Risk Management in Procurement of Construction Industry in Lebanon

---

A Thesis

presented to

The Faculty of Engineering

At Notre Dame University- Louaize

In Partial Fulfillment

of the Requirements for the Degree

Master of Science in Civil Engineering - Project Management

---

by

CHARBEL NASSIF HADDAD BAROUKE

MAY 2020

Notre Dame University- Louaize

Faculty of Engineering

Department of Civil and Environmental
Engineering

We hereby approve the thesis of

Charbel Nassif Haddad Barouke

Candidate for the degree of Masters of Science in Civil
Engineering - Project Management

[Signature]

Dr. Dima Jawad Supervisor, Chair

[Signature]

Dr. Sophia Ghanimeh Committee Member

[Signature]

Dr. Atef Harb Committee Member

Acknowledgments

First and foremost, I am extremely thankful for my parents who have encouraged me to pursue a master's degree at Notre Dame University. I would like to thank them for their unconditional love, encouragement and support, and faiths in me. Next, I would like to thank my academic advisor and chair of the thesis committee Dr. Dima Jawad. This thesis would have been infeasible without her steering vision, enormous support, leadership, and guidance. Moreover, I would like to express my deep gratitude and appreciation for the constant advice of the master's thesis committee members Dr. Sophia Ghanimeh and Dr. Atef Harb. Furthermore, I am very appreciative of being a student at Notre Dame University which has provided me with great support during my academic studies and preparation of the master's thesis. Last but not least, I am grateful for the participation and contribution of every Lebanese civil engineer who has participated in the in-depth interviews and surveys.

Contents

List of Figures

List of Tables

Abstract

Given the high complexity of construction projects, these projects carry numerous inherent risks and uncertainties. Such risks if managed properly can turn threats into opportunities. With the current decline in the construction and economic sectors in Lebanon, the application of risk management in construction projects has become imperative and more needed than ever. This master's thesis looks into the current state-of-the-practice of risk management in construction projects in Lebanon focusing on procurement methods in these projects to identify the main obstacles in its application. The thesis is three-fold: the first aims to assess the state of the practice of risk management in the Lebanese construction industry and the attitude of civil engineers towards the application of risk management through the use of a large-scale online survey after a proper literature review & bibliometric analysis is done. The second fold of the thesis aims to qualitatively assess the most important risks as identified by the Lebanese civil engineers while taking into consideration design-bid-build lump sum projects by using the result of the previous large-scale online survey and conducting in-depth interviews with procurement experts working in this field. The outcome pinpointed the level of each risk and the important role of the risk priority number. The third fold of the thesis is a case study of quantitatively analyzing risks of a real design-bid-build lump sum infrastructure project using Primavera Risk Analysis software. The case study analyzed the risks quantitatively while using the outcome of the questionnaire and the in-depth interview for identifying various risk responses and owners. This research reveals the perception of Lebanese civil engineers of risks and compares the impact of risks after the

application of specific response strategies.

It was found that they are mostly risk-averse or risk-neutral while the most occurring risk is the poor risk identification where it is the most occurring and hardest to detect. In addition, the research indicates that the main obstacles of applying risk management in the Lebanese construction procurement are the lack of awareness of the benefits of risk management and the lack of knowledge in risk management, thus, highlighting the importance of annexing a third-party risk analysis consultant in construction projects which would provide specialized training to procurement engineers, and the need for more innovation in procurement and bidding practices.

1. Introduction

1.1 Problem Background

The construction industry is probably one of the main sectors that is always subjected to high risk. Risk is defined by an unforeseen event with a known and controllable outcome which if occurs can affect the scope, time, or cost of a construction project. A project risk is made up of three components: the risk event itself, the likelihood of occurrence of the risk and the impact the risk has on the impacted event(s) (Hilson, 2014). A risk can be considered as an opportunity or threat if it causes a positive or negative impact respectively. Risks are much different from uncertainties since uncertainties are unforeseen events but associated with unknown outcomes that cannot be managed (Usmani, 2019).

Risk management is the process of identifying the project risks, assessing the risks in terms of their likelihood of occurrence, impact, and detection, responding to each risk selectively, and monitoring the risks in order to track their effects and achieve continuous improvement (Weaver, 2008). The topic of risk management was investigated the first time after world war two, and the first two books written by Mehr, William, and Hens were published in the years 1963 and 1964 respectively (Dionne, 2013). However, risk management has not been applied in the construction industry until the 1990s where it was first applied in few countries such as the United States of America and the United Kingdom (Reilly, 2017).

Construction projects are highly volatile to risks since construction projects are conflict-ridden by nature involving multi-stakeholders where each stakeholder has conflicting interests. Additionally, construction projects have become global, multi-cultural, and more complex surpassing the natural borders and making construction projects more vulnerable to the risks of each local market (Mcnichol, 2013). Construction projects could be faced with risks of different natures such as technical, construction, physical, organizational, financial, socio-political, and environmental which necessitates the application of risk management (Landage, 2016).

Risk management in the construction industry is very central if one seeks to increase the effectiveness and profitability while decreasing the efforts needed. Procurement of construction is the primary tool used for the allocation of different risks that occur in a construction project where each contract type entails a varied risk distribution and risk profile such as design-build contracts which allocate most of the risk to the contractor.

1.2 Problem Statement

The construction sector in Lebanon is one of the most essential sectors in Lebanon accounting for 3.8% of Lebanon’s GDP (BRITE, 2018) and providing employment for five percent of the total Lebanese workforce (UNDP, 2011). However, Lebanon’s construction sector is very volatile as shown in figure 1 where the number of registered construction meters decreased from 1.15 million m^2 in the year 1996 to almost 550,000 m^2 in the year 2000 after which it increased to reach its maximum of 1.5 million m^2 in the year 2010. Then, the number of registered meters decreased to reach its all-time lowest of 490,000 m^2 in the year 2019.

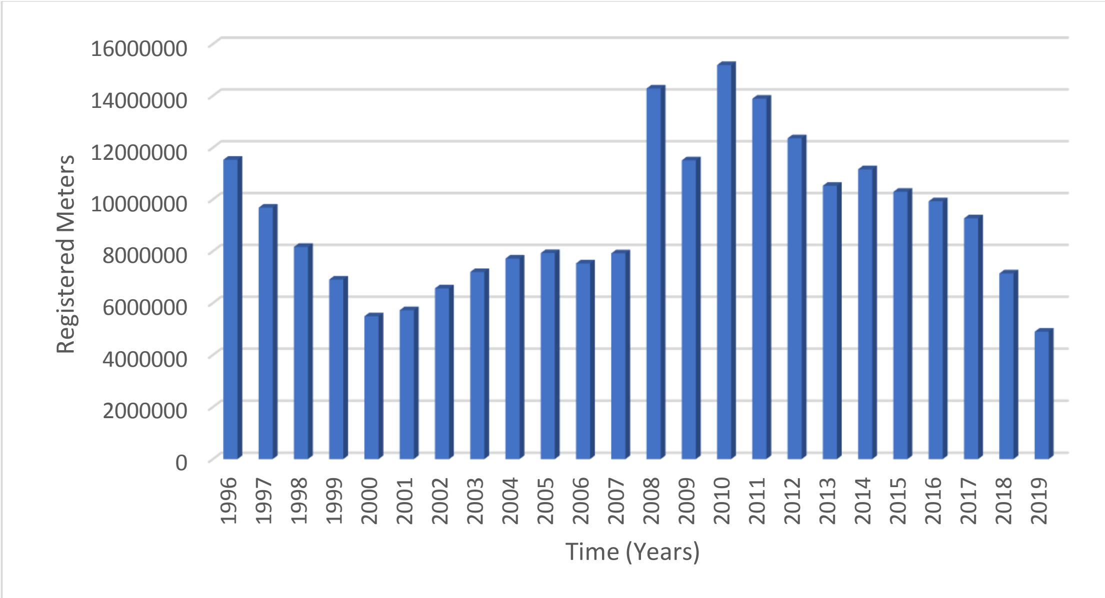


Figure 1: History of Registered Meters in the Order of Engineers and Architects in Lebanon (OEA, 2020)

The latter decrease in the registered meters in the year 2019 may be because the Lebanese construction industry lacks the efficient knowledge in risk management and has suffered from major risks such as the freezing of the housing loans by the central bank, the conditions in the neighboring countries, the fluctuation of the exchange rate, etc. All of which necessitate the application of risk management in the construction industry in Lebanon and the spread of awareness in risk management's benefits. Thus, resulting in a more stable construction sector for the welfare of the Lebanese workforce especially with the current deteriorating economic conditions in Lebanon. The efficient knowledge and application of risk management tools would also result in a much more resilient and sustainable construction industry where contingency plans could be created to mitigate and respond to severe risks such as the COVID-19 which is expected to correspond to a loss of $2.7 trillion loss in the global economy (Bloomberg, 2020).

1.3 Research Objectives and Research Questions

The main objective of this master's thesis is to determine the state-of-the-practice of risk management in the procurement of the construction industry in Lebanon. Another objective is to qualitatively assess the most important three risks in each phase of the procurement cycle in design-bid-build lump sum construction projects. This master's thesis also aims to showcase a quantitative assessment of the most important three risks in the execution phase of a real-world infrastructure project in Lebanon.

Based on the stated research objectives, the following research questions were formulated:

1) What is the overview and attitude of civil engineers towards risk management in procurement, and what are the appropriate project delivery methods and contract types taking into consideration the presence of the numerous risks in procurement?
2) What are the most important procurement risks that occur during each phase of the construction procurement process, and to which level of risk do they belong to? Which of the top three risks are the most occurring, cause the highest impact to the project and are hardest to detect respectively in design-bid-build lump sum construction projects?
3) What are the main barriers against the application of risk management in the procurement of the construction industry in Lebanon?

4) How is risk management applied in the project execution phase of an actual infrastructure project in Lebanon that uses a design-bid-build delivery method and lump sum contract?

1.4 Research Methodology

The thesis objectives are achieved through a three-fold methodology made up of a 1) comprehensive literature review coupled with a bibliometric analysis of the review and a large-scale online survey about risk management in the construction industry that targets Lebanese civil engineers, 2) in-depth interviews and 3) a case study. The methodology detailed flowchart is shown in figure 2. The literature review outcomes are used to identify the main types of risks in the procurement of the construction industry and track the main research topics in the procurement of the construction industry. While the survey includes questions to identify the top and most important risks in each phase of the procurement process in the construction industry from the perspective of the Lebanese civil engineers.

Consequently, the likelihood of occurrence, severity, and detection of the most important three risks in each phase of the procurement cycle as resulted in the survey will be explored thoroughly for design-bid-build lump sum construction projects through an in-depth interview with key experts working in the construction industry.

Then, a case study is made to show clearly how risk management is applied in the project execution phase of a sample design-bid-build lump sum project in the construction industry in Lebanon through the use of primavera risk analysis. Note that the study will be restricted to construction projects and working civil engineers in Lebanon.

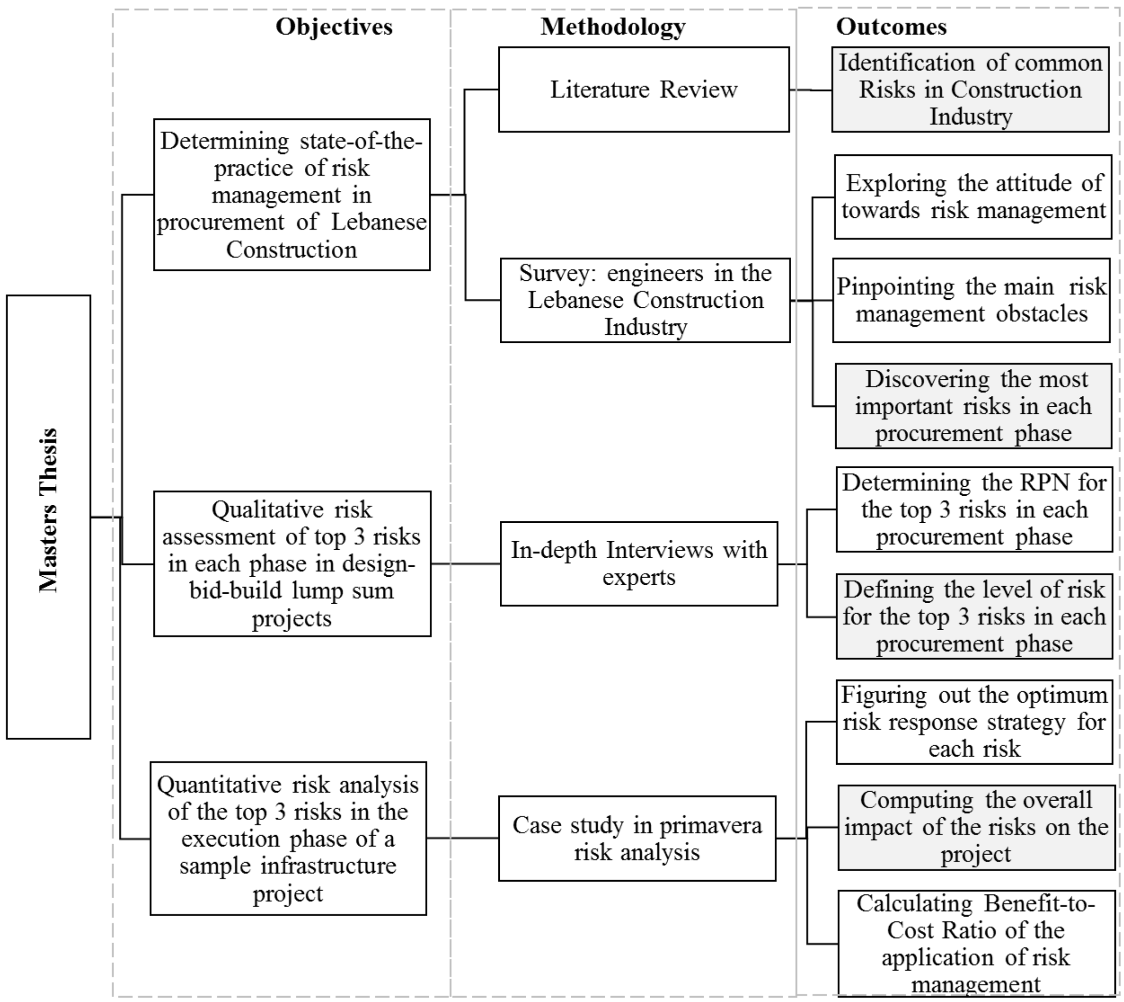


Figure 2: Methodology Flowchart

2. Theoretical Background

The theoretical background is provided on the main topics which this master's thesis focuses on the main contract types and project delivery methods in the construction industry and an overview of the process of the application of risk management in construction in addition to its importance, benefits, and link with the procurement of construction. The latter will provide the necessary information and concepts about the main topics the master's thesis aims to discover and investigate.

2.1 Main Contract Types in Construction

The three main types of contracts in the construction industry are as follows: fixed price (lump sum), unit price, and negotiated contracts (Halpin and Senior, 2011). The main characteristics of these contracts are presented in table 1. The latter table shows each contract type and compares them with respect to the scope characteristics, price characteristics, risk allocation, and flexibility. Moreover, each type of contract is associated with certain features or results.

For example, lump-sum contracts result in claims and disputes. Several risks exist during the procurement process that starts from strategic organizational procurement analysis and planning to the planning of procurement activity, sourcing, selection of procurement strategy, preparation and issuance of solicitation documents, receipt and opening of offers, evaluation, procurement review and award, contract finalization and issuance, contract management and logistics such as inadequate needs analysis, etc.

2.2 Main Project Delivery Methods in Construction

A project delivery method is a comprehensive process of assigning the contractual responsibilities of designing and constructing a project (Ding, Wang and Hu, 2018). The project delivery method affects the risk allocation between the different parties. There are three procurement types as shown in figure3: designer-led, management-led, and producer-led. Each of the latter procurement types differs according to the process and the connections between the different parties involved in the project. These differences will be discussed subsequently for each procurement type.

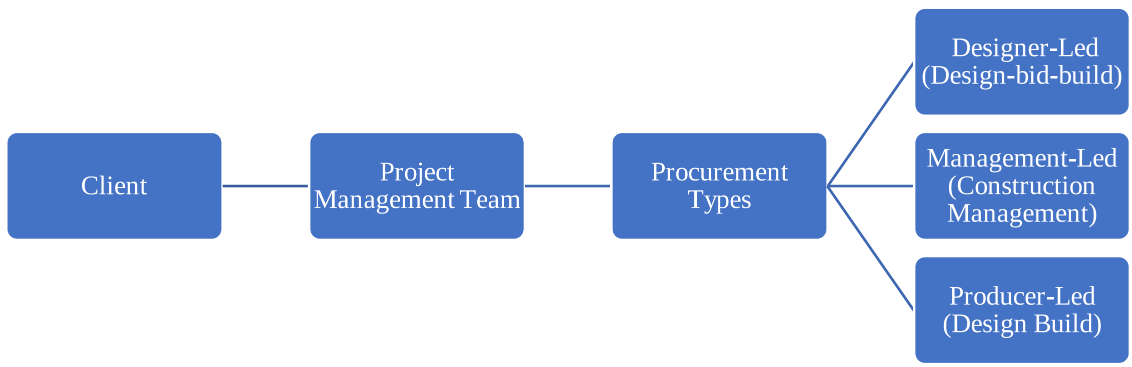


Figure 3: Types of Procurement (Murdoch and Hughes, 2000)

The main project delivery methods are design-bid-build, design-build, construction management (CM), and partnership. Both design-build contracts and lump-sum contracts share a common feature that the contractor has to do all that is necessary to achieve the contractual scope of the works without an adjustment in price. Without any alteration to the latter, the design-build contract is a subset of lump-sum contracts. The design-build contracts provide a single point of contact to the owner where a single contractor provides the entire project as a single contract package.

The designer-led procurement process starts first with the concept planning as shown in figure 4 which identifies the owner's needs and finished with the finished construction process executed by the main contractor.

Table 1: Characteristics of Main Contracts

Contract Type	Scope	Price	Risk Allocation	Flexibility	Results
Fixed Price (Lump Sum)	Clear	One price Covering all work	High uncertainty for the contractor Low uncertainty for the owner	Low	Disputes Claims Adverse Relationships
Unit Price	Unclear	Unit price for each work item	Risk-sharing between the owner and contractor	High	Accommodati-on of variation between field and estimated quantities
Negotiated	Unclear	Different forms : cost + % of cost , cost + fixed fee, cost + sliding fee	Low uncertainty for the contractor High uncertainty for the owner	High	Possible price renegotiation if the deviation from estimated quantities exceeded 10%

The owner only signs a contract with the contractor as shown in figure 5 who will himself or herself be contractually responsible and liable for the design and build of the facility. There are several risks in this type of delivery method; however, most are taken care of by the contractor. The only risk that the owner takes responsibility for according to the procurement system shown in figures 4 and 5 is that the brief of the project must adequately describe the requirements of the project. While all the remaining risks of the design and construction are allocated to the contractor. In design-bid-build projects, the main contract between the general contractor and the owner is mostly a lump sum contract (Chipman and Asklof, 2015).

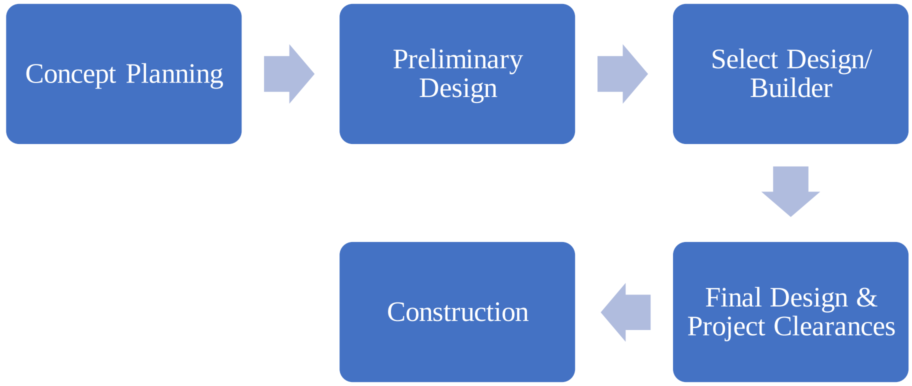


Figure 4: Design-Build Procurement Process (Jim Hall, 2010)

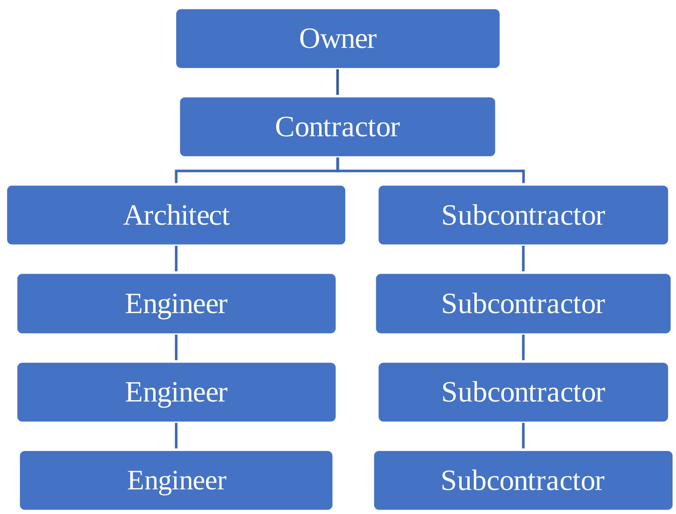


Figure 5: Parties in Design-Build Procurement (Gkk Works, 2013)

Design-bid-build is the lengthy traditional sequential approach where the owner holds two separate contracts one with the architect/engineer for the design of the project and another separate contract with the main contractor for the construction of the project (Halpin and Senior, 2011). The process of the design-bid-build procurement process is different from that of the design-build procurement process since the selection of the contractor is done after the completion of the final design by the architect as shown in figure 6.

