. Importantly, if it affects 33% of the isometrics, it also 33% of the piping scope, since isometrics contain instrumentation as well. Therefore 33% of the E&I scope*

Q: How much delay from this particular change?

A: *We estimated a 7-week delay just from this particular change*

Q: Regarding the impacts from this particular change, could you share your thoughts?

A: *Changes usually have knock-on effects on other change, as a result of which there is the cumulative effects. So, when we have to re- do everything in the specifications and drawing, other things get affected. We had to re-order the materials. There was BOM revision by ISO, also the works*

connected to the change had to be managed. Since the workload was increased, there was work overtime in prefabrication shop.

Q: Could you elaborate on the second and the final issue?

A: *The second change was delay in delivery of the duplex materials, which as you can see led to other effects. The duplex materials had to be delivered by the client but did not order enough piping materials as a result we had to order them ourselves, something not planned at the start. So, we had to order materials, hire extra tools and equipment and since there were not enough materials, work had to stop temporarily. This impacts other works depending on this. And the last change was cabinets in the control room were received later than planned. The connecting cables were supposed to arrive by week 42, instead arriving on week 48 (which is around end of November). This resulting in 6 weeks delay.*

Q: Apart from the three were there any other issues crucial?

A: Well, we had a lot of changes throughout the project and since they all almost occur at the same time, it is a lot harder to isolate the changes and individually determine them. But, as far as we are concerned, the three changes I mentioned were the most crucial.

Q: From a management perspective, do you think changes can have interaction?

A: *Well, when you say interaction, it means having certain effects that somehow connect the two together leading to requirements of more resources. Yes, certainly.*

Q: Would your answer change if there was a case when the changes are occurring in different discipline?

A: *Well, interesting. No. Because you see, we have a project management team that has to deal with the changes. Now, a few changes are not a problem, but when you have a lot of multiple changes occurring at a single time, they cannot decide which change to manage. Now when we have big changes, their concentration turns to the big changes, while having to focus on the other changes while also having to do their normal work of work-preparation or whatever. This affects their focus, affecting the scope of the project. Hence, you could say this is a form of an interaction.*

Q: Finally, in terms of management, what control measures were applied to keep the project down to respectable delay time?

A: *Well, as you can see, we estimated the impacts from the three changes would lead to 12 weeks of delay. However, we took certain measures to keep it to 7 weeks. You must accept change, you must allow for changes, deal with it and implement it as efficiently as possible. What usually happens is we do the change without proper work preparation and engineering. What could help is having a change management team only to deal with the engineering side. One can only adapt to a situation if they accept it. Also, communication, plays a very important role. You must be able to communicate with your team, with the clients, build a level of trust.*

APPENDIX D- INTERVIEW PROJECT 2

Case: Construction of SDA-WS3

Interviewed: Norbert Lardinois, project manager, ENGIE

Date: October 3, 2018

Location: ENGIE services, Rotterdam, The Netherlands

Questions and Answers

The following questions were answered by the project manager after determining the significant changes, their causes and discipline of operation, from the list of top changes.

Q: What was the intended finish time and what time did you actually deliver the project?

A: *Well, this was a rolling project, so there was not intended finish time. We had work packages that were agreed upon at the start as part of a general agreement with Shell for doing projects for the next five years, irrespective of the type of project. There was an agreement for the number of work-hours. So, we had work packages that were estimated to be 34 days of work but ended up with 40 weeks.*

Q: Which issues were crucial to the delay of the project?

A: *There was primarily one issues that was the reason for the delays. There was a work front gap. As you can see in this graph, we were supposed to receive the documents much earlier than we received. Let's see for this particular incident, 12 weeks after they should have delivered the documents, we could do the data preparation, then wait until the inspectors were done with the KNR's and we needed them to start the actual work in shop (in Dordrecht) and field work so as you can see, there was big gap in work and a lot of red k's. Hence, no work could be started up until then to do the actual work. All the projects were delayed. One of them does not make a real impact. The project was supposed to be finished by early July, but adding all the delayed work, then there is a big problem. And all this caused by Engineering not being on time.*

Q: How much delay from this particular change?

A: *Well it is difficult to estimate that as the issue is spread throughout the project in all early phases of all the different stages. But the delays of the project surely was a result of this change, so 7-8 weeks from this.*

Q: Regarding the impacts from this particular change, could you share your thoughts?

A: *This change had effect on other changes and the project as a whole. We had a lot of staff changes due to this. the scope of the project was not set in stone when we calculate our first staff estimate, since it was a rolling project. We thought we were going to have 26 work packages, turns out we had 38. Negatively it just had cost impact as a big effect. We also had to hire an extra supervisor to keep up with demands of the extra work packages.*

Q: Could you elaborate on the second and the final issue?

A: *People working in the project work in different teams, answerable to different bosses, thus complicating things when there are changes in staff. This also meant there was an effect on connecting works. Also, I told you about the hiring extra supervisor. This was because of the earlier changes, as we were going to do more things simultaneously. If it wasn't for this change, then the project would have extended more. This was out of choice since it had cost impact, but a necessary one due to the many changes occurring at the same time*

Q: Apart from the three were there any other issues crucial?