Moreover, the owner will sign two separate contracts with the architect and the contract for the completion of the design and the construction of the project respectively as revealed in figure 7.

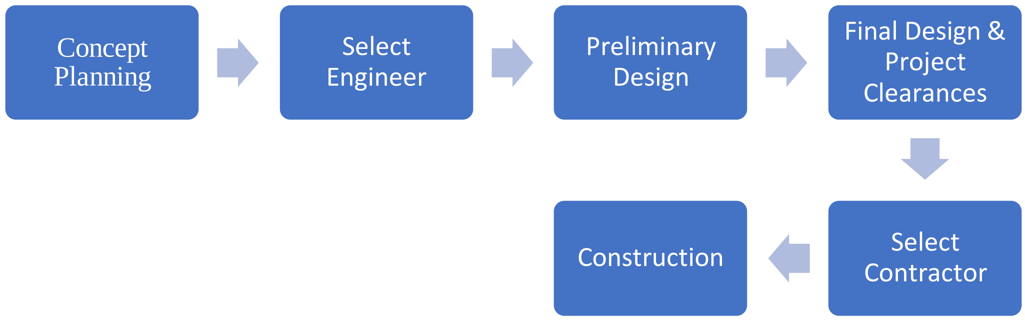


Figure 6: Design-Bid-Build Procurement Process (Jim Hall, 2010)

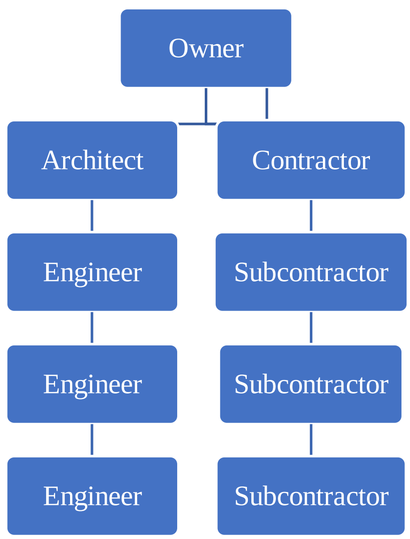


Figure 7: Parties in Design-Bid-Build Procurement (Gkk Works, 2013)

The main risks, according to the procurement system shown in figures 6 and 7, associated with the owner are that the design meets the project brief, the contract documentation reflects the design, and that the contract documents are complete. However, the contractor's risks are mainly related to constructing the project within the specifications and lump-sum specified and holding the responsibility for all workmanship and materials.

In CM contracts, one firm coordinates all types of activities from conceptualization to the acceptance by the owner. The main risk associated with the owner is that the brief should meet the project requirements. However, the CM firm takes full responsibility for design, scope, construction, workmanship, and materials. Note that there is a special type of CM contract named "construction management at-risk" where the construction manager will hold more risks and will be responsible for the construction of the project within the predetermined time and budget. The relationship between the owner and the other parties in a CM contract is shown in figure 8. For example, the owner signs three different contracts with the architect, the subcontractor and the CM where the architect will be responsible for the project's design, the subcontractors will be responsible for the project execution and the CM firm will be held liable for the project management and monitoring. The last type of delivery method to be discussed next is the partnership where two or more parties share responsibility for all the risks. There are no claims and no disputes in this type of delivery method.

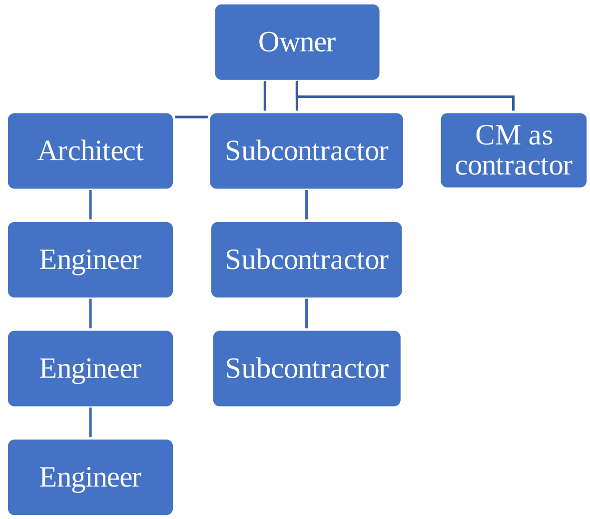


Figure 8: Parties in Construction Management Procurement (Gkk Works, 2013)

The selection process for the partnership is shown in figure 9 where there are two possible routes. The best route according to Terra and Aqua (2015) is to select the best contractor and invite him/her to participate in a workshop in preparation for the project.

To conclude, a design-build contract carries the highest risk for the contractor, whereas the management contracting contract is the riskiest for the owner as shown in figure 10. It is important to mention however that many risks are not allocated to specific owners which could change the results shown in figure 10 had the latter risks been agreed upon between the parties.

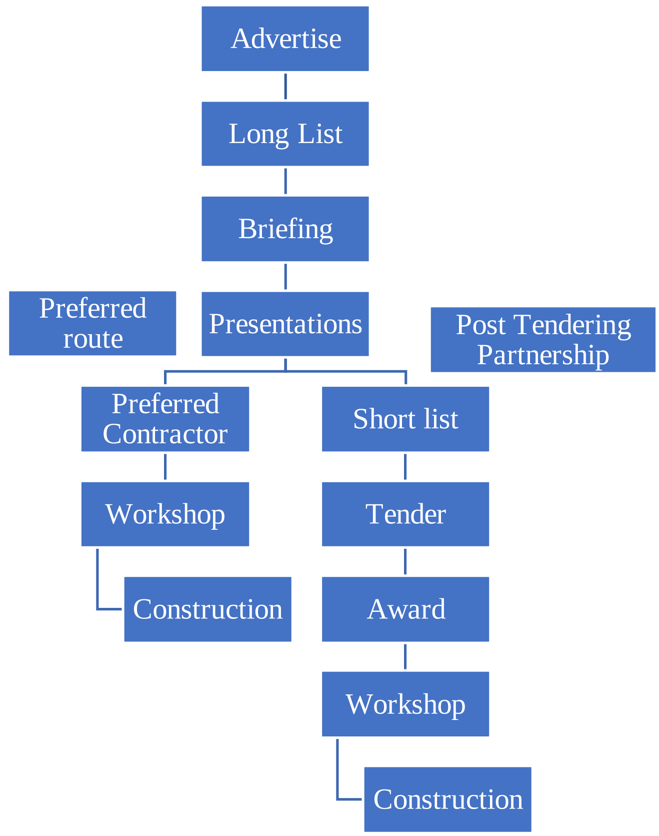


Figure 9: Selection Process for Partnership Procurement Type (Terra et Aqua, 2005)

Note that there are risks of choosing the contractor solely based on price and not the qualifications and the quality and other risks that are still not agreed upon between the parties towards which party should hold the responsibility for them in the contract documents.

This should be solved by using negotiation in cost-plus contracts where the owner can choose a contractor based on his risk management skills and experience if he/she wishes for example. Also, there are other forms of partnerships such as public-private partnerships which are a form of contracts where the private entity holds more risk than the public entity.

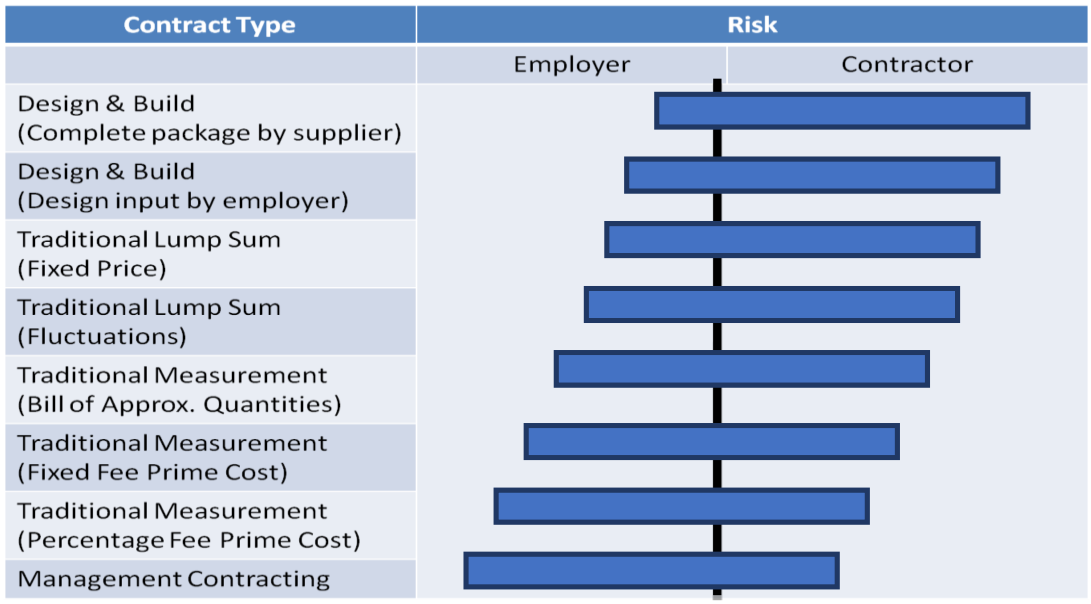


Figure 10: Risk Allocation between Parties (Ignatius and Buertey, 2016)

2.3 Overview of Risk Management Process

Risk management is the approach followed to proactively and systematically manage uncertainty surrounding a project. It is an important aspect of effective project management.

Risk management applies the law of Murphy "assuming that everything that can go wrong will go wrong". It includes several steps as shown in figure 11: identifying risks, performing qualitative analysis and quantitative analysis, plan risk response, and monitor risks (PMI, 2014). The latter figure elaborates on each step of the risk management process.

Identification of risks is important to recognize threats or opportunities of growth that are faced by the project at a certain uncertainty. The main tools used in identifying risks are checklist, brainstorming, risk documentation form, periodic risk reporting, collaboration with customers and stakeholders. The output of this process is the risk register.

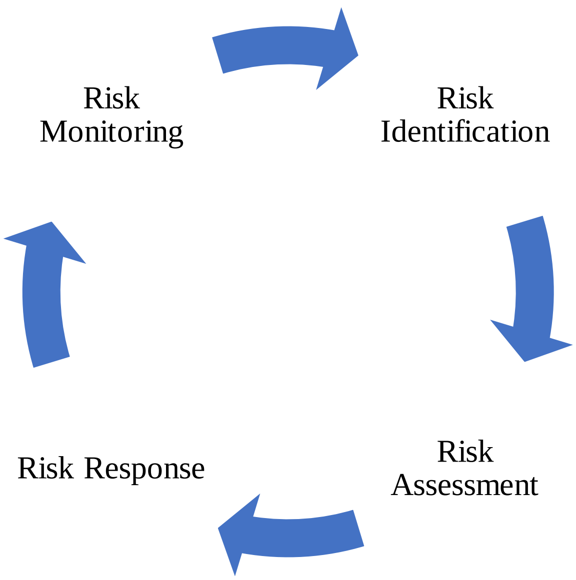


Figure 11: Overview of Risk Management Process (PMI, 2014)

Qualitative risk analysis is done to prioritize the risks. Several tools are available for this task such as SWOT analysis, root cause analysis, and PI matrix which helps in determining the probability and estimating the impact in order to prioritize the risks.

Quantitative risk analysis is done to determine the overall project risk. It is enacted using tools such as sensitivity analysis using tornado diagram, expected monetary value, decision trees (positive sign for opportunities and negative sign for threats), modeling, and simulation such as Monte Carlo simulation.

The comparison between quantitative and qualitative risk analysis is shown in table 2. However, it is important to mention that it is rare for qualitative risk analysis tools to be solely applied unless the project is small and simple. Moreover, as displayed in the table below, quantitative risk analysis tools require more resources and expertise than qualitative risk analysis tools. The response strategies for negative risks i.e. threats are to avoid, mitigate, or to transfer. While, the response strategies for positive risks i.e. opportunities are to exploit, to enhance, or to share. Other strategies for planning risk response are as follows: risk avoidance when there is a high risk, risk mitigation when the risk is unavoidable that one is forced to deal with the risk, risk transfer when one wants to pay a premium to an insurance firm in order not to deal with risk and risk acceptance when the expected profit is greater than the expected risk to deal with. The monitoring and control process is through auditing and reports in order to identify new risks, monitor triggering events, and track old and identified risks. The importance of risk management lies in the following: better project decisions, prioritizing project tasks, effective resource allocation, improved planning, and reduced project costs and stress.

Table 2: Evaluation of Quantitative and Qualitative Risk Analyses

Criteria\ Risk Analysis	**Qualitative Risk Analysis**	**Quantitative Risk Analysis**
Type of Risks	All project risks	Risks prioritized through qualitative analysis
Application	Performed in every project	Performed in large and complex projects
Principles	Subjective judgment of probability and impact	Calculation and measurement of impact on project objectives (cost and time)
Characteristics	Quick and easy	Time and cost intensive
Tools	Expert judgment, PI analysis, urgency analysis, etc	EMV analysis, decision tree analysis, Monte Carlo simulation, etc
Special Tools	No special software/tools	May require special tools

Risk management principles are centered on value creation and protection such as continuous improvement, best available information, human and cultural factors and integration, collaboration, and customization.

Risk management is directly related to procurement through risk allocation where the choice of the optimal contract type will lead to the success of the project and collaboration between different parties. Whereas, choosing the ill-chosen contract type and project delivery method might lead to an adverse relationship, losses, claims, and disputes which might lead to a disaster to all parties.

3. Literature Review and Bibliometric Analysis

3.1 Introduction

Risk management is the approach followed to proactively and systematically manage uncertainty surrounding a project. It is an important aspect of effective project management. The first publication on the topic of risk management in the procurement of construction was in the year 2004, whereas contractual risks were first investigated in the year 2007 which shows the necessity for further research and revision of the application of risk management in the procurement of construction. Moreover, the number of published articles on risk management in the procurement of construction has increased in the recent years due to the increase in awareness of the advantages of the application of risk management which results in augmented project performance, effective coordination and increased profitability as shown in the bibliometric analysis done and which is considered essential and vital especially in countries experiencing an economic crisis. Furthermore, the increase in the research on the topic of risk management in the procurement of construction might be due to the increase in the innovation in the procurement of construction. As a result, a bibliometric analysis is presented in this chapter in order to provide a comprehensive literature review on the topic of risk management and risks in the procurement of construction where a brief introduction in section 2 focusing on the methodology is described in detail showing the importance of each step. After this, the bibliometric analysis outcomes in section 3 are presented in addition to the content analysis in section 4 showing each of the five categories along with their respective sub-categories.

3.2 Methodology

A literature review and bibliometric analysis are conducted in order to explore and investigate the topic of risk management in the procurement of construction between the years 1989 and 2019. The latter methodology consists of the following steps as shown in figure 12: searching the following keywords: “procurement risks”, “risk management in construction”, “procurement definition” and “risk management in the procurement of construction”. Then, 143 articles were selected which are related to civil engineering and in the English language. Subsequently, 106 articles were retained that were considered of scientific significance and added value where the average number of journals left had an impact factor greater than 1 and belonged to Q2 or Q1.Afterward, a search was made on Google scholar to make sure that the retained pertinent articles included articles of the highest number of citations on Google scholar. The next major step conducted was conceptual analysis where the abstract and the full content of the articles were analyzed.

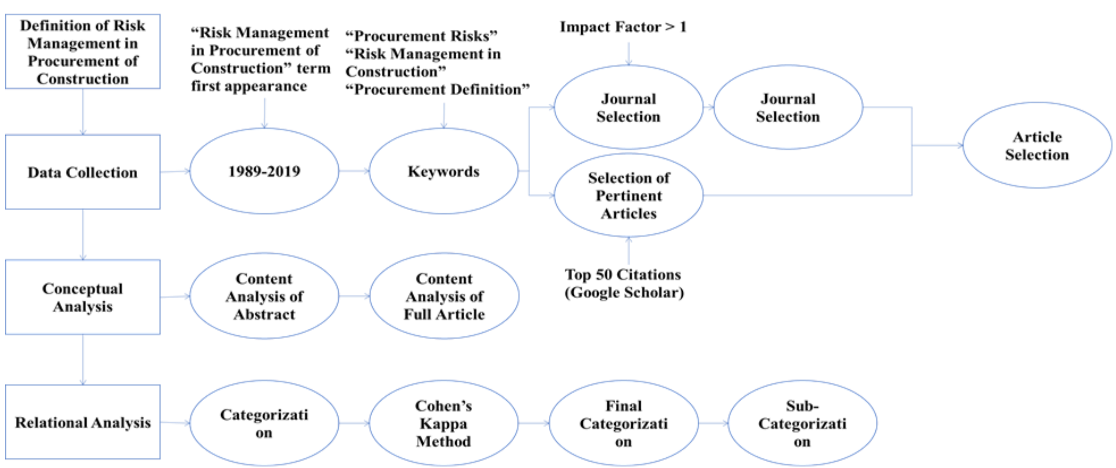


Figure 12: Research methodology: literature review and bibliometric analysis

The last step included applying relational analysis where the articles were categorized using content analysis and Cohen's kappa method where Cohen's coefficient was greater than 0.8 showing great agreement.

3.3 Outcomes

The bibliometric analysis proves that the application of risk management in the procurement of construction is very recent where only 10% of the articles were published between the years 1989 and 2006. Most of the articles were published in the year 2014 as depicted in figure 13 and table 3 after which there was a slight decrease in the number of published articles. The journals with the highest number of published articles are Procedia Engineering (7), Applied Mechanics and Materials (7), and International Journal of Project Management (6).

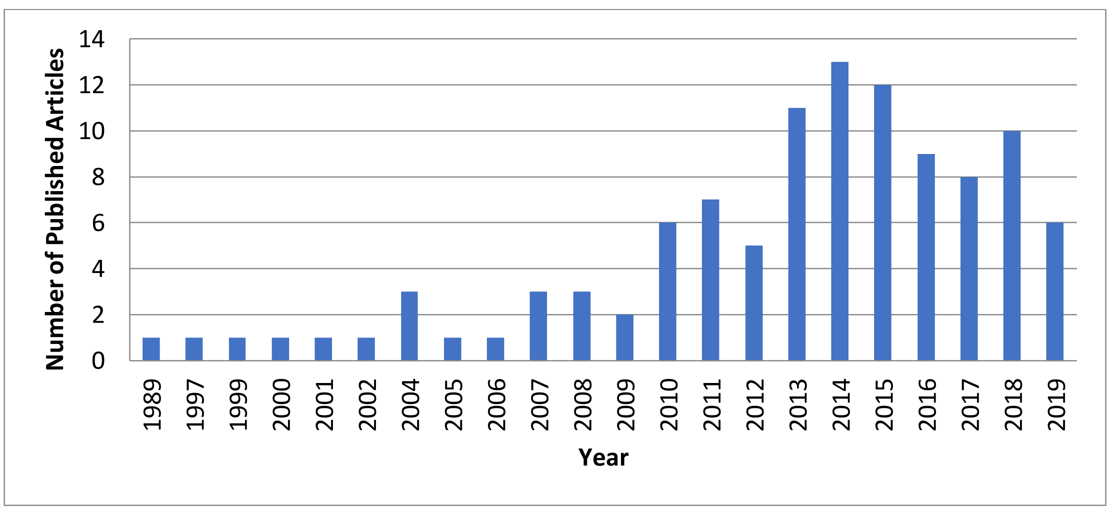


Figure 13: Risk Management in Procurement of Construction Papers Published over the Last 3 Decades

Table 3: Risk Management in Procurement of Construction Papers Published over the Last Three Decades (Journal list)

Journals	1989	1997	1999	2000	2001	2002	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	Total
International Journal of Strategic Property Management	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0	2
IJPM	0	1	0	0	0	0	1	0	0	1	0	0	0	1	0	0	1	0	0	0	1	0	6
CIB	0	0	0	0	0	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	2
Applied Mechanics and Materials	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	3	3	0	0	0	0	0	7
International Research Journal of Engineering and Technology	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	2	0	4
Procedia Engineering	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	2	0	3	0	0	7
Project Management	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1	0	2
Cost Engineering	1	0	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	3
European Journal of Social Science Research	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	2
Engineering, Construction and Architectural Management	0	0	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	3
Creative Construction Conference	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	2
Construction Management and Economics	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0	2
Management in Engineering	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1	0	0	0	0	2
Procedia Social and Behavioral Sciences	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	0	0	0	0	3
Total	1	1	1	1	1	1	3	1	1	3	3	2	6	7	5	11	13	12	9	8	10	6	106

As shown in table 4, most of the cited articles belong to Procedia social and behavioral sciences and Procedia engineering. The articles were then distributed into specific categories as explained in the methodology and shown in figure 13.

As observed in table 5 and figure 14, the research areas that are more appealing and interesting to researchers are “overview of the application of risk management in construction”, “process of risk management in construction” and “risk management in the procurement of construction". The limitation of this methodology is that it does not point out gaps in the literature of risk management in the procurement of construction.

Table 4: Top 50 Citations

Journals	Number of Articles	Number of Citations
International Journal of Project Management	3	1414
European Journal of Operational Research	1	436
Applied Soft Computing Journal	1	346
Procedia - Social and Behavioral Sciences	5	254
Procedia Engineering	5	186
International Journal of Strategic Property Management	2	140
Building and Environment	1	135
Emerald: Engineering, Construction and Architectural Management	1	130
Journal of Business Economics and Management	1	100
Technological and Economic Development of Economy	2	87
Journal of Management in Engineering - ASCE	2	79
International Journal of Managing Projects in Business	1	78
Construction Management and Economics	1	78
Engineering, Construction and Architectural Management	2	71
Procedia Computer Science	1	59
Procedia Economics and Finance	1	51
Canadian Journal of Civil Engineering	2	49
European Commission	1	47
the European Journal of Social Science Research	1	47
Cost Engineering	2	46
journal of civil engineering science and application	1	46
International Research Journal of Engineering and Technology	5	45
International Council for Building - CIB	2	43
Journal of Econometrics	1	40
KSCE Journal of Civil Engineering	1	40
Journal of Construction Management and Economics	2	36
HBRC Journal	1	35
Safety Science	1	27
Total	**50**	**4145**

Table 5: Number of articles and citations by category (TOP 50 articles)

Categories	Number of articles	Number of Citations
Procurement in Construction	5	218
Risks in Procurement of Construction	8	324
Overview of the Application of Risk Management in Construction	19	2119
Process of Risk Management in Construction	8	756
Risk Management in Procurement of Construction	10	728
Total	50	4145

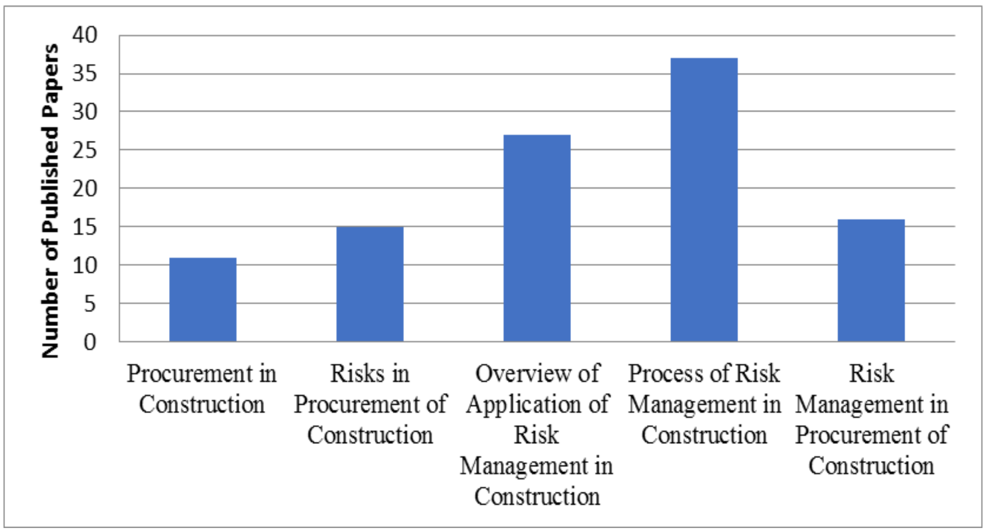


Figure 14: Risk Management in Procurement of Construction Categories

3.4 Content Analysis

The categories of relevant articles were divided into subcategories in order to perform a qualitative analysis of the articles in each subcategory. It is important to note that only relevant and cited articles are retained in the subcategories. The subcategories were decided upon after analyzing the content of the relevant articles where 143 articles were selected for review, yet only 106 articles were retained and applying Cohen's Kapa method.

As a result, the articles are distributed into five categories: procurement in construction, risks in the procurement of construction, overview of the application of risk management in construction, process of risk management in construction, and risk management in the procurement of construction.

3.4.1 Category: Procurement in Construction

This category introduces the topic of risk management in the procurement of construction by defining procurement and the types of contracts applied in construction. This category has a stable and constant growth throughout the years as shown in table 6. Moreover, this category also focuses on methods to improve the procurement process in construction by applying plan do study act cycle in order to achieve continuous improvement which is one of the most familiar and common techniques adopted in lean construction.

Table 6: Procurement of Construction Category

Category and Sub-categories	1989	2001	2002	2007	2008	2009	2010	2011	2013	2015	2019	Total	%
Procurement in Construction	1	1	1	1	1	1	1	1	1	1	1	11	10
Continuous Improvement	0	0	0	1	0	0	0	0	0	0	0	1	9
Procurement Definition	0	0	0	0	1	0	0	1	0	1	0	3	28
Types of Contracts	1	1	1	0	0	1	1	0	1	0	1	7	64

Sub-Category: Continuous Improvement

This sub-category has the least amount of articles where it only focuses on implementing methods from lean construction to achieve continuous improvement.

Continuous improvement can only be achieved through plan do check act cycle. The latter cycle is one of the main principles of lean manufacturing and lean construction, and its main purpose is to improve any process or individual. As a result, plan do study act cycle should be done in all phases of a project including procurement to achieve kaizen and sustainably better results (Bernardez, 2007).

Sub-Category: Procurement Definition

This sub-category focuses on providing a definition for the procurement process in construction in order to clearly define the boundaries of this process and parties involved in it. "A procurement system is an organizational system that assigns specific responsibilities and authorities to people and organizations and defines the relationships of the various elements in the construction of a project" (Naoum and Egbu, 2015).

As a result, procurement is directly related to risk management through the following factors: project delivery method, payment method, and degree of the partnership (Osipova and Eriksson, 2011a). However, despite the latter, there is a misalignment between the risk management tools available and their usage in contract risk management where the risk management tools are not used in an optimal and efficient way (Adams, 2008).

Sub-Category: Types of Contracts

The latter sub-category has the highest amount of articles in this category where it mainly highlights the definition of each type of contract used in construction. It is important to mention that the types of contracts used in construction are diverse and have unique characteristics that result in a different distribution of the risks between the involved parties.

Moreover, the type of the chosen contract has several impacts on the project and its objectives since it affects the control of quality, and the parties involved since the financial incentive is considered a very important enticement to all parties especially the contractors (Antoaneta Claudia Butuza, 2010). For instance, choosing the wrong procurement type has been one of the main reasons for poor project performance in African construction projects (Chege and Rwelamila, 2002). There are several types of contracts such as fixed price, unit price, and cost-plus contracts. Fixed Price contracts are used when the scope is well defined and work is quantifiable, whereas unit price contracts are used when the scope is known but not easily quantified. On the other hand, cost-plus contracts are only used when the scope is unclear (Ironmonger, 1989). Other forms of contracts include but are not limited to the following contracts: design-build, design-bid-build and public-private initiatives such as PPP and PFI (Oyegoke *et al.*, 2009) where PFI is an alternation of PPP with the difference in funding, and it is used mostly in the construction of public schools (Frédéric BLANC-BRUDE, 2013). Furthermore, contract costs are made up of direct costs and indirect costs in addition to the profit (Floor, 2001) where numerous procurement mechanisms can be applied such as multi-sourcing, single-point sourcing, average-bid method and truncated auction (Engel and Wambach, 2019).

3.4.2 Category: Risks in Procurement of Construction

This category introduces the concept of contractual risks in the procurement of construction and discusses the risk allocation between different parties in the project and the several models used in order to distribute the risks in an optimal manner where the risk owner will be the most competent party to handle and deal the risk.

This category is very recent where the articles are spread between the years 2007 and 2019 and where the most growth has occurred between the years 2015 and 2019 as depicted in table 7.

Table 7: Risks in Procurement of Construction Category

Category and Sub-categories	**2007**	**2008**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**Total**	**%**
Risks in Procurement of Construction	1	1	3	1	1	2	2	1	1	2	15	14
Overview of Contractual Risks	0	0	1	0	1	2	2	0	0	1	7	47
Risk Allocation	0	0	1	1	0	0	0	0	1	1	4	27
Risk Allocation Model	1	1	1	0	0	0	0	1	0	0	4	27

Sub-Category: Overview of Contractual Risks

This sub-category introduces the risks that occur in the procurement of construction where construction, contractual and engineering risks are the most occurring type of risks in construction (Mubin, Jahan and Gavrishyk, 2019). There are many procurements and contractual risks in each project. Each risk has a certain probability of occurrence, impact, and level of importance. An example of a highly occurring risk is a material requirement (Chen, 2012), whereas design error is regarded as the risk with the highest impact in highway projects (Ankit Vishwakarma *et al.*, 2016).

On another hand, having obtained the normal distribution, the probability of a particular magnitude of risk for a particular contract type can be determined, and as a result, the size of financial reserves could be planned (Dziadosz, Tomczyk and Kapliński, 2015).

The risks that have the greatest impact on tenders are the safety of workers, the interest rate, the disposal of bad plant and equipment, the unforeseen site conditions, the contractor default, and the change in scope (Sunday, 2016).On another hand, risk factors are found in every project and have an impact on increasing poor project management and costs.

The contractual risk factors that influence the construction procurement performance the most are corruption risks, conflict of interest, and unsuccessful technical feasibility (Dahiru and Bashir, 2015). For example, several types of risk factors are found in FIDIC contracts such as claims, time delays, and scope changes which show the need for high-quality risk management (Guo, Hu and Liu, 2014).

Sub-Category: Risk Allocation

The next sub-category in risks in the category of procurement of construction defines the risk allocation and shows how it is applied through the procurement of construction. Risk allocation, distribution of risks to different parties in the project, is usually done by the owner which might bring unfavorable conditions upon the contractor to start with (Peckiene, Komarovska, and Ustinovicius,2013).

The risk and effort level of the firm must be distributed downward from the best level of effort where an exogenous uncertainty can increase the effectiveness of the project (Deneckere, de Palma and Leruth, 2019). Compared to the owners, contractors are less indecisive on risk allocation (Ashmawi *et al.*, 2018). On the other hand, a firm becomes less risk-averse as it grows older and gains more experience (Campo, 2012).

Sub-Category: Risk Allocation Model

The last sub-category in the category of procurement of construction displays the several risk allocation models applied in the procurement of construction in order to obtain a sustainable and optimal risk allocation between the different parties in a project. This sub-category has several advantages where it leads to the obtaining of maximum benefits from risk allocation and mitigates any losses. Moreover, the choice of procurement is critical when solving disputes especially with the inherent risk allocation in each type of procurement (Younis and Wood, 2008). As a result, risk allocation models are needed to examine the allocation of risks based on accepted risk allocation principles instead of using the standard clauses of contracts (Lam *et al.*, 2007). For example, multiple criteria decision analysis can be used along with fuzzy topsis to determine the optimum risk allocation (Garshasb Khazaeni, Mostafa Khanzadi, 2012). On the other hand, other models are also in risk management such as maturity web-based models which are created to assess organizations' risk management maturity such as models based on ISO 31000 (Proenca *et al.*, 2017).

3.4.3 Category: Overview of Application of Risk Management in Construction

This category provides an overview of the application of risk management in construction by presenting the following sub-categories: definition of risk management, risk management barriers, risk management advantages, and drivers and project risks. This category contains articles dated from the year 1999 till the year 2018 proving that risk management has been applied in construction very lately in the 20th century.

Moreover, this category experiences unsteady growth from the year 2013 until the year 2018 as displayed in table 8. The importance of this category lies in the fact that it gives the reader a general and comprehensive view of the application of risk management in the construction industry.

Table 8: Overview of Application of Risk Management in Construction Category

Category and Sub-categories	1999	2006	2008	2010	2011	2013	2014	2015	2016	2017	2018	Total	%
Overview of Application of Risk Management in Construction	1	1	1	1	1	2	5	3	4	2	6	27	25
Definition of Risk Management	0	0	0	1	1	0	3	0	1	2	3	11	41
Risk Management Barriers	0	0	0	0	0	0	0	2	1	0	0	3	11
Risk Management Advantages and Drivers	0	0	1	0	0	1	0	1	1	0	1	5	18
Construction Project Risks	1	1	0	0	0	1	2	0	1	0	2	8	30

Sub-Category: Definition of Risk Management

A definition of risk management process in construction is provided in this sub-category highlighting its importance and showing its connection and relevance with construction project management where this sub-category has the highest amount of articles in the category of application of risk management in construction. Risk management, an essential part of project management, is the complete process of identifying, assessing, and responding to different types of risks in projects, and it is tightly linked with other forms of management such as the management of subcontractors and stakeholders (Ghaeli, 2018). For example, risk management can be integrated with stakeholder management to be more effective (Xia *et al.*, 2018). Furthermore, risk management can also be used for resource allocation which is dependent on the type of risk being managed (Zhao, Hwang, and Phng, 2014).

The earlier risk management is executed in a project, the more successful it is (Pawar, Bajad, and Shinde, 2017). Another form of risk management is joint risk management which could be achieved through several activities in procurement such as joint technical specification by all parties to the contract, cost-plus contract, and joint contracting with the subcontractors by the client and contractor (Osipova and Eriksson, 2011b).

Risk management should be done in every company in order to reduce the effects of risks. Moreover, risk management is done mostly in an informal manner (Nadaf *et al.*, 2018). Risk management can be beneficial in small projects in the long run, while the government can provide financial incentives such as tax rebates and grants (Hwang, Zhao and Toh, 2014).Among the several parties applying risk management in construction projects, project engineers are the party that uses the risk management tools the least in Lebanon whereas the most occurring risks in Lebanon are client-related as indicated in a quantitative risk assessment study done in Lebanon using risks identified in Malaysia and

Pakistan (Abou Chakra and Ashi, 2017). While, the size of the project and experience of the contractor plays an important role in the behavior and role of contractors in risk management (Kululanga and Kuotcha, 2010). Among the plentiful risk management techniques, expert judgment based on experience is considered as the most effective risk management technique in African construction projects in Ghana (Gyamfi and Boateng, 2016).

Then, after the application of risk management, a web-based approach can be used for answering questions to find out the level of maturity of risk management of an organization and to keep a record of its risk management history and benefit from past experiences (Serpella *et al.*, 2014).

Sub-Category: Risk Management Barriers

Barriers play an important role in decreasing the effectiveness of risk management in the procurement of construction. This sub-category discusses the main barriers in general and points to the barriers related to specific parties in the project.The main risk management barriers are the lack of knowledge and lack of experience (Serpell *et al.*, 2015). Other barriers are lack of awareness, passive consultants and clients, and the need for more investment as learned from the IT industry (Hwang and Chen, 2015).

The disadvantage of risk management and risk analysis is that they are based on principles that may mislead decision-makers such as how uncertainty is treated and how risk analysis is combined with techniques (Aven, 2016).

Sub-Category: Risk Management Advantages and Drivers

The role of this sub-category is to highlight the risk management advantages and drivers in order to illustrate the significance of the application of risk management in construction especially with the presence of several challenges. The advantages of risk management are many such as less effort, more precision, increased profitability, and more confidence in achieving the project objective as in increased project performance (Renault and Agumba, 2016).

There are some preventive measures to enhance risk management such as having more supervision from the government into risk insurance and enforcing internal risk management in organizations (Zhang and Zhao, 2013). Meanwhile, a robust risk management model is emphasized to be one of the optimal solutions that contribute to effective project management (Titarenko *et al.*, 2018).

On the other hand, the main risk management drivers are joint risk management, open dialogue, effective coordination, training, general conditions of the contracts, and early identification of potential risks (Osipova, 2008). While, schedule and quality are the main cost risk drivers (Kordas, 2015).

Sub-Category: Construction Project Risks

Construction project risks are of several types where each type must be managed in a unique and separate manner. As a result, this sub-category introduces several types of construction project risks where risks must be categorized and managed during each phase of the lifecycle of the project (Martin, 2006). Moreover, risks affect the objectives of the project and the ability of the parties to meet their targets.

There are several types of risks such as technical risks (e.g. change in the demand of the client), financial risks, logistics and construction risks, management risks, socio-political risks, and environmental risks (Sahu and Dudhe, 2016). Financial risks are more important than country risks and construction and operation (Al-Azemi, Bhamra, and F.M.Salman, 2014) and are regarded to have the highest likelihood of occurrence in Arabian construction projects (Eskander, 2018). The latter risks could be handled by using look-ahead schedules while implementing failure mode and effect analysis (Wehbe and Hamzeh, 2013). Moreover, project risks are affected by several factors such as the availability of resources and the level of complexity of the project (Akinbile, Ofuyatano, Oni, and Agboola, 2018). Each party perceives risks differently from its point of view. For example, the highest risk according to consultants was considered the low level of productivity due to the poor performance of subcontractors, unskilled workers, and difficulty in finding skilled workers on time (Vidivelli and Surjith, 2014).

In addition to the latter, both owners and contractors give the highest importance to risks such as safety, quality of work and financial failure (Syed M. Ahmed, Riaz Ahmad, 1999).

3.4.4 Category: Process of Risk Management in Construction

This category has the highest percentage of articles since it focuses on the process of risk management and the steps needed. As can be seen in table 9, there is a certain growth experienced after the year 2010 which shows an increase of interest in the topic of risk management in the construction industry where the highest number of articles were published in the years 2013 and 2014.

Sub-Category: Risk Identification

The most common set of steps of the risk management process are risk identification, risk analysis, risk assessment, risk control, risk surveillance, and goal control (Szymański, 2017a).This sub-category focuses on the first which is risk identification where risk identification and preliminary risk analysis through matrix diagrams are the most popular (Dziadosz and Rejment, 2015). The most used risk identification tools are brainstorming, checklists, lessons learned, risk review meetings, and Delphi technique (Nawaz, Waqar, Shah, Sajid and Khalid, 2019).

Table 9: Process of Risk Management in Construction Category

Category and Sub-categories	**1997**	**2000**	**2004**	**2005**	**2007**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**Total**	**%**
Process of Risk Management in Construction	1	1	1	1	1	1	1	5	2	6	7	3	1	2	3	2	37	35
Risk Identification	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	1	3	8
Risk Analysis	1	0	0	0	1	0	0	2	1	1	4	0	0	0	1	0	11	30
Qualitative Risk Analysis	0	0	0	0	0	0	0	1	0	0	1	0	0	0	0	0	2	5
Quantitative Risk Analysis	0	0	0	1	0	0	0	1	1	2	1	1	0	0	2	0	9	24
Project Safety Risk Assessment	0	0	0	0	0	0	0	1	0	1	1	0	0	0	0	1	4	11
Risk Response	0	1	1	0	0	1	1	0	0	1	0	1	1	1	0	0	8	22

Sub-Category: Risk Analysis

The 2nd step in the risk management process is risk analysis. This sub-category has the largest number of articles in the category of the process of risk management in construction which shows the criticality and importance of this step. Risk analysis is used to assess the impact of a certain risk on the project objectives where time and cost risks are correlated in order to obtain accurate results. The impact of a risk is obtained by calculating the product of the probability of occurrence and level of severity (Chan *et al.*, 2011). The development of risk analysis techniques has very low growth (Olalekan Mumuni Ogunbayo, 2014).

A radar diagram can be used to select the most appropriate risk analysis technique according to four criteria such as maturity, complexity, size, and focus (De Marco and Jamaluddin Thaheem, 2014). Note that radar diagrams are considered themselves as qualitative risk analysis techniques (Marco *et al.*, 2012). The main driver of risk assessment is the coordination and involvement of construction teams (McGoey-Smith, Poschmann, and Campbell, 2007).

While, the main barrier to risk analysis is the lack of understanding of project managers which requires education and training (MacLeod and Akintoye, 1997). More innovative risk analysis techniques can be created by combining several tools such as the fuzzy approach and the analytical hierarchy process (Rezakhani, 2013). The fuzzy approach can contribute by changing linguistic risk surveys into quantitative measures (Nieto-Morote and Ruz-Vila, 2011). Else, fuzzy can be combined with other methods such as topsis to develop more complex models (Taylan *et al.*, 2014). As a result of applying risk assessment and risk mitigation, time and cost contingencies, and reserves decrease (Aderbag, Elmabrouk, and Sherif, 2018).

Sub-category: Qualitative Risk Analysis Techniques

Few articles focus on qualitative risk analysis since they are fairly simple and do not require major simulation or study. Qualitative risk analysis techniques include but are not limited to the following: interviews, P-I matrix, expert judgment, questionnaires, surveys, risk breakdown structure, comparing options, root cause analysis, descriptive analysis, and ranking options.

Moreover, surveys and interviews require reliable sources of information are engineers, project managers, and doctorate holders (Liu and Li, 2014). Qualitative risk analysis techniques are used more than quantitative risk analysis techniques in the construction industry.

A typical example of the latter would be the Lithuanian construction industry (Banaitienė, Banaitis, and Norkus, 2011).

Sub-Category: Quantitative Risk Analysis Techniques

Quantitative risk analysis techniques differ from qualitative risk analysis techniques since they are more complex and require more specialized tools that offer more space for research as shown in table 9 where authors are tempted to do more research on quantitative risk analysis techniques. The quantitative risk analysis techniques are numerous and include but are not limited to the following: fuzzy risk assessment to appropriately deal with contractor's risks, earned value management, judgmental risk analysis process which provides better risk prioritization when faced with limited data, risk assessment impact model which is simple, not time-consuming and flexible, FMEA, decision making/risk matrix, fault tree analysis, Monte Carlo simulation method, PERT, fuzzy logic, FMEA in last planner system, AHP, breakeven analysis, multi-criteria risk assessment, CPM with careful scheduling for claims, expected monetary value, trend analysis where time and cost are related and sensitivity analysis.For instance, earned value management (Devi, 2018), decision tree analysis (Thaheem, Marco and Barlish, 2012), multi-criteria risk assessment (Tamošaitienė, Zavadskas, and Turskis, 2013) and topsis (Gupta and Thakkar, 2018) are used to analyze delays. While, critical path method is important for contracts concerning settling down claims at the end of the project (Liu, 2013).

Each of the techniques stated above has its advantages and disadvantages, yet the most suitable method for obtaining an output a range remains to be Monte Carlo simulation (Wang and Shi, 2014) which depends on the different distribution of each risk studied (Sato, Kitazume and Miyamoto, 2005).

Expert judgment, the likelihood of occurrence, and impact help to transform the risk analysis procedure from qualitative and subjective to objective and quantitative (Lin, Lin and Tyan, 2011). For the latter purpose, several techniques are invented such as the analytical hierarchy process which is flexible, systematic and includes several views through averaging, yet it is considered one of the time-consuming risk analysis techniques (Sharma, 2015).