A: *We had a lot of changes during construction. Very difficult to determine the individual impacting changes or issues. Individually, the impacts are very hard to isolate as there are so many changes at*

the same, and we have so many documents for the changes that getting that data will take a lot of time with very little outcome. But you can see we had a delay at the end and all started with the gap in work. There are so many key players and members involved in the project, all in different discipline and answerable to different people, thus when there is a single or two changes, it is easier to handle that. But with three or more, the focus has to be redefined. The work front gap was the issue that is very much in sight and easy to determine. Other than that, this was a very successful project, so not many issues.

Q: From a management perspective, do you think changes can have interaction?

A: *Well, yes, they do. Obviously, there is interaction among the changes when there are many occurring together. Changes depend on common resources and to manage them there is usually one project management team with the task of handling all the changes. You can see the problem.*

Q: Would your answer change if there was a case when the changes are occurring in different discipline?

A: *Again yes, because of a similar people having to manage all the changes.*

Q: Finally, in terms of management, what control measures were applied to keep the project down to respectable delay time?

A: *Well, I am trying not to give you a general answer. But this was not a typical project. This was a successful project. We had 3 members in the Quality Control (QC) department, we only needed two. So, if one of the changes occurred, one of those guys could come and help us. Same holds for the work preparator to keep everything on track, communicating with people the changes, by adapting, and controlling it within a small space. There is never a sure solution and a perfect answer. We must deal with the changes by adapting and communicating with one another and prepare for the change by not involving those not necessary but only communicating with the people necessary*

APPENDIX E- INTERVIEW PROJECT 3

Case: Construction of tank terminal in the oil and gas industry, The Netherlands

Interviewed: Alex Söntgerath, project manager, ENGIE

Date: October 9, 2018

Location: ENGIE services, Rotterdam, The Netherlands

Questions and Answers

The following questions were answered by the project manager after determining the significant changes, their causes and discipline of operation, from the list of top changes.

Q: What was the intended finish time and what time did you actually deliver the project?

A: *Umm, we had to had to finish in 32 weeks. But the project took around 42 weeks to be completed. So, 10-week delay.*

Q: Which issues were crucial to the delay of the project?

A: *In terms of important issues, we had a few of them. There were engineering issues and design errors in documents which led to many changes. As the designs by the Engineering firm were faulty, there was more time needed as you can see in the change 'Extension of Time Rubis. There was also extra cost resulting from the engineering issue sand design issues. You can see the expiration costs. These were results of other changes with faults in them.*

Q: Could you elaborate on the first major change?

A: *As the designs by the Engineering firm were faulty, we had to order cables and redesign it ourselves, which had cost and time impact along with additional work, meaning gathering resources from other disciplines and areas of the project. It is crucial to remember that these changes were all being carried out at the same time as other changes, thus working on a specific change meant stalling other works connected to this work, which meant further delays*

Q: How much delay from this particular change?

A: *We estimate a 10-week delay just from this particular change*

Q: Regarding the impacts from this particular change, could you share your thoughts?

A: *Well we had to design it ourselves, which meant additional work on top of our planned work. We had to order the cables ourselves, costing more money and since delivery takes time, we had to wait for it. What this does is, delays the works depending on this particular completion. So additional work, delays and cost increases.*

Q: Could you elaborate on the second and the final issue?

A: *the next issue was basically extra costs or staffing cost from week 21 to week 42 due to extra work and a desperate attempt of reducing any further delays. Again this was caused by two other changes due to errors in design. They were errors and faulty specifications in the piping and mechanical discipline. Due to errors in design of the pipes, there was additional work of redesigning and re-ordering of piping materials. This meant ENGIE had to order new materials and re-design the pipes as per required specifications. This is very similar to the last change. There was stalling of other works connected to this discipline. This meant having to add extra resources to one discipline while limiting them in other disciplines, as they were all occurring at the same time and finally additional costs in hiring more people resulting in extra staffing costs and schedule expenses*

Q: Apart from the three were there any other issues crucial?

A: it is very difficult to isolate and give information about all the changes among a large number of changes. There are so many changes occurring at a single time, determining a single impact is very difficult

Q: From a management perspective, do you think changes can have interaction?

A: There is surely an interaction between two or changes when occurring at the same time, regardless of any discipline or type of change as there is sharing of common resources and all the changes are supposed to be managed by a common project management team

Q: Finally, in terms of management, what control measures were applied to keep the project down to respectable delay time?

A: That depend the type of answer you are looking for. This project was undertaken almost 3 years ago, so it is not possible to remember any technical control measure or method. But yes, if you want a general answer, we have to adapt to changes. It is very essential to adapt. We have to be ready to accept that there will be changes and think what we can do now. This is why communication matters, as you can adapt easier if you involve your team members and staff along with the change. Thus, even trust plays a role, as involving the people in a project requires trust.