Sub-Category: Project Safety Risk Assessment

Safety of workers and accidents are one of the most persistent concerns on a daily basis for the project manager and site engineer. This sub-category explores project safety risk assessment where it is considered as a key aspect for efficient construction project management since construction sites serve as one of the most frequent places of accident events (Aminbakhsh, Gunduz and Sonmez, 2013). Furthermore, falling from high elevations and being trapped between two objects are given more significance when studying occupational accidents due to their high level of severity (Koulinas *et al.*, 2019). Occupational safety can be increased by implementing efficient preventive measures and investing in machinery, safety equipment, and better training of employees (Majumder, Debnath and Biswas, 2014). However, data from previous construction accidents are complex and cannot be used to predict the risk for a certain accident type due to the specific and unique characteristics of each project site (Lin, Lin and Tyan, 2011).

Sub-Category: Risk Response

This sub-category focuses on risk response which depends on the attitude of the risk owner where there is no one best way to deal with all types of risks (Perera, 2009).

For example, risk retention or mitigation depends mostly on the contractor's willingness (Jarkas and Haupt, 2015). As a result, several risk responses exist such as risk avoidance, risk transfer, risk mitigation or reduction, risk exploit, risk share, risk enhance, risk acceptance, and contingency plan. The risk response and plan are usually studied in order to check how to share or mitigate the risks and their impacts (Rauzana, 2016).

Risk reduction is the most used risk response after which comes risk transfer, risk elimination, and risk retention (Lyons and Skitmore, 2004). Risk reduction includes but is not limited to calculating the budget and time needed, risk description, and responsibility allocation (Khumpaisal, 2010). On another hand, several activities can be done to transfer risks in highway projects such as contract negotiation, subcontracting, insurance, claims, or to avoid risks such as improving execution, signing favorable contracts, investigating bid conditions, and signing supplementary contracts (Li, 2013). While for risk mitigation, the most effective technique lies in producing an accurate schedule or close supervision and coordination (Szymański, 2017). After a risk response is enacted, the risk management plan can be documented for future use (Kim and Bejaj, 2000).

3.4.5 Category: Risk Management in Procurement of Construction

This category is one of the most important categories since it further explores the process of risk management in the procurement of construction. The growth rate fluctuates between the years 2010 and 2019 as revealed in table 10. The latter category is made up of the following sub-categories: the definition and application of risk management in the procurement of construction and the effect of the chosen procurement type in construction.

The effect of the chosen procurement type on the risk management in the procurement of construction will make it the choice of contract type more clear for the parties in the construction project which will decrease the need for arbitration, the number of disputes and the stress and increase coordination between the parties in a construction project.

Table 10: Procurement Risk Management Category

Category and Sub-categories	2004	2010	2013	2015	2016	2017	2019	Total	%
Risk Management in Procurement of Construction	2	3	1	3	2	4	1	16	15
Definition and Application of Risk Management in Procurement of Construction	0	2	1	1	0	4	0	8	50
Effect of Chosen Procurement Type	2	1	0	2	2	0	1	8	50

Sub-Category: Definition of procurement risk management

The first sub-category in the category of risk management in the procurement of construction focuses on defining the application of risk management in the procurement of construction where the most important stage in procurement risk management is a clear allocation of responsibility for the management of a certain contractual risk to an accountable individual (Murray, 2013).

The latter is usually done in the general conditions of a contract which are well-developed documents that facilitate clear risk allocation between the project's actors (Procurement, 2017). Another way of applying risk management is through studying each clause and condition of the contract and then applying qualitative and quantitative risk analysis and suggesting several methods of management such as payment for extra costs, re-estimation, and insurance (Pawar, Jain and Gaikwad, 2015). The latter application of risk management in procurement could be developed through a construction risk management system (Park, Lee and Ahn, 2017).

Note that after the risks are identified and responded to using procurement risk management in public contracts, risk can be decreased in public procurement by decreasing risk aversion and increasing innovation in procurement (L. Tsipouri *et al.*, 2010). For example, contractors' bids could be evaluated on more sustainable criteria such as level of expertise, risk maturity, quality of work, etc (Perrenoud *et al.*, 2017).

On another hand among the different parties involved in a project, contractors are considered to be most active in risk management, while joint risk management is still considered to be the optimal procurement option for unknown risks (Gupat, Divya and Sharma, 2017). In addition to the latter, for innovation to be applicable in the procurement of construction, the public sector should become more familiar and able to deal and manage all contractual risks using comprehensive risk management strategies since the latter will become inevitable in high-risk projects (Kalvet, 2010).

Sub-Category: Effect of Chosen Procurement Type

The last sub-category focuses on the effect of the chosen procurement type on risk management in the procurement of construction where it is proven that the frequency of risk categories is directly related to the contract type chosen (Bloomfield *et al.*, 2019). There is a clear connection between the procurement option and risk management in the chosen construction projects where the most recent trend is towards partnerships and the integration of information technologies (Ruparathna and Hewage, 2015). For instance, design-bid-build contracts do not create opportunities for open discussion of project risks and joint risk management, design-build projects offer a higher degree of collaboration in risk management due to the involvement of the contractor in early phases while partnering helps to establish cooperative relationships.

Meanwhile, all project risks including procurement risks change their rankings during the project lifecycle which necessitates further actions in order to achieve effective risk management in all contract types and delivery methods (Tsai and Yang, 2010). Procurement options are more prone to technological risks than natural disasters (Gyamf, 2016). Moreover, lack of involvement and participation of contractors especially in the tendering stage leads to increased financial risks such as poor resources (Taghipour *et al.*, 2015). For example, using CM, the errors in design and specifications will be minimized since the contractor would be participating from the early phases of the project (R.A. *et al.*, 2016). On the other hand, a third-party contract is considered as a source of risk to the owner in terms of finishing the project on time and within budget (CIDB: South Africa, 2004). Moreover, balancing the fixed price in design-build contracts and not failing at tendering is very important to mitigate future risks in procurement where design-build contracts are considered to be more sensitive to economic and political risks. Furthermore, the client should pay great attention to providing detailed design drawings in the bid documents and reducing the number of change orders to mitigate contractual risks (Öztaş and Ökmen, 2004).

4. State of the Practice of Risk Management in Procurement of Construction Industry in Lebanon

4.1 Introduction

The first main objective of this research is to determine the state-of-the-practice of risk management in the procurement of construction industry in Lebanon, identify the most important risks as per practicing engineers, and to discern any obstacles for its full deployment. To do so, a survey was conducted using an online questionnaire.

This survey was done according to the following steps: research on the population involved, research on the survey method, research on analysis procedure of survey results, and the preparation of the questionnaire and its translation to the languages needed.

Target Population

The target population is working engineers in the construction industry in Lebanon. The main organization that oversees the construction industry is the Order of Engineers and Architects (OEA) in Lebanon. According to OEA, the total number of active and registered civil engineers in Lebanon, excluding north Lebanon, is 6,413 engineers (OEA,2019). Out of these, the number of civil engineers working in Lebanon is 2,402; however, only 1,431 have provided their contacts to the OEA and can be contacted. The sample size required when the population size is 1,431 while assuming a confidence level of 95% and a margin of error of 10% is calculated using Cochran's formula (Bartlett, Kortlik and Higgins, 1977). Note that the population size does not affect the sample size needed as shown in Cochran's formula. As a result, the survey was also shared on linked in resulting in a population of 2000.

Cochran's formula is given by $n = \frac{Z^2pq}{e^2} = \frac{1.645^2 * 0.5^2}{0.1^2} = 67.65$ where e is the estimated level of error, p is the estimated percentage of the population that possesses the tested criteria where 50% is the maximum and conservative value and Z is the abscissa on the Z curve corresponding to a certain confidence level. A margin of error of 10% is typical to the margin of error assumed in all surveys used in the papers presented in the literature review that include surveys. Therefore, a minimum of 68 respondents is required.

The Questionnaire

The questionnaire contained 21 questions with multi-choice answers as displayed in the appendix. Note that the survey questions were made available in both the English language and the Arabic language according to the preference of the respondent. The questionnaire was developed after a comprehensive literature review of the topic and the theoretical background. The direct results of the questionnaire are plotted using histograms in addition to the correlation test to show the relationship between the respondents' backgrounds and the several aspects tested (Ramshaw, 2018). The questionnaire was composed of four parts. The first part was made up of the first six questions which are general questions focused on age, job position, formal education, years of experience, nature of projects involved in, and work experience outside Lebanon.

The second part consisted of five questions which tend to investigate the attitude of Lebanese civil engineers towards risk management where the questions are centered on the following topics: perception of risks, the party applying risk, stage in the procurement of construction in which the application of risk management is considered the most effective and the knowledge and application of risk management stages in the procurement of construction.

The third part includes only four direct questions that ask the respondent to choose the most important risk in each of the following phases: preliminary, tendering, execution and completion phases in the procurement of construction industry in Lebanon.

The final part focuses on risk response, risk monitoring and the main barriers of applying risk management in the procurement of construction where the respondent will select the main obstacle of applying effective risk management in the procurement of construction, his/her preferred risk response strategy, risk monitoring tool, preferred contract type and project delivery method taking into consideration the different risks that can occur in the procurement of construction in the Lebanese industry.

Survey Implementation and Response Rate

The questionnaire was built using Google forms and sent to the intended population using the following online platforms: bulk SMS, WhatsApp, LinkedIn, and e-mail. The response rate obtained using each of the latter platforms is shown in table 11.

The overall response rate was 14 % which is acceptable as the response rate is expected to be less than 20% for internet-based questionnaires (Wiley, 2015). The platform with the highest response rate is Linkedin.

Table 11: Response Rate for Each Platform Used

Tool Used	Sent	Received	Retained
What's App	300	22	22
Linked In	500	193	155
SMS	1000	29	27
Email	200	42	37
Total	2000	286	241
Percentage	100.00	14.30	84.27

Analysis Tools

After implementing the survey, 286 responses were received. These responses data were validated, formatted, and inputted into SPSS, a statistical analysis software, where different analysis tools were utilized.

4.2 Survey Statistical Validity

4.2.1 Internal Reliability

As mentioned earlier, 286 responses were received initially, yet after screening the responses and eliminating non-valid responses 241, responses were retained. Cronbach's alpha was tested for internal reliability and internal consistency of the responses and it resulted to be almost 0.6 as shown in table 12 which is considered acceptable for exploratory studies (Leimeister, 2009). In non-explanatory studies, Cronbach's alpha should be at least 0.7 to be justified (Darren and Mallery, 2003).

Only numerical items were used to test the reliability factor to avoid any errors: age, years of experience, number of countries the respondents worked in other than Lebanon, number of types of projects the respondents were involved in, number of risk management stages respondents are familiar with and apply respectively, number of parties that apply risk management and the number of preferred risk responses chosen.

Table 12: Reliability Statistics

Cronbach's Alpha	Cronbach's Alpha Based on Standardized Items
0.569	0.657

4.2.2 Normality Test

A normality test was conducted in order to check if parametric or non-parametric tests should be used. Accordingly, the skewness and kurtosis were tested for all the data obtained with the results shown in table 13.

Skewness is used to indicate the amount of the deviation of the overall shape of the data's distribution from a normal distribution. While kurtosis is tested to compare how much the tails of the data distribution differ from the tails of a normal distribution.

For the data to be normally distributed, the skewness should be zero, and the kurtosis should be greater than three (Date, 2019).As shown in the results, the skewness of all the variables is different than zero and the kurtosis is less than three. Thus, the data is not normal and non-parametric tests should be used.

Table 13: Normality Test Using Kurtosis and Skewness

Criterion Tested	N	Skewness		Kurtosis	
	Statistic	Statistic	Standard Error	Statistic	Standard Error
Most Important Risk in Preliminary Phase	241	-.786	.157	-.313	.312
Knowledge of Risk Management Stages	241	-.734	.157	.045	.312
Work Experience Outside Lebanon	241	-.570	.157	-.956	.312
Risk Response Strategy Preferred	241	-.503	.157	-.594	.312
Perception of Risks	241	-.296	.157	-1.270	.312
Application of Risk Management Stages	241	-.272	.157	-.866	.312
Contract Type Preferred	241	-.159	.157	-1.530	.312
Tools Used to Monitor Risks	241	-.115	.157	-1.754	.312
Most Important Risk in Execution Phase	241	-.113	.157	-1.274	.312
Most Important Risk in Completion Phase	241	-.049	.157	-.938	.312
Party Applying Risk Management	241	.179	.157	-1.440	.312
Phase for Most Effective Application	241	.186	.157	-1.234	.312
Main Obstacle for Applying Risk Management	241	.597	.157	-.544	.312
Job Position	241	.643	.157	-1.362	.312
Most Important Risk in Tendering Phase	241	.853	.157	-.737	.312
Years of Experience	241	.981	.157	-.393	.312
Nature of Projects Involved In	241	1.127	.157	.407	.312
Delivery Method Preferred	241	1.198	.157	.613	.312
Formal Education	241	1.437	.157	2.986	.312
Age	241	1.933	.157	2.458	.312
Valid N	241				

4.3 Survey Results

4.3.1 General Questions

The general questions asked the respondent to provide information about his background. The majority of the respondents ranged from 24 and 34 years old. The average age of respondents was 33.6 years with a standard deviation of 9.078. While, most of the respondents were either site engineers, consultants, or construction project managers as shown in figure 15. On another hand, when grouping site engineers, construction project managers, procurement engineers, and contractors, it would result in almost 60% of the respondents working in a contracting position, while only 35% of the respondents were working in a consultancy position (estimation engineers and consultants).

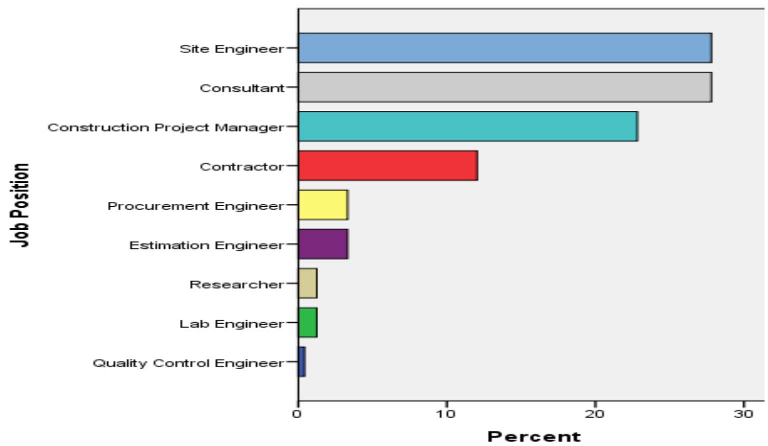


Figure 15: Job Position Distribution

With respect to formal education, the majority of the respondents held either a bachelor's or master's degree as depicted in figure 16. While, only about 5% and 1% held a Ph.D. and MBA degree respectively.

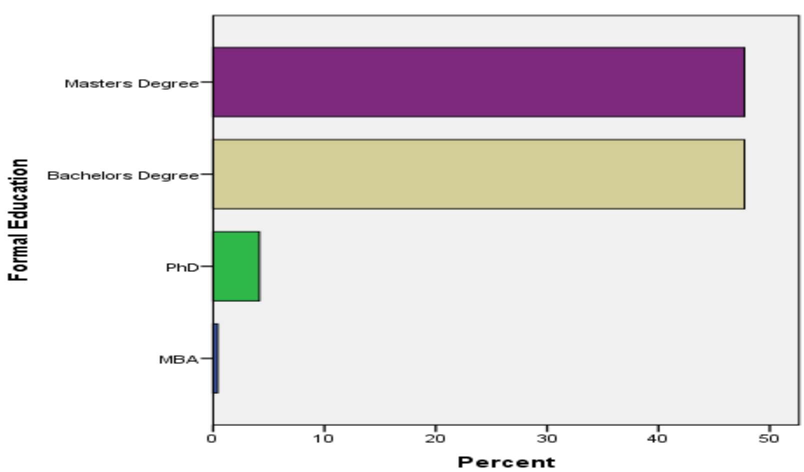


Figure 16: Formal Education Distribution

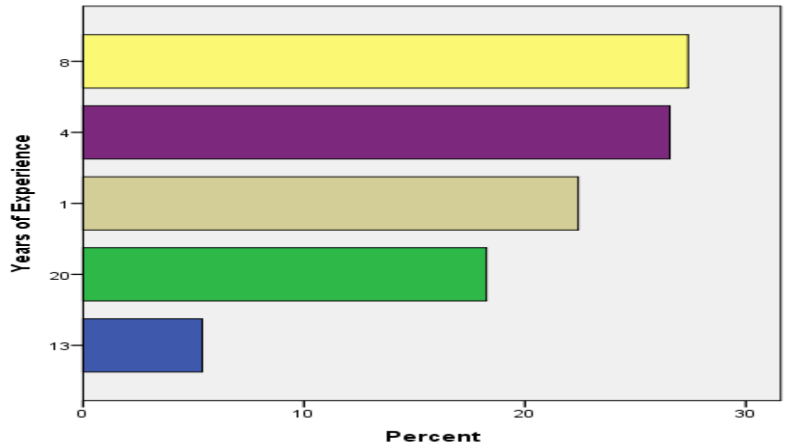


Figure 17: Years of Experience Distribution

Concerning the years of experience, the average years of experience among the respondents were 7.43 years with a standard deviation of 3.597 years. In addition to the latter, only 18% of the respondents had 20 years of experience as displayed in figure 17.

While 42% of the Lebanese civil engineers worked in Lebanon only, about 38% of the Lebanese civil engineers worked in the MENA region as it is clearly evident in figure 18.

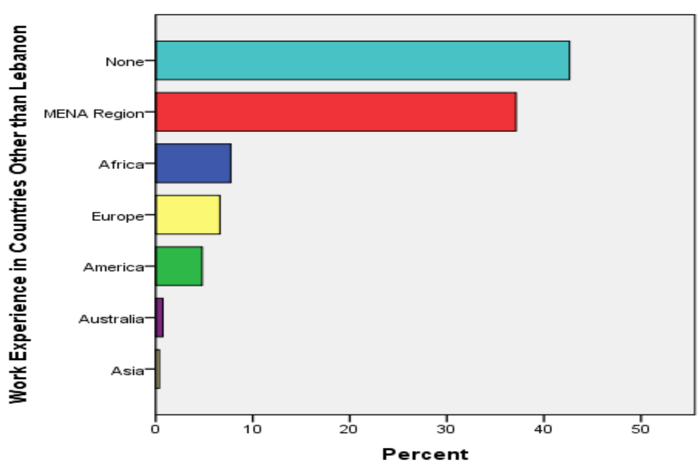


Figure 18: Work Experience outside Lebanon

Finally, with respect to the nature of the projects, the respondents were involved in, buildings; infrastructure, and transportation were the highest selected choices as depicted in figure 19. Moreover, it is shown that on average each respondent worked in at least two types of projects throughout his career as shown in figure 20.

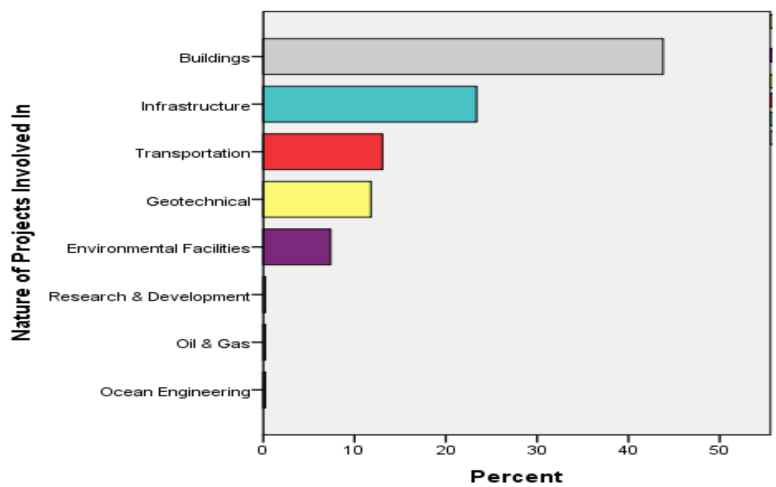


Figure 19: Histogram of the Nature of Projects Involved In

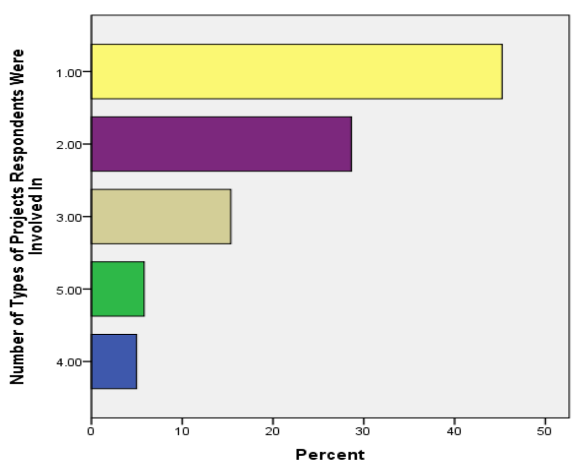


Figure 20: Histogram of the Number of Types of Projects Respondents Were Involved In

4.3.2 Attitude towards Risk Management in Procurement of Construction

The survey responses indicated that 37% of Lebanese civil engineers claim to be familiar with all risk management stages.

However, only 11.6% of the respondents apply all the risk management stages as shown in tables 14 and 15. Moreover, on average each Lebanese civil engineer applies and is familiar with only two risk management stages.

Furthermore, risk identification is the most applied and known risk management stage in Lebanon. In addition to the latter, almost 50% of the Lebanese civil engineers agree on the fact that the application of risk management would be most effective if applied in the tendering phase of the procurement process as shown in figure 21.

Table 14: Knowledge and Application of Risk Management Stages

Risk Management Stage \ Criterion	Knowledge	Application
Risk Identification	31%	32.8%
Qualitative Risk Analysis	22.2%	18.3%
Quantitative Risk Analysis	21.1%	17.7%
Risk Response	21.5%	25%
None	4.2%	6.3%

Table 15: Number of Risk Management Stages: Known and Applied by the respondent

Number of Selected Risk Management Stages	Knowledge	Application
0	10%	12%
1	29.9%	33.6%
2	21.2%	27.8%
3	2.5%	14.9%
4	36.5%	11.6%

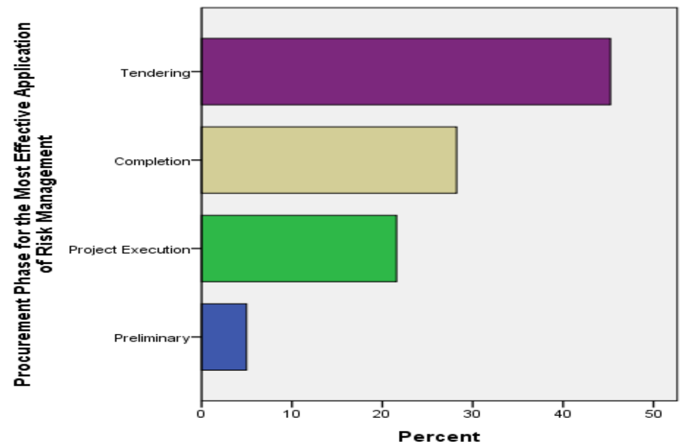


Figure 21: Histogram of the Procurement Phase for the Most Effective Application of Risk Management

On another hand, on average two parties with a standard deviation of one were involved in the application of risk management as shown in figure 22. However, the contractors were the parties mostly conducting risk management as depicted in figure 23.

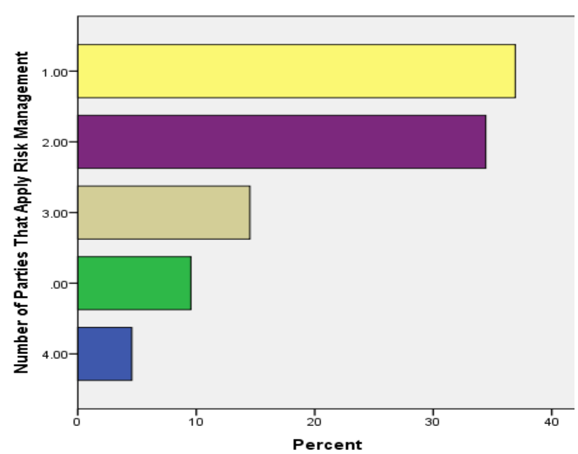


Figure 22: Histogram of the Number of Parties Applying Risk Management

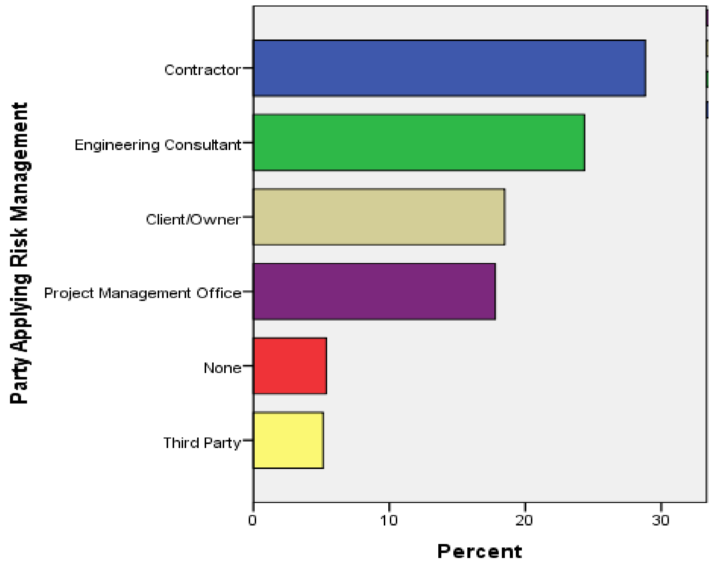


Figure 23: Histogram of the Party Applying Risk Management

With respect to the perception of risks, almost 39% of Lebanese civil engineers are risk-neutral. While almost 38% of Lebanese civil engineers are risk-averse perceiving risks as threats, and only 22% of Lebanese civil engineers are risk-seeking or risk-taking perceiving risks as opportunities as shown in figure 24.

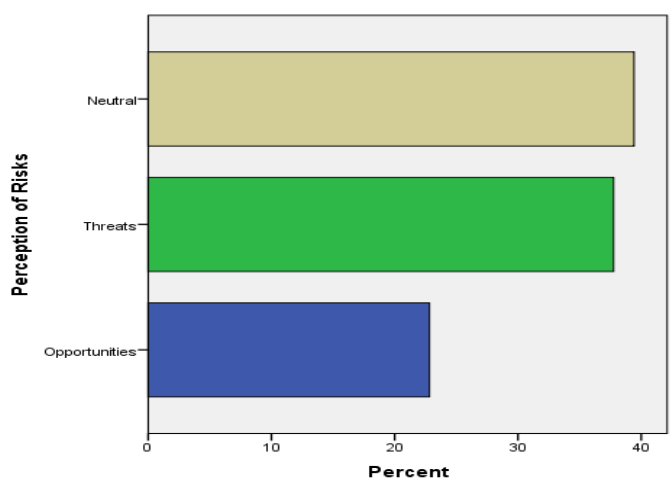


Figure 24: **Histogram of the Perception of Risks**

4.3.3 Risks in Each Procurement Phase

In this section, respondents were asked to identify various risks in order of importance as per their opinion in four phases of construction: preliminary, tendering, execution, and completion. The most important risks in each procurement phase are plotted versus the percentage of votes each risk received in its respective phase in figure 25. The responses show that the most important risks in the preliminary phase are poor risk identification (35.7%), lack of financial resources (24.9%), and under/over-statement of the needs (13.3%). Next, the most important risks in the tendering phase are the evaluation of tenders according to the lowest cost only (42.7%), high competition between tenderers (11.2%), and inadequate tenders full of errors (9.5%). Subsequently, the most important risks in the execution phase are the unforeseen site conditions (23.2%), defective design (14.1%), and communication barriers (9.5%). While, the most important risks in the completion phase are difficulty obtaining the completion certificate due to construction errors (24.9%), disputes/need for arbitration (20.7%) and delay in the release of the final payment (19.9%).

Furthermore, the overall most important risks between all phases in decreasing order of importance are the evaluation of tenders according to the cost only, poor risk identification, and difficulty obtaining completion certificate due to construction errors.

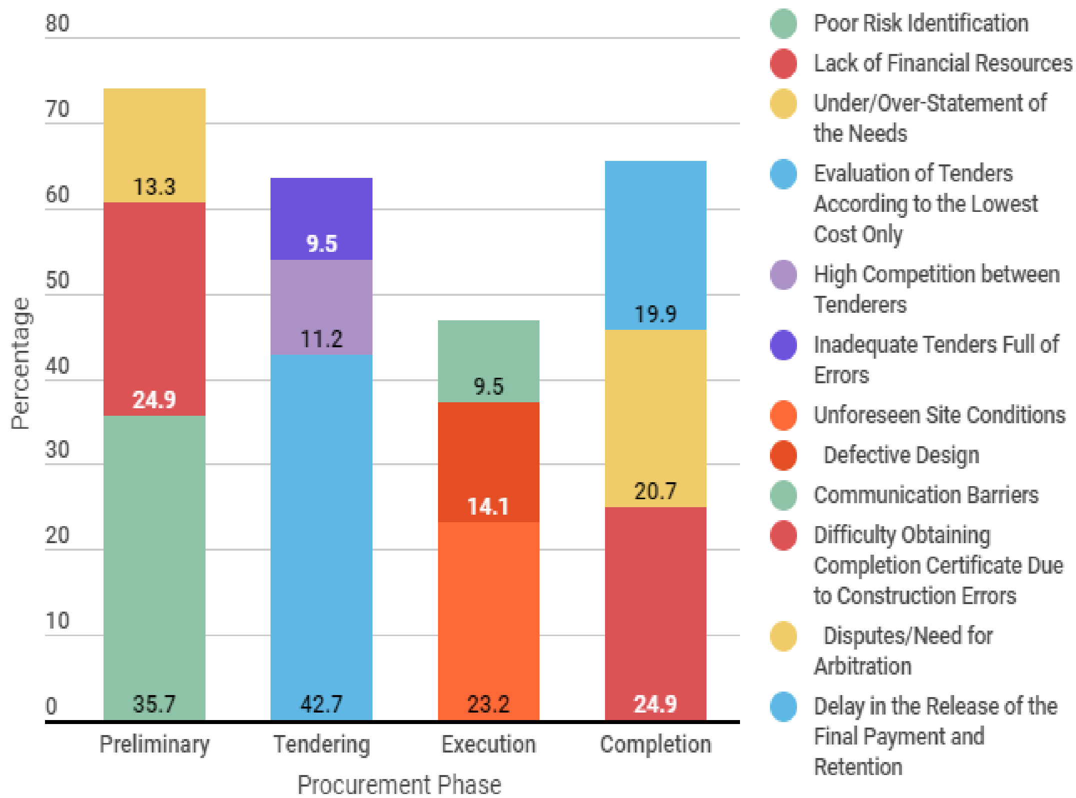


Figure 25: Most Important Risks in Each Procurement Phase

4.3.4 Risk Monitoring, Risk Response, and Barriers of the Application of Risk Management

The survey results show that Lebanese civil engineers use reports and earned value management mostly as tools for monitoring risks, yet only 20% of Lebanese civil engineers use meetings as shown in figure 26.

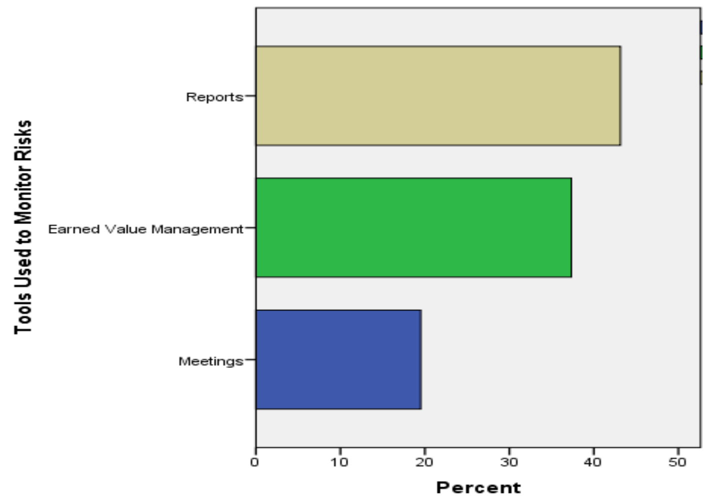


Figure 26: Histogram of Tools Used to Monitor Risks

With respect to the preferred risk response strategy, risk mitigation, avoidance and sharing were the most selected risk responses, and each respondent prefers two risk response strategies on average in order to deal with the variability of risks in the procurement of construction industry in Lebanon.

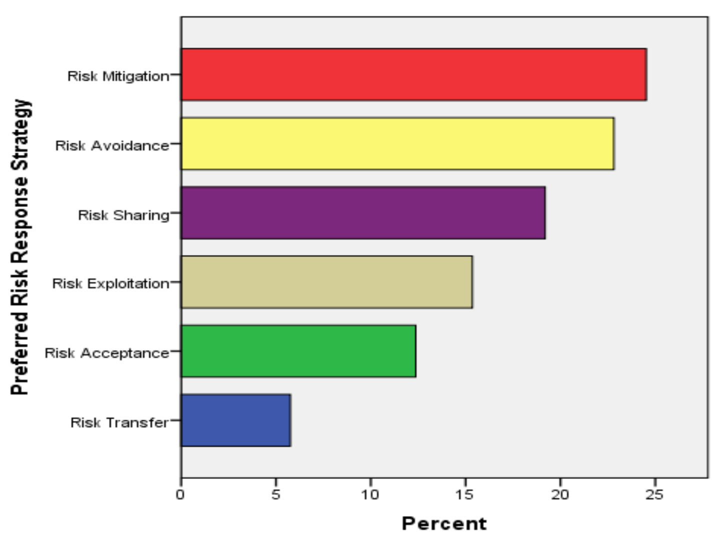


Figure 27: Histogram of Preferred Risk Response Strategy

Regarding the preferred project delivery method and contract type, the respondents indicated their preference of the “CM” delivery method and “unit price” contract as shown in figures 28 and 29respectively with almost 80% of the respondents not preferring any form of partnership and sharing of risks.

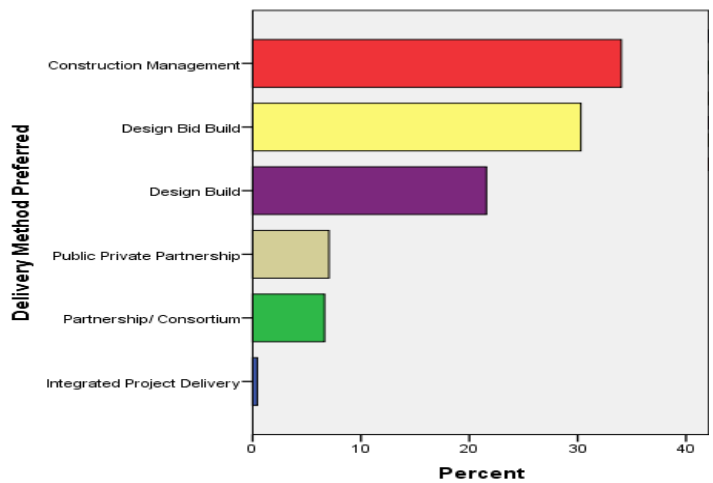


Figure 28: Histogram of Delivery Method Preferred

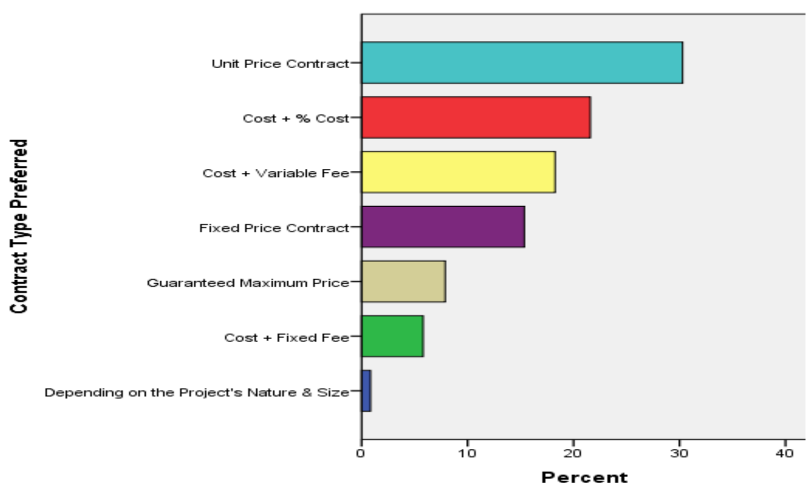


Figure 29: Histogram of Contract Type Preferred

The main barrier for applying risk management in the procurement of the construction industry in Lebanon is the lack of awareness of the benefits of risk management as shown in figure 30.

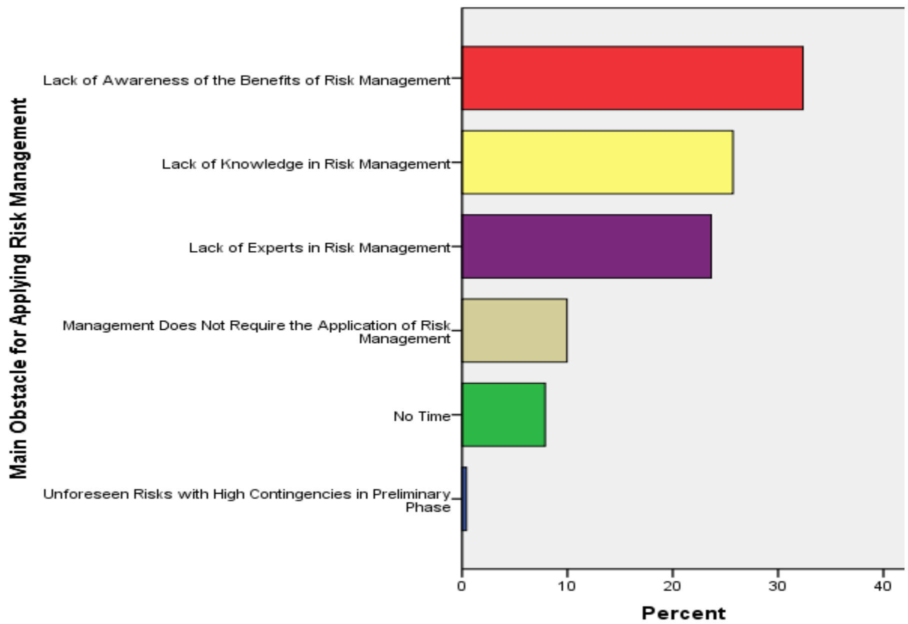


Figure 30: Histogram of Obstacles for Applying Risk Management

4.4 Survey Results Analysis

4.4.1 Cross-Tabulation

To check how the different characteristics provided by the respondents interact among each other's and investigate any trends or underlying patterns, these variables were cross-tabulated using SPSS.

Knowledge of Risk Management Stages

Knowledge of risk management was checked against other parameters.

The results indicated that the average number of risk management stages respondents are familiar with is two throughout all the age ranges, level of education, and years of experience.

The respondents who had the most knowledge of all the risk management processes are from 24-34 years old (24.1%), have a master's degree (18.3%), and 5-10 years of experience (11.2%). On another hand, it was observed that respondents who were involved in one or two (25.7%) specific types of construction projects and worked in only one or two countries at most outside Lebanon (21.6%) or in MENA Region or Lebanon only (19.1%) were familiar the most with all the risk management stages. Furthermore, construction project managers (9.5%) and consultants (10.4%) are more familiar with all the risk management stages.

Application of Risk Management Stages

With respect to the application of risk management stages, respondents of all ages, years of experience, and formal education apply on average two risk management stages. Respondents who mostly apply all risk management stages are 24-34 years old (7.5%), have a bachelor's degree (6.6%), and have either 0-2 or 20 years of experience (6.6%). Furthermore, construction project managers (2.9%) and site engineers (3.3) apply all the risk management stages the most. In addition to the latter, respondents who have worked in only one type of project (4.1%) other than Lebanon or in the MENA region (3.7%) have more applied all the risk management stages.

Procurement Phase for the Most Effective Application of Risk Management

Consultants (14.1%) and contractors (4.6%) selected tendering as the procurement phase for the most effective application of risk management.

Moreover, respondents mostly chose Tendering (45.2%) as the procurement phase for the most effective application of risk management irrespective of the type of projects they were involved in.

Party Applying Risk Management

The average number of parties applying risk management is two irrespective of the type of project the respondents were involved in.

Perception of Risks

Analyzing the respondents' perception of risks, it was found that most contractors perceive risks as threats (55%), whereas consultants were more risk-neutral (31.3%)seeking to maximize their profits without considering risks.

Additionally, Lebanese civil engineers who have only work experience in one type of construction projects are considered to be the most risk-averse (17.4%) among all of the respondents. While respondents who have worked in environmental projects only are the most risk-seeking (6.6%).

Choice of Most Important Risk in Each Procurement Phase

The choice of the most important risks in each procurement phase is related to the job position of the respondent. It is observed that there is an agreement between the choice of the most important risks in the preliminary and tendering phase between the contractors and consultants as shown in figures 31 and 32.

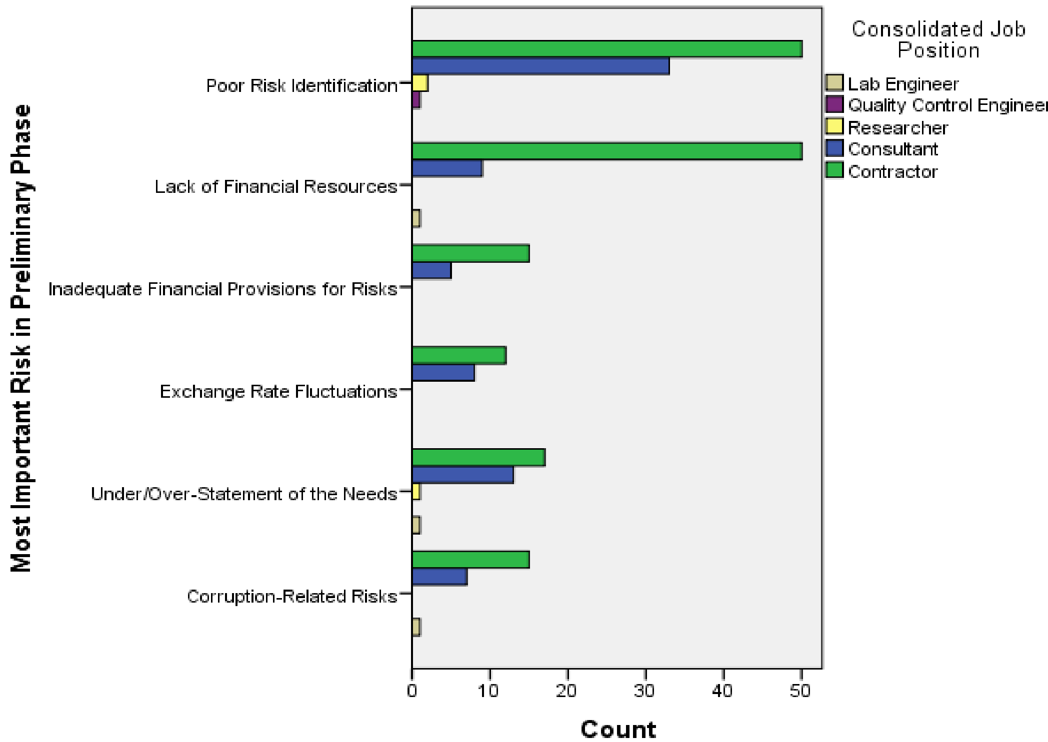


Figure 31: Association between Job Position & Most Important Risks in Preliminary Phase

Whereas in the execution phase, contractors chose communication barriers as the third most important risk, unlike consultants who selected contract termination as a result of the main contractor's default as shown in figure 33.

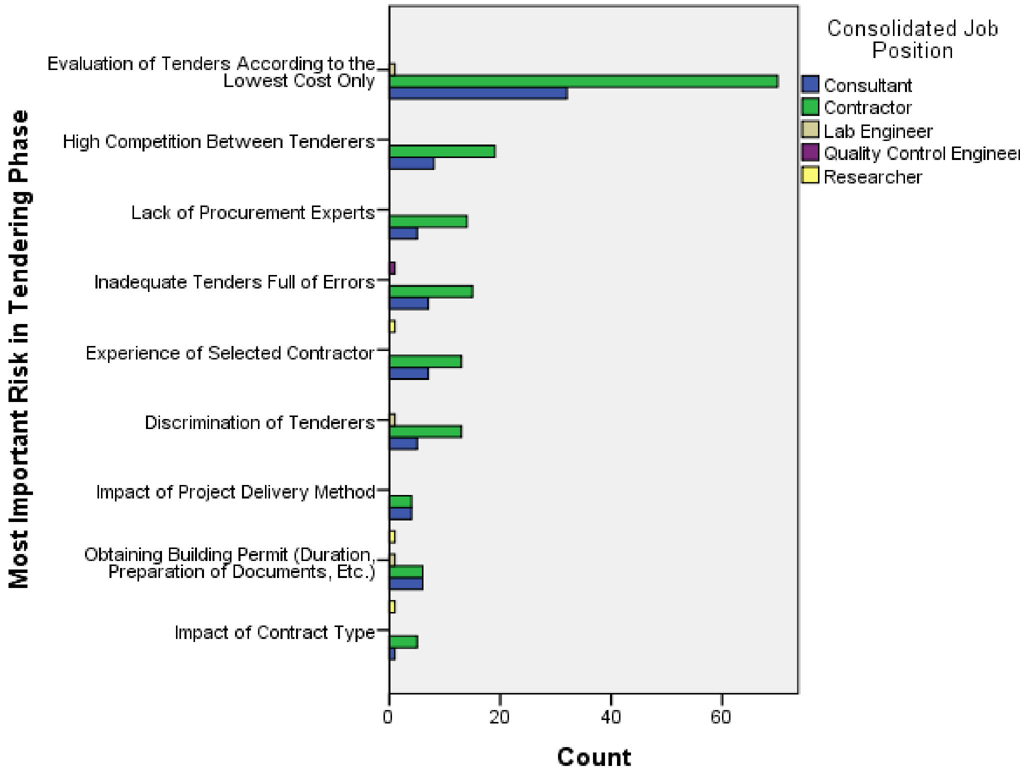


Figure 32: Association between Job Position & Most Important Risks in Tendering Phase

Likewise, in the completion phase, the consultants selected the delay in the release of the final payment and retention as the most important risk, unlike the contractors who chose disputes/need for arbitration as observed in figure 34.

On another hand, a relationship was observed between the choices of the most important risks in the preliminary, execution, and completion phases and the nature of the projects respectively. However, the most important risks in the tendering phase were independent of the nature of the projects the respondents were involved in.

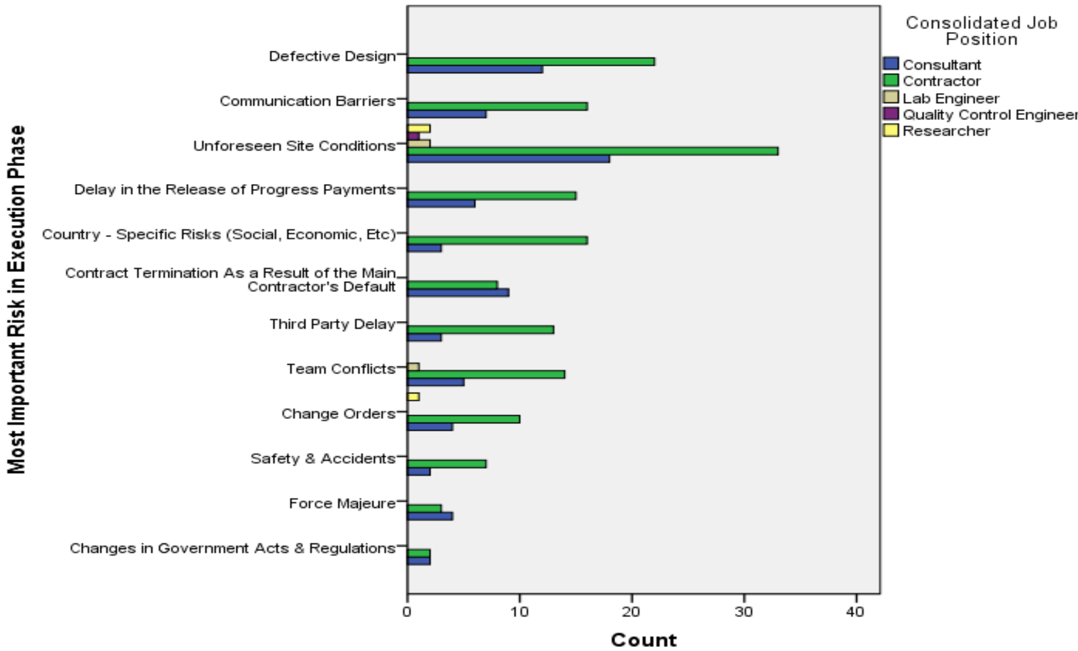


Figure 33: Association between Job Position & Most Important Risks in Execution Phase

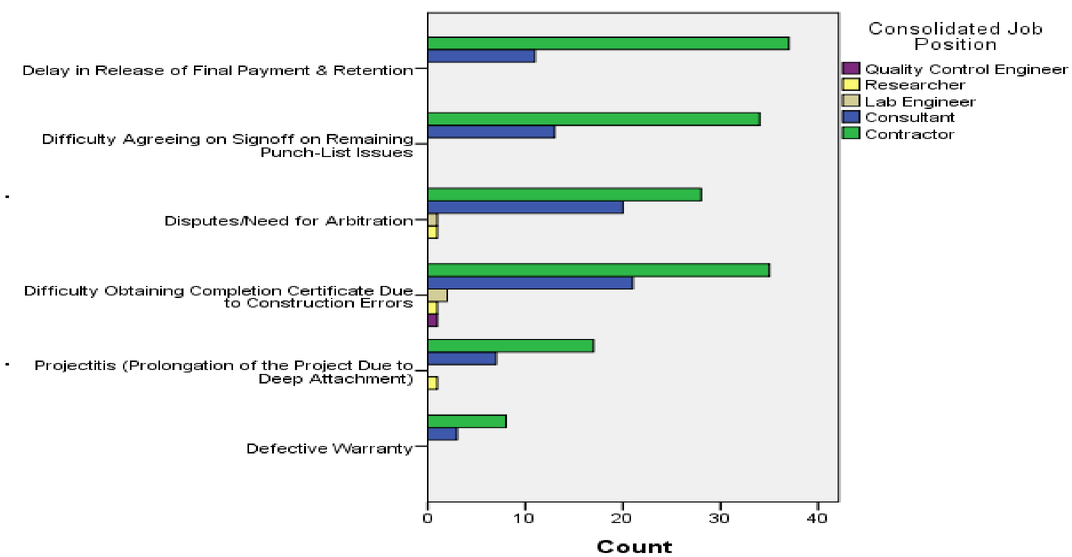


Figure 34: Association between Job Position & Most Important Risks in Completion Phase

In the preliminary phase, corruption-related risks were more relevant in infrastructure and geotechnical projects whereas under/over-statement of the needs was more important in transportation and building projects as it is vivid in figure 35.

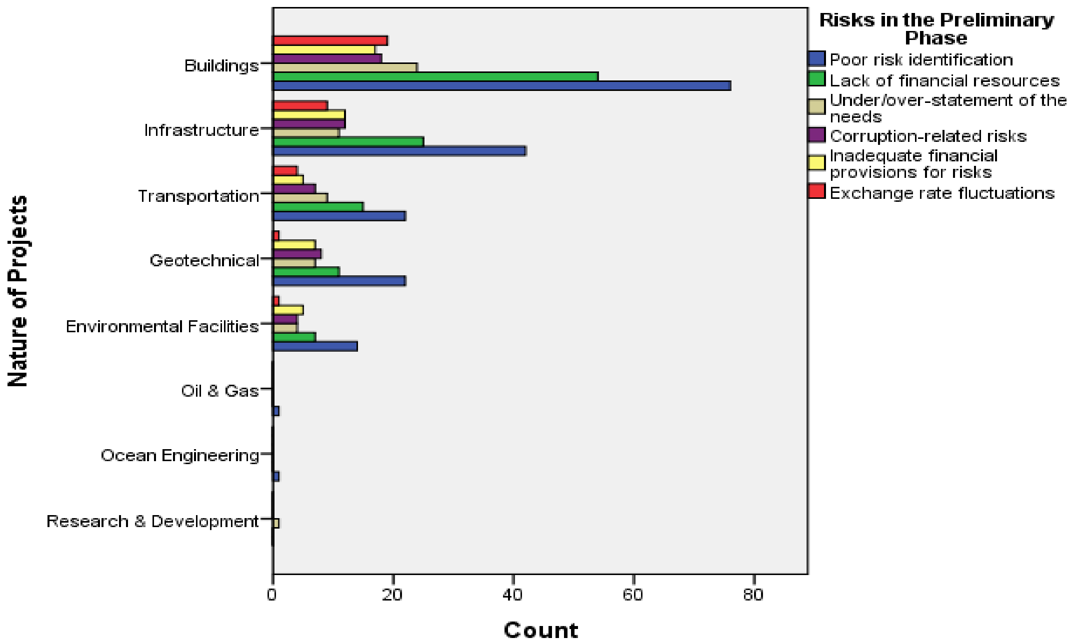


Figure 35: Association between Types of Projects & Most Important Risks in Preliminary Phase

During the project execution phase as described in figure 36, communication barriers were more pertinent in infrastructure, geotechnical, and environmental projects. While team conflicts and delays in the release of progress payments were more present in transportation and building projects. Finally, throughout the project completion phase, disputes were more noteworthy in transportation, buildings, and geotechnical projects unlike the delay in the release of the final payment and retention which was most vivid in infrastructure projects as shown in figure 37.

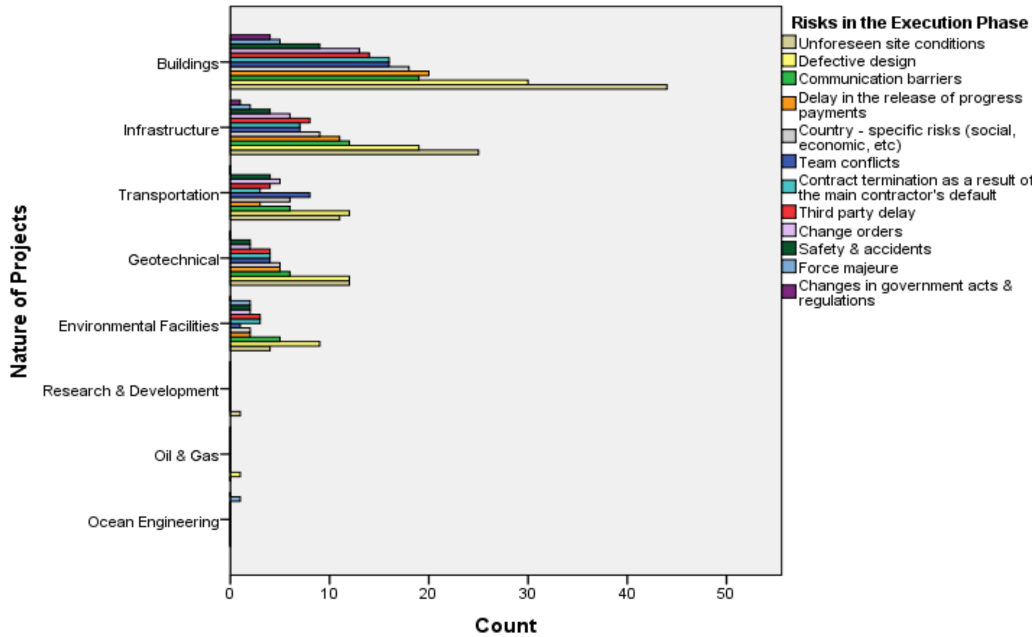


Figure 36: Association between Types of Projects & Most Important Risks in Execution Phase

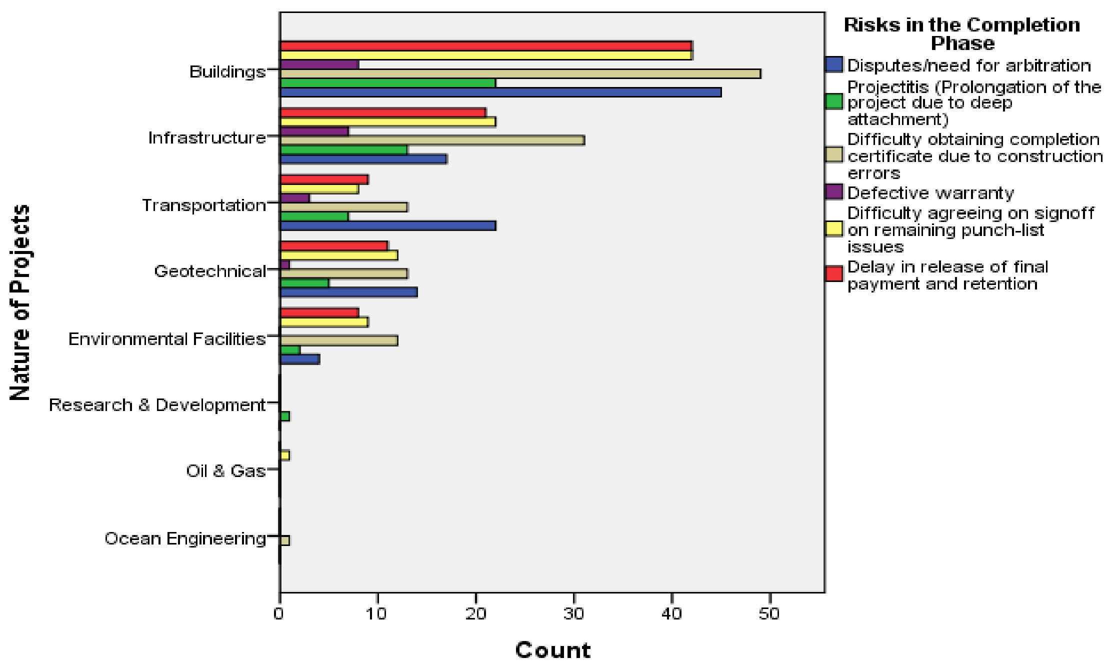


Figure 37: Association between Types of Projects & Most Important Risks in Completion Phase

Preferred Risk Monitoring Tool and Risk Response Strategy

Both contractors (14.1%) and consultants (28.2%) prefer the use of reports to monitor risks and risk mitigation to respond to risks. Moreover, risk avoidance is mostly preferred in geotechnical (12%) and environmental projects (8.3%) whereas risk mitigation is mostly chosen in infrastructure (20.3%), transportation (13.3%), and buildings (41.9%) projects.

Preferred Delivery Method and Contract Type

Both contractors (21.2%) and consultants (8.3%) prefer unit price contracts while taking into consideration the different procurement risks.

On another hand, contractors (25%) prefer CM, while consultants prefer design-bid-build (9.95%) as a contract to deal with the several types of risks in the procurement of construction in the Lebanese industry.

Main Barriers for Applying Risk Management

Contractors (21.2%) and consultants (10.4%) experience mostly the lack of awareness of the benefits of risk management which acts as the main obstacle against effectively applying risk management in the procurement of construction in the Lebanese industry.

4.4.2 Independence/Association Test

Fisher's exact test is usually done to check whether there is a non-random association between two variables, however, it lacks to show whether independence is positive or negative which necessitates the application of correlation tests (Weisstein, 2020). Two-tailed fisher's exact test was applied using a 95% level of confidence and Monte Carlo simulation between the different variables in the survey; however, no dependence/association was observed between the selected variables that were already mentioned in the cross-tabulation section. Accordingly, the test was repeated using a 75% level of confidence. It was observed that there is an association between the perception of risks (p-value of 0.05) and the most important risks (p-value of 0.04) in the tendering phase and the job position respectively. While the number of risk management stages respondents are familiar with (p-value of 0) is associated and dependent on the respondent's formal level of education.

4.4.3 Correlation Test

Two-tailed Kendall's tau-b correlation test was applied at 75% confidence interval in order to check the strength and direction of the association between all of the variables (Lund, 2018), yet the results where only a correlation is found are summarized below:

Number of Types of Projects Respondents Were Involved In

Weak positive correlation: the number of parties that apply risk management (99% level of confidence).

Number of Risk Management Stages Respondents Are Familiar With

Weak positive correlation: the number of parties that apply risk management and the number of preferred risk responses chosen. (99% level of confidence).

Strong positive correlation: Numbers of risk management stages respondents apply (99% level of confidence).

Number of Risk Management Stages Respondents Apply

Weak positive correlation: number of parties that apply risk management, number of preferred risk responses chosen and years of experience (99% level of confidence)

Number of Parties That Apply Risk Management

Weak positive correlation: the number of preferred risk responses chosen (99% level of confidence)

Years of Experience

Weak positive correlation: number of countries respondents worked in other than Lebanon (99% level of confidence)

4.4.4 Regression Test

Regression test was conducted at a 95% level of confidence in SPSS using automatic linear regression for the following parameters: knowledge of risk management stages, application of risk management stages, nature of projects, and preferred risk response strategies. However, no significant results were obtained as the accuracy parameter "R^2" was low in all of the built models.

4.5 Discussion

Lebanese civil engineers on average apply and are familiar with only two risk management stages which reiterate the fact that construction companies in the Middle East have not yet effective and wholly encompassed risk management in the construction industry (Deloitte, 2017). The most known and applied risk management stage is risk identification which is the initial yet most important step of the risk management process.

Concerning the perception of risks, Lebanese civil engineers are risk-neutral seeking to maximize their profits irrespective of the identified risks which might lead to disastrous impacts on the project and reduced profits had the risks occurred due to the absence of any risk management plan. The latter was evident in the choices of risk mitigation and risk avoidance as the most preferred risk response strategies to deal with a certain potential risk in the procurement process. Moreover, the perception of risks is dependent on the job position where contractors are proven to be more risk-averse than the consultants. Lebanese civil engineers also chose Tendering as the phase for the most efficient application of risk management which reiterates the important role contracts play in the efficient allocation of the risks to the parties that can manage them the most efficiently in the least costly and timely manner resulting in better communication and collaboration between the parties. A comparative analysis done in a project in the MENA region showed that when risk management is applied in the tendering and contract negotiation stages, it resulted in a 68% decrease in the occurrence of unplanned variations and a 36% decline in contingency expenditures proving the importance of the application of risk management in the tendering phase (Turner & Townsend, 2018).

The overall most important risks are the evaluation of tenders according to the lowest cost only, poor risk identification, and lack of financial resources. The latter proves that financial risks are more important than country-specific risks as shown in Arabian construction projects (Eskander, 2018).

The most important risks in the preliminary phase are poor risk identification, lack of financial resources, and under/over-statement of the needs.

Then, the most important risks in the tendering phase are the evaluation of tenders according to the lowest cost only, high competition between tenderers, and inadequate tenders full of errors.

The most important risks in the execution phase are unforeseen site conditions, defective design, and communication barriers. While, the most important risks in the completion phase are difficulty obtaining the completion certificate due to construction errors, disputes/need for arbitration and delay in the release of the final payment and retention.

The choice of the most important risks in Lebanon is highly dependent on the perception of risks where Lebanese civil engineers were noted to be risk-neutral and have a lack of knowledge in risk management. The latter is greatly evident in the results where Lebanese civil engineers as discussed previously are familiar with only half of the risk management stages.

On another hand, a relationship was established between the choice of the risks and the job position and nature of the projects respectively. For example, contractors prioritized the following risks: contract termination and delays in the release of the final payment, unlike consultants who ranked the disputes and communication barriers as one of the most important risks. While, it was very noticeable that corruption-related risks were mostly evident in infrastructure and geotechnical projects in Lebanon, and disputes were noteworthy in transportation, building, and geotechnical projects.

The preferred delivery method and contract type are construction management and unit price contract respectively. The construction management delivery method allocates the risks mostly to the owner, unlike the unit-price where the parties share the risk equally.

A more innovative project delivery method that provides better results than the traditional methods is the integrated project delivery where the owner, architect, and general contractor sign only one contract and are more involved and collaborate since the early phases of the project (Rached *et al.*, 2014).

The main obstacles for applying risk management efficiently is the lack of awareness of the benefits of risk management and the lack of knowledge in civil engineering which is one of the main barriers for the application of risk management in the construction industry in the MENA region (Kotb *et al.*, 2018). Thus, highlighting the need for a third-party risk management consultant.

Correlation and regression tests were executed on selected variables in the questionnaire. A weak association is observed between the perception of risks and the most important risks in the tendering phase and the job position respectively. Whereas, a weak association/dependence exists between the number of risk management stages respondents are familiar with and the respondent's formal level of education. The latter is directly related to the increase in the knowledge and experience the Lebanese civil engineers gain advanced formal education levels.
Regression test was also applied to several parameters, however low accuracy was obtained because the risk is in its nature unpredictable and due to the need for consideration of more variables to increase the accuracy of the models.

5. In-depth Interviews

5.1 Introduction

The second tier of the research investigation was conducted through a qualitative risk assessment that builds on the results of the first tier (i.e., the questionnaire) that identified the top risks in each phase of the procurement process as per the opinion of the practicing engineers.

The in-depth interviews seek to qualitative assess the top risks selected by the Lebanese civil engineers in design-bid-build lump sum construction projects. In-depth interviews are conducted with 12 experts in project management, consultancy, and contracting.

The experts were chosen after thorough research of reputable construction companies working in Lebanon that have a considerable number of years of experience in the construction of megaprojects in the region. Then, 24 companies were solicited for potential in-depth interviews, yet only 12 experts from 12 different companies agreed and participated.

5.2 In-depth Interview Questions

The interview includes general questions about the expert's formal level of education, years of experience, job position, and the average value of projects the respondent was involved in. Then, the respondent was presented with the risks identified earlier in the questionnaire and was asked about the likelihood of occurrence, the average severity of risk on both the cost and duration of the project, risk detection, risk response, risk owner and affected project activities of each risk-taking into consideration design-bid-build lump sum construction projects as per tables 16 and 17.Likert scale (one-five) is used for consequences and probability of occurrence where one would represent the very low impact and probability each of 0-20%, two would represent low impact and probability each of 20-40%, three would represent moderate impact and probability each of 40-60%, four would represent high impact and probability each of 60-80% and five would represent the very high impact and probability each of 80-100%.

Table 16: Likelihood, Severity, and Detection of Procurement Risks

Procurement Phase	Procurement Risks	Likelihood	Severity	Detection
Pre-Conceptual	Poor Risk Identification			
	Lack of Financial Resources			
	Under/Over-Statement of the Needs			
Project Tendering	Evaluation of Tenders according to the Lowest Cost Only			
	High Competition between Tenderers			
	Inadequate Tenders Full of Errors			
Project Execution	Unforeseen Site Conditions			
	Defective Design			
	Communication Barriers			
Project Completion	Difficulty Obtaining Completion Certificate Due to Construction Errors			
	Disputes/Need for Arbitration			
	Delay in the Release of the Final Payment and Retention			
	Use Likert scale (1 - 5): 1 (very low), 2 (low), 3 (medium), 4 (high), 5 (very high)			

The t-test in SPSS will be used to analyze the data. T-tests are usually used for sample sizes of less than 30 (Andrea, 2020). The one-sample and one-tail t-test are used to compare the mean of the scores to a certain hypothesized population mean (Yeager, 2020). The hypothesis is that the mean is less than three, and then the likelihood of occurrence, severity, or detection is respectively low. Else, the hypothesis is rejected and the likelihood of occurrence, severity, or detection is respectively above average.

Table 17: Risk Response, Risk Owner and Affected Project Activities of Each Risk

Procurement Phase	**Procurement Risks**	**Risk Owner**	**Risk Response**	**Phase of Affected Activities**
Pre-Conceptual	Poor Risk Identification			
	Lack of Financial Resources			
	Under/Over-Statement of the Needs			
Project Tendering	Evaluation of Tenders according to the Lowest Cost			
	High Competition between Tenderers			
	Inadequate Tenders Full of Errors			
Project Execution	Unforeseen Site Conditions			
	Defective Design			
	Communication Barriers			
Project Completion	Difficulty Obtaining Completion Certificate Due to			
	Disputes/Need for Arbitration			
	Delay in the Release of the Final Payment and Retention			

5.2 In-depth Interview Results

Results Reliability

The internal reliability was tested using Cronbach's alpha where it was calculated to be approximately 0.7 as shown in table 18 which is considered acceptable since Cronbach's alpha should be at least 0.7 to be accepted. The items tested include the likelihood of occurrence, impact, and detection of all of the most important risks in each phase of the procurement process.

Table 18: Internal Reliability of the Interview

Cronbach's Alpha	Cronbach's Alpha Based on Standardized Items
0.670	0.616

General Questions Results

The job position of the respondents was equally split between contractors, project managers, and consultants. Moreover, most of the experts interviewed held a master's degree in civil engineering, had on average 23 years of experience in the construction industry and participated on average in approximately 200 million USD as shown in figures 38, 39, and 40.

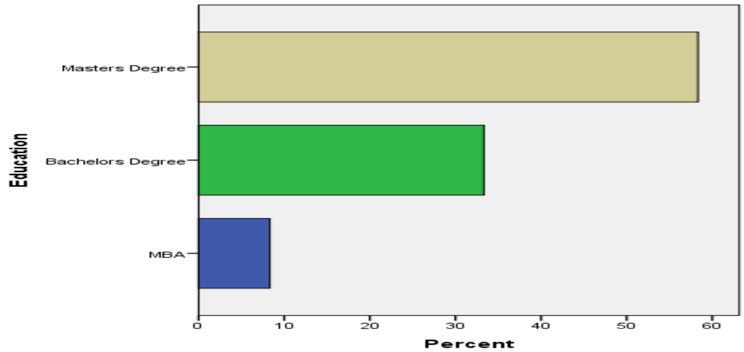


Figure 38: Formal Level of Education Histogram

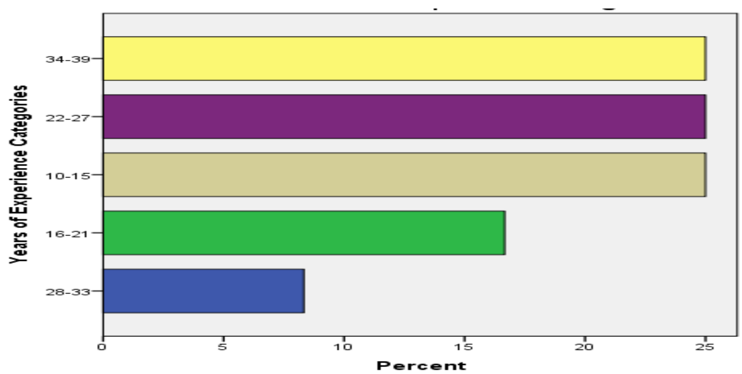


Figure 39: Years of Experience Histogram

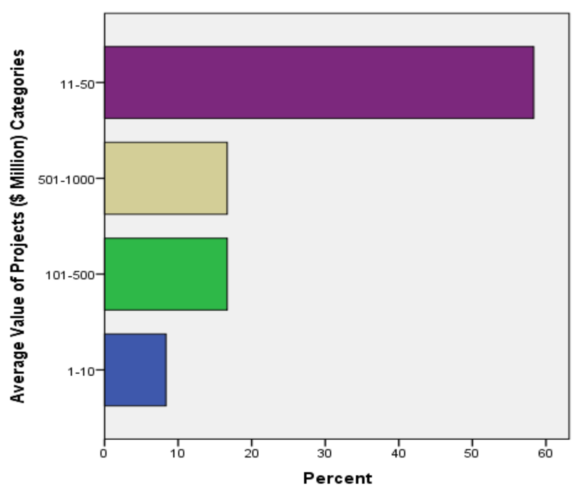


Figure 40: Average Value of Projects Histogram

Risks Assessment Questions Results

The average results for the likelihood, severity, and detection for each of the risks are shown in figure 41. The risk response and risk owner for each of the risks are summarized in table 19.

The experts decided unanimously that each risk affects certain event or events in each of the following procurement phases. It can be observed that risk mitigation and risk avoidance are the most preferred risk response strategies, while the owner was allocated the responsibility and ownership of most of the risks. The latter might be affected by the attitude of Lebanese civil engineers towards risk management and their perception of risks.

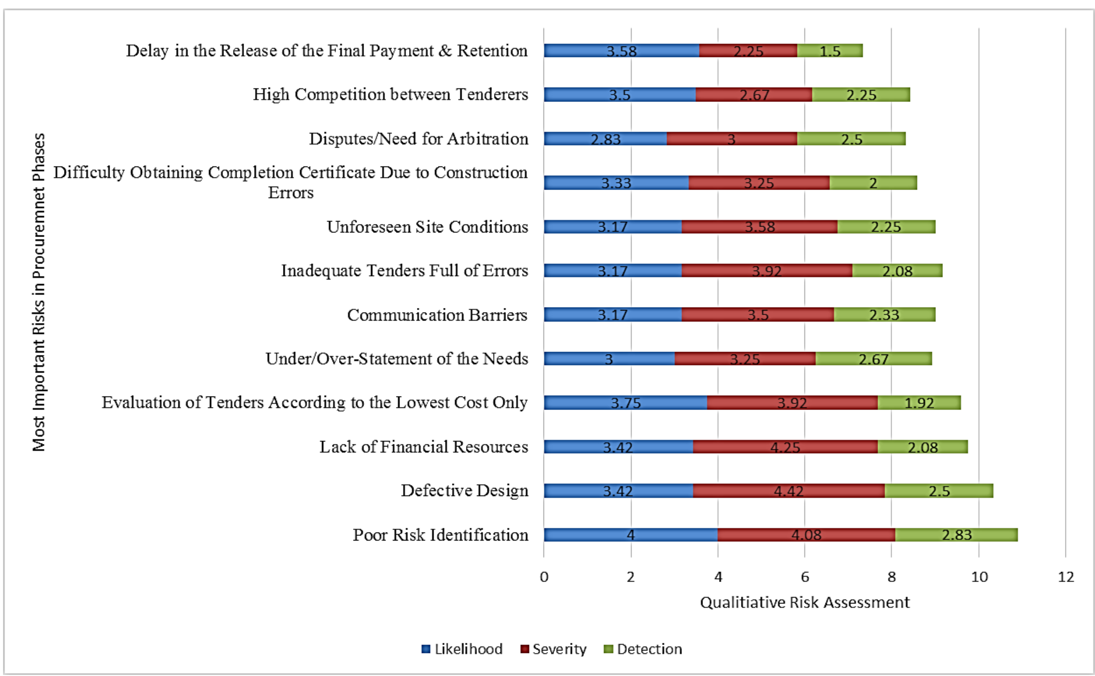


Figure 41: Summary of the Detection, Severity and Likelihood of the Risks

Table 19: Risk Response and Owner of Each Risk

Risk \ Criterion	Risk Response	Risk Owner
Poor Risk Identification	Mitigation	Owner
Lack of Financial Resources	Mitigation	Owner
Under/Over-Statement of the Needs	Avoidance	Owner
Evaluation of Tenders According to the Lowest Cost Only	Mitigation	Owner
High Competition between Tenderers	Acceptance	Contractor
Inadequate Tenders Full of Errors	Avoidance and Mitigation	Owner
Unforeseen Site Conditions	Acceptance, Avoidance and Mitigation	Contractor
Defective Design	Mitigation	Consultant
Communication Barriers	Avoidance and Mitigation	Owner
Difficulty Obtaining Completion Certificate Due to Construction Errors	Acceptance	Contractor
Disputes/Need for Arbitration	Avoidance	Owner
Delay in the Release of the Final Payment and Retention	Acceptance	Owner

5.3 In-depth Interview Results Analysis

A one-sample one-tail t-test was conducted at a 95% level of confidence where the null hypothesis was that the risks' likelihood, severity are medium (score is less than or equal to three). The calculated p-value was less than five percent for the following variables which were considered significantly different from being average: poor risk identification's detection, lack of financial resources' likelihood, under/over-statement of the needs, unforeseen site conditions and high competition between tenderers likelihood, severity, and detection, inadequate tenders full of errors' likelihood, defective design's likelihood and detection, communication barriers' likelihood, detection and severity and difficulty obtaining completion certificate's likelihood and severity.

On another hand, the detection, severity, and likelihood of occurrence of each of the risks are summarized in figure 41 where poor risk identification is the most occurring risk and hardest to detect and defective design causes the most damage. A comparison was made between the risk allocation choices of the experts based on their job position as shown in table 20. It is evident that the experts agreed on the allocation of one-fourth of the risks, yet they did not agree to share risks. However, project managers unlike consultants and contractors (16%) proposed that 40% of the risks must be shared. Further analysis of the results were conducted using the risk priority number (RPN) and the risk assessment matrix. The RPN is calculated by multiplying the likelihood by the severity and detection of each risk respectively as shown in figure 42. RPN allows the risks to be sorted from highest to lowest in terms of importance and criticality where poor risk identification was ranked first, defective design second and lack of financial resources third.

Table 20: Risk Allocation by Each Party

Risk \ Respondents	Consultants	Contractors	Project Managers
Poor Risk Identification	Owner and Consultant	Owner	Contractor, Owner and Consultant
Lack of Financial Resources	Owner	Owner	Owner
Under/Over-Statement of the Needs	Owner	Consultant	Contractor
Evaluation of Tenders According to the Lowest Cost Only	Project Manager and	Owner	Contractor and Owner
High Competition between Tenderers	Contractor	Owner	Contractor and Owner
Inadequate Tenders Full of Errors	Owner	Owner	Contractor
Unforeseen Site Conditions	Owner	Consultant	Contractor
Defective Design	Consultant	Consultant	Consultant
Communication Barriers	Owner	Owner and Consultant	Owner and Contractor
Difficulty Obtaining Completion Certificate Due to Construction	Contractor	Owner and Contractor	Owner
Disputes/Need for Arbitration	Owner	Owner and Contractor	Owner and Project Manager
Delay in the Release of the Final Payment and Retention	Owner	Owner	Owner

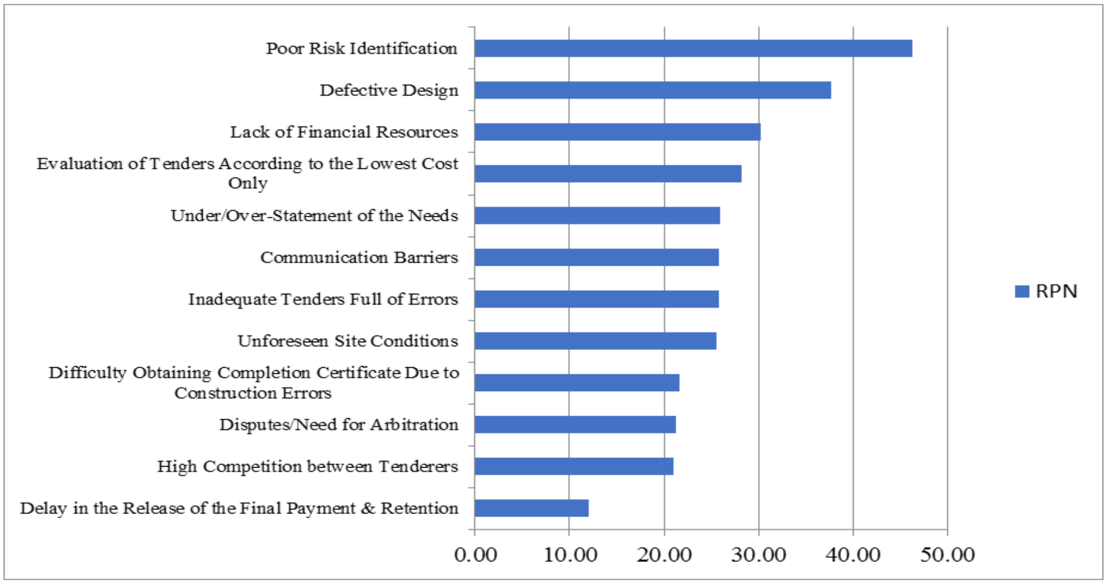


Figure 42: Risk Priority Number of Each Risk

Subsequently, a risk assessment matrix is done by plotting the likelihood of each risk in terms of its severity to obtain the level of each risk and to be able to categorize it.

Four levels of risk exist which are as follows: minor risk which causes no effect -low risk (green), a moderate risk which requires mitigation - medium risk (yellow), high risk (pink), and extreme risks that require specific actions(red).The four levels of risks as shown in figure 43.

Based on the severity and likely hood score of each risk, the risk assessment matrix is developed as shown in figure 43 where the risk's likelihood of is plotted versus the average impact of the risk on the project's time and cost. The label for each risk is shown in table 21.

Table 21 : Label of Each Risk in Risk Assessment Matrix

Risk	Label
Poor Risk Identification	A
Lack of Financial Resources	B
Under/Over-Statement of the Needs	C
Evaluation of Tenders According to the Lowest Cost Only	D
High Competition between Tenderers	E
Inadequate Tenders Full of Errors	F
Unforeseen Site Conditions	G
Defective Design	H
Communication Barriers	I
Difficulty Obtaining Completion Certificate Due to Construction Errors	J
Disputes/Need for Arbitration	K
Delay in the Release of the Final Payment and Retention	L

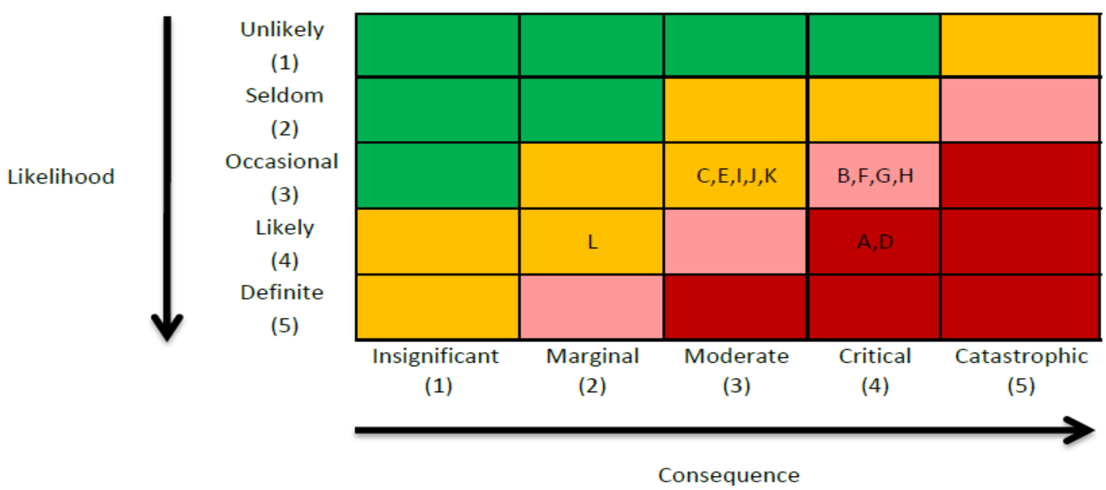


Figure 43: Risk Assessment Matrix

5.4 Discussion

As it was highlighted in the results, expert Lebanese civil engineers were mostly risk-averse since the most chosen risk response is risk mitigation in addition to the fact that most of the risks were allocated solely to the owner. The latter shows that expert Lebanese civil engineers do not tend to share risks as it was already proven in the survey where only 20% of the Lebanese civil engineers chose any form of partnership as a delivery method or contract type.

After the experts allocated a score to each of the risks taking into consideration design-bid-build lump sum projects, the most occurring and hardest to detect risk was discovered to be poor risk identification which is directly related to the lack of knowledge in risk management which could inhibit its proper and efficient application. Moreover, lack of financial resources and design defects are the fifth most occurring risks although they typically rank as the most occurring in construction projects (Eskander, 2018).

The most severe risk is the defective design which if occurs might cause drastic damages to the construction project's time and cost especially that the design is finalized before the selection of the contractor and the construction project's start date as discussed previously in figure 6. However, design risks were proven to have an only moderate impact on project's cost and time in the MENA region from the perspective of multinational companies where it was found that financial risks have a high impact on the project's cost and moderate impact on the project's schedule (Al-Sabah, 2012).

The qualitative risk assessment of the top risks in design-bid-build lump sum projects was done using a risk assessment matrix and RPN respectively. The risk assessment matrix showed that half of the risks are moderate level risks, whereas the extreme risks are poor risk identification and evaluation of tenders according to the lowest cost only where both were allocated solely to the owner. The latter is verified due to their high likelihood of occurrence and impact where poor risk identification can lead to the mismanagement of highly important risks which can cause severe damages to the project's scope, cost and time and might lead eventually to the project's failure. Whereas, evaluation of tenders according to the lowest cost only ignoring the worker's experience and other important qualifications can sabotage the quality, scope, and duration of the project leading to eventually even more costs to the project and less efficiency. On another hand, the experts allocated most of the risks (75%) solely to the owner, although usually the contractor holds the responsibility for most of the risks in design-bid-build fixed price projects (Nicał and Wodyński, 2015). The sole allocation of these risks to one party only will cause less collaboration, communication & motivation between the parties involved in the construction project which might decrease the effectiveness of the application of risk management.

When the detection of the risks is considered, the risks are re-ordered in terms of their importance and priority were the following risks were the most important in decreasing order as follows: poor risk identification, defective design, and lack of financial resources. The latter showed that even though the defective design and lack of financial resources are high-level risks, yet they require more managerial attention and have higher priority since they are very difficult to detect. Thus, proving the importance of RPN to track the reduction of the impact of negative risks and be able to avoid unprecedented failures due to the poor ability to detect very severe risks.

6. Case Study: Quantitative Risk Analysis of Construction Project

6.1 Introduction and Project Description

A case study is undertaken to illustrate the application of quantitative risk analysis of a real-life construction project in the project execution phase. This application is built upon the results of the previous sections concerning the prevailing risks in the Lebanese construction industry as well as its likelihood, severity, and impacts.

The risk analysis results compare the impact of moderate and high-level risks in the execution phase in the construction project while considering pre-mitigation and post-mitigation stages. The project delivery method of the construction project is a design-bid-build utilizing a lump sum type of contract. The case study involves the construction of a bridge that has a length of 700m and a width of 20m. The planning of the project is done using Primavera software resulting in project total cost of USD/4,544,220/, and a project duration of 366 days.

The activities of the project are divided into the following main categories:

- general phase constituting mobilization and general requirements
- materials and shop drawing submittals and approval
- the procurement of long-lead items
- the first phase of construction works made up of constructing the pedestrian underpass, the box culvert strengthening, the concrete works over the bridge culvert and the finishing works on the bridge
- the second phase of construction works focusing on road works on road furniture

- the final phase organizing the final testing and commissioning

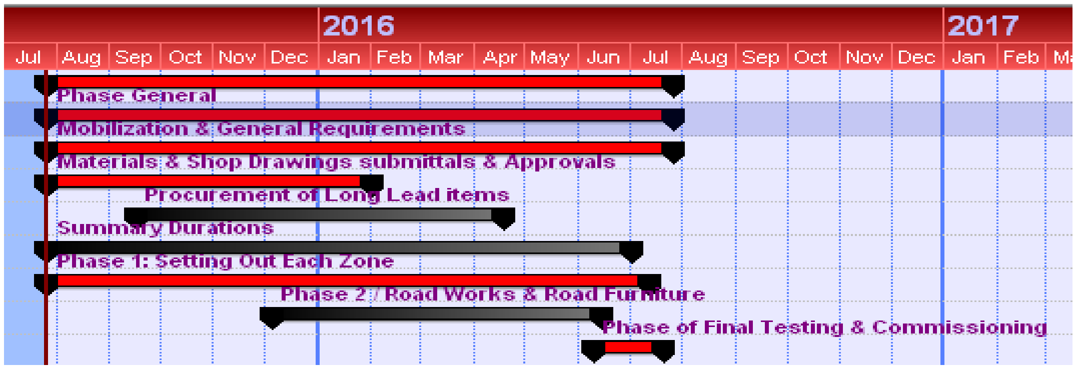


Figure 44: Gantt chart of the main categories of the construction project

Figure 44 illustrates the Gantt chart of the main categories of the construction project while the appendix includes the full schedule including the critical path and the full 273 activities and resource tables. Note that the first phase has the highest cost since the pedestrian underpass would result in a total cost of almost $1.5 million which is one-third of the project's total cost.

6.2 Risk Analysis: Input and Process

After obtaining the project schedule and costs, quantitative risk analysis is conducted using Primavera Risk Analysis Software. The risks that are investigated in this case study are based on the results obtained from the questionnaire which identified the three most important risks in the project execution phase in the Lebanese construction industry.

These risks are unforeseen site conditions, defective design, and communication barriers. The risks and their corresponding labels are shown in table 22. The latter risks are also plotted in a risk matrix in figure 45 using their respective likelihood and severity as obtained in the in-depth interviews where it was proven that unforeseen site conditions and defective design are high-level risks. While communication barriers are considered as moderate level risks.

Table 22: Labels of Risks Investigated in Case Study

Risk	Label
Unforeseen Site Conditions	G
Defective Design	H
Communication Barriers	I

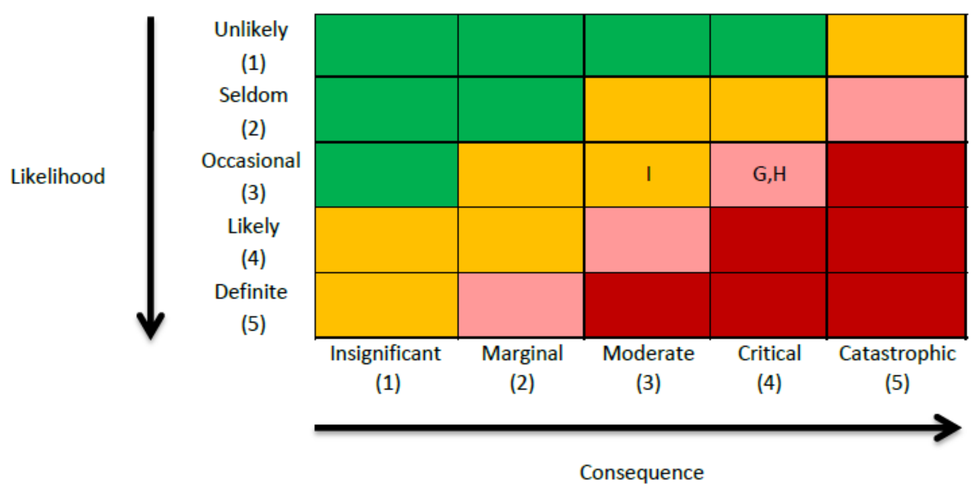


Figure 45: Risk Matrix - Case Study

The risk response and risk owner of each risk are obtained from the results of the in-depth interviews, and a specific risk response method is suggested for each of the three risks as shown in table 24.

The risk response method identifies the risk response, the cost of the risk response, the residual risk, and the risk owner. The risk response and risk owner used are obtained from the results of the in-depth interviews in section 5 of this thesis where risk acceptance would require no further action and the risk owner would retain 100% of the risk, while risk avoidance would result in 0% residual risk since the risk would be avoided by taking a completely different approach.

The following assumptions were made to calculate the cost of each risk response:

- detailed site investigation costs 3% of total construction costs which is between 0.2 and 5% of total construction costs (Goldsworthy et al.,2007),
- the average cost of change in design/ redesign and 3rd party auditing is 5.36% and 2.89% of construction costs respectively (Wilson, 2012),
- design contingency cost is on average 2.68% of construction costs (Hawkes, 2017)
- the cost of pre-qualification is on average 2.07% of construction costs (Motiar Rahman, 2015),
- a communication platform is suggested to mitigate communication barriers where 30 members are assumed to be using the platform at a cost of 8 USD per month (Field Chat, 2020).

Each risk and its associated parameters, shown in table 23, in addition to its severity and impact is input into primavera risk analysis to compare the bearing of each of these three risks on the project in terms of schedule and cost sensitivity using tornado graphs.

Note that the simulation is repeated for each risk separately to obtain the most optimum risk response strategy which has the lowest cost sensitivity and duration sensitivity in the pre-mitigation and post-mitigation phases.

Then, a final simulation is executed using the three risks and response strategies simultaneously to investigate which risk owner would be most affected.
The latter simulation would be done using the most optimum risk response strategy for each risk which is obtained from individual risk simulations.

Table 23: Risk Response and Ownership of Risks - Case Study

Risk	Risk Response	Cost of Risk Response	Residual Risk	Risk Owner
Unforeseen Site Conditions	Risk Acceptance: No Action Needed	0	100%	Contractor
	Risk Avoidance: Detailed Site Investigation	3% of Construction Costs=0.03*4554220=$136 627	0%	Contractor
	Risk Mitigation: Topographic Study and Redesign	$10,000 + 5.36% of construction costs =$254106	50%	Contractor
Defective Design	Risk Mitigation: Third Party Auditing	2.89% Construction Costs =$131617	50%	Consultant
	Risk Mitigation: Redesign/ Change in Design	5.36% Construction Costs=$244106	10%	Consultant
	Risk Mitigation: Design Contingency	2.68% Construction Costs=$122053	5%	Consultant
Communica tion Barriers	Risk Mitigation : Project Coordinator	$1000/month = $12000	10%	Owner
	Risk Mitigation: Communication Platform: Field Chat	$ 8/ month/ member = $8*12*30=$4320	5%	Owner
	Risk Avoidance: Pre-Qualification for same language	2.07% Construction Costs=$94272	0%	Owner

Risk Analysis: Results

6.2.1 Unforeseen Site Conditions

The impact and probability of each risk on the impacted activities is input into primavera risk analysis and quantitative risk analysis is run using Monte Carlo simulation and 1000 iterations.

Table 24: Unforeseen Site Conditions Risk Input – Pre-mitigation Plan

Risk Response	Probability	Cost	Time	Response Actions	Phase of Affected Activities
Risk Acceptance	50%	60-80%	60-80%	No Action Needed	Phase 1: Setting out Site & Survey Works for Zones A, B,C & E
Risk Avoidance	50%	60-80%	60-80%	Detailed Site Investigation	
Risk Mitigation	50%	60-80%	60-80%	Topographic Study & Redesign	

Table 25: Unforeseen Site Conditions Risk Input – Post-mitigation Plan

Risk Response	Response Cost	Probability	Cost	Time
Risk Acceptance	$.00	50%	30-40%	30-40%
Risk Avoidance	$136,626.60	0%	0.00%	0.00%
Risk Mitigation	$254,106.19	25%	15-20%	15-20%

The cost and duration sensitivity is investigated for each risk response technique in order to show how much is the impact of the risk related to the project's events. As shown in table 26, the optimum risk response strategy for unforeseen site conditions is risk avoidance since it would result in the lowest cost sensitivity and duration sensitivity in the post-mitigation phase.

Table 26: Risk Response for Unforeseen Site Conditions

Phase	Pre-Mitigation		Post-Mitigation	
Risk Response Strategy\Sensitivity	**Cost Sensitivity (%)**	**Duration Sensitivity (%)**	**Cost Sensitivity (%)**	**Duration Sensitivity (%)**
Risk Avoidance - Detailed Site Investigation	58	42	0	0
Risk Acceptance - No Action Needed	61	67	91	95
Risk Mitigation - Topographic Study and Redesign	58	41	36	21

6.2.2 Defective Design

The impact and likelihood of occurrence of the defective design risk are inputted into primavera risk analysis for each of the pre-mitigated and post-mitigated plans using beta pert distribution as shown in tables 27 and 28. Then, quantitative risk analysis is also run to obtain the cost sensitivity and design sensitivity of each risk response technique.

Table 27: Defective Design Risk Input – Pre-mitigation Plan

Risk Response	Probability	Cost	Time	Response Actions	Phase of Affected Activities
Risk Mitigation	50%	60-80%	60-80%	Design Contingency	Phases 0, 1&2: Setting out Site & Survey Works for Zones A, B,C, E and Shop Drawings.
Risk Mitigation	50%	60-80%	60-80%	Third Party Audit	
Risk Mitigation	50%	60-80%	60-80%	Redesign	

Table 28: Defective Design Risk Input – Post-mitigation Plan

Risk Response	Response Cost	Probability	Cost	Time
Risk Mitigation - Design Contingency	$131,617	2.5%	3-4%	3-4%
Risk Mitigation - Third Party Audit	$244,106	25%	30-40%	30-40%
Risk Mitigation - Redesign	$122,053	5%	6-8%	6-8%

With respect to the defective design risk, risk mitigation using design contingency has the lowest impact on the project although redesign or change in few concepts of the design is relatively very close and considered the second-best risk response strategy as shown in table 29.

Table 29: Risk Response for Defective Design

Phase	Pre-Mitigation		Post-Mitigation	
Risk Response Strategy\Sensitivity	**Cost Sensitivity (%)**	**Duration Sensitivity (%)**	**Cost Sensitivity (%)**	**Duration Sensitivity (%)**
Risk Mitigation - Design Contingency	61	41	0	0
Risk Mitigation - Third-Party Audit	57	39	100	100
Risk Mitigation - Redesign/ Change in Design	57	40	8	6

6.2.3 Communication Barriers

The probability and impact of the communication barriers risk are inputted into primavera risk analysis where all of the phases are impacted as displayed in tables 30 and 31. Then, quantitative risk analysis is done using Monte Carlo simulation and 1000 iterations in both the pre-mitigation and post-mitigation plans respectively in order to compare the duration and cost sensitivity of each risk in both stages.

Table 30: Communication Barriers Risk Input – Pre-mitigation Plan

Risk Response	Probability	Cost	Time	Response Actions	Phase of Affected Activities
Risk Mitigation	50%	40-60%	40-60%	Project Coordinator	All Phases
Risk Mitigation	50%	40-60%	40-60%	Communication Platform	
Risk Avoidance	50%	40-60%	40-60%	Pre-Qualifications	

Table 31: Communication Barriers Risk Input – Post-mitigation Plan

Risk Response	Response Cost	Probability	Cost	Time
Project Coordinator	$12000	5%	4-6%	4-6%
Communication Platform	$4320	2.5%	2-3%	2-3%
Pre-Qualifications	$94272	0%	0%	0%

As clearly vivid in table 32, risk avoidance using pre-qualification is the most optimum risk response strategy since it results in the lowest cost and duration sensitivity in the post-mitigation phase. Moreover, there is only a 3% difference between the cost sensitivity of any of the risk response strategies in the pre-mitigation plan.

Table 32: Risk Response for Communication Barriers

Phase	Pre-Mitigation		Post-Mitigation	
Risk Response Strategy\Sensitivity	**Cost Sensitivity (%)**	**Duration Sensitivity (%)**	**Cost Sensitivity (%)**	**Duration Sensitivity (%)**
Risk Mitigation - Project Coordinator	57	41	95	95
Risk Mitigation - Communication Platform	58	41	30	28
Risk Avoidance - Pre-Qualification	60	41	0	0

6.2.4 Case Study Outcomes

A simulation is done using the optimum risk response strategy for each risk as done in the previous sections. The new Gantt chart showing the link between the activities and the risks of each activity is shown in full detail in the appendix.

As it is clearly shown in table 33, before risk response, the risks were arranged as follows in ascending order in terms of the schedule and cost sensitivity: communication barriers, unforeseen site conditions, and defective design.

Yet, after responding to each of the risks in an optimum manner, unforeseen site conditions would result in the highest impact on the project as its duration sensitivity is 100% and its cost sensitivity is 87% as shown in table 28. Moreover, communication barriers and design defect would impact the project in a negligible to very low manner after the specific risk responses are enacted.

Table 33: Optimum Risk Response Strategy for Each of the Risks

Phase	**Pre-Mitigation**		**Post-Mitigation**	
Risk Response Strategy\Sensitivity	**Cost Sensitivity (%)**	**Duration Sensitivity (%)**	**Cost Sensitivity (%)**	**Duration Sensitivity (%)**
Risk Avoidance - Detailed Site Investigation	58	51	87	100
Risk Avoidance - Prequalification	47	40	0	0
Risk Mitigation - Design Contingency	63	61	0	0

On another hand, as shown in figures 46 and 47, there is only a 12% probability that the deterministic duration and cost of the project will be achieved respectively in the pre-mitigation plan. The latter is due to the severe impact of the risks in terms of cost and time of the project. Spearman’s correlation is tested using primavera risk analysis and recorded as 0.87 which indicates a high correlation between the cost and duration of the project.

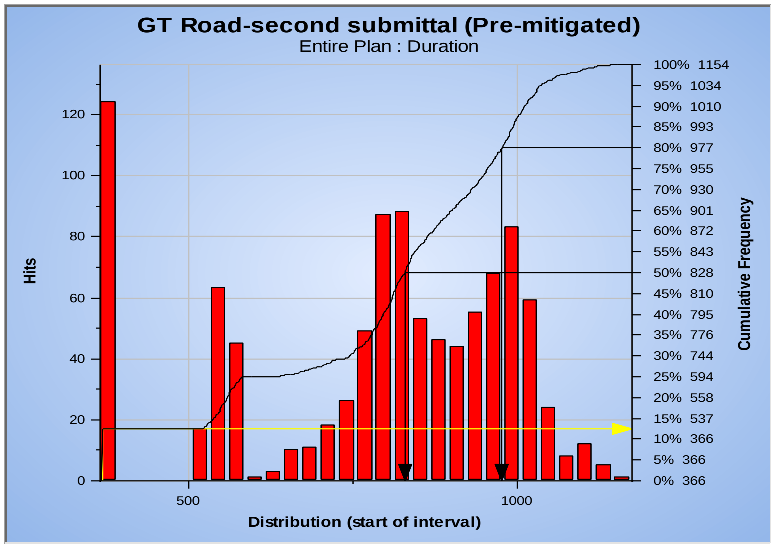


Figure 46: Distribution of Project's Duration in Pre-mitigation Plan

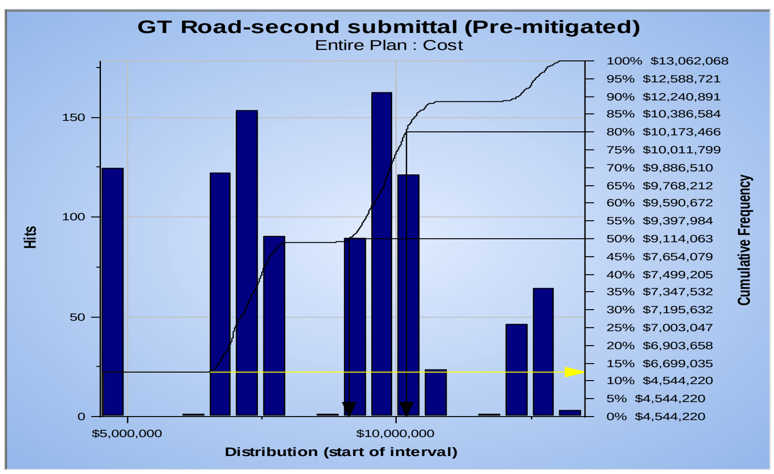


Figure 47: Distribution of Project's Cost in Pre-mitigation Plan

After the appropriate risk responses are executed, there is a 98% probability that the deterministic duration and cost of the project will be achieved as shown in figures 48 and 49 indicating that the effect of the risks on the project's cost and time will be very low. Spearman's correlation coefficient between the cost and duration of the project is 0.92 which is almost 6% higher than the latter in the pre-mitigation phase.

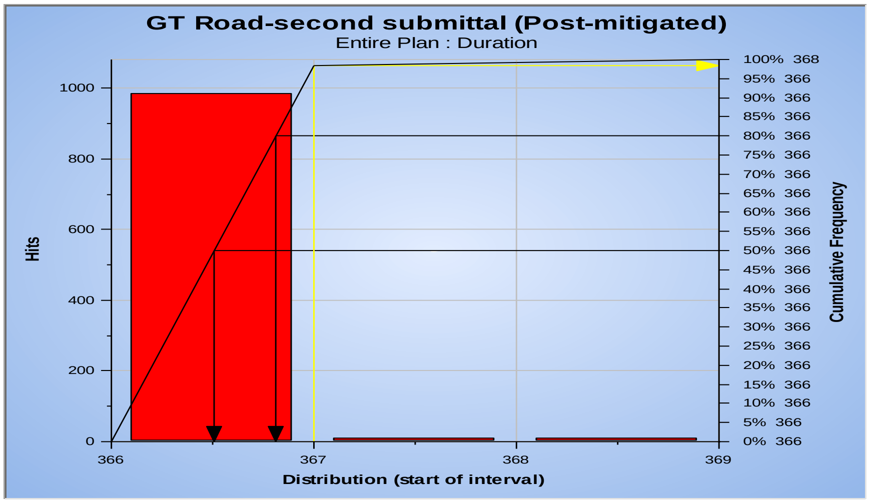


Figure 48: Distribution of Project's Duration in Post-mitigation Plan

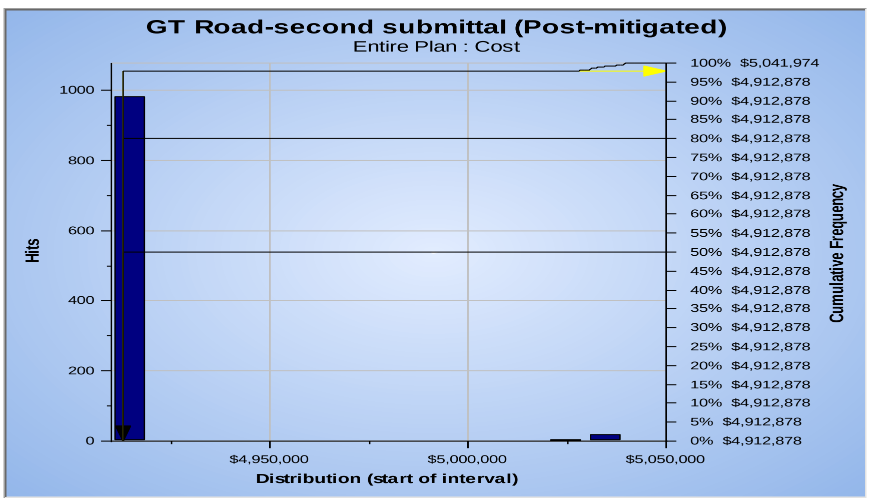


Figure 49: Distribution of Project's Cost in Post-mitigation Plan

Then, in order to calculate the average benefit-to-cost ratio “BCR” of applying risk management, the difference between the average cost of the project in the pre-mitigation and the post-mitigation plan is obtained as shown in table 34.

Table 34: Comparison between the Total Costs in the Pre-Mitigation & Post-Mitigation Plans

Plan\ Cost	Minimum Cost	Maximum Cost	Average Cost	Deterministic Cost
Pre-Mitigation	$4,544,220	$13,062,068	$8,533,110	$4,544,220
Post-Mitigation	$4,912,878	$5,041,974	$4,915,309	$4,912,878

$BCR=\frac{8{,}533{,}110-4{,}915{,}309}{131{,}617+94{,}272+136{,}627}=14.80>1$ which highlights the much-needed implementation of risk management in the construction industry.

6.3 Discussion

The risk analysis of the project has resulted in identifying risk avoidance and risk mitigation as the most optimum risk response strategies resulting in low-cost sensitivity and duration sensitivity in the post-mitigation phase of the construction project. Prior to the proper response to each of the risks, the consultant was the risk owner that was liable to a high-cost sensitivity and duration sensitivity; on the other hand, in the post-mitigation plan, the contractor is now responsible for the highest impact on the cost and duration of the construction project with the owner held liable only for the communication barriers risk which had a negligible impact on the cost and duration of the project showcasing the uppermost impact that the unforeseen site conditions have on the project (Sunday, 2016).

Moreover, it was noticeable that high-level risks cause a significantly higher impact on the project than moderate level risks even in the pre-mitigation phase.

Thus, showing that moderate level risks can be managed using additional managerial effort or resources while high-level risks need senior management attention to make major adjustments to the project plans (Government of Canada, 2018).

The application of risk management was proved to be justified and highly beneficial in this project since the average BCR was much higher than 1 and the risks had only2% impact on the project's cost and time after the application of efficient and specific risk responses. On another hand, the application of risk management also demonstrated that fewer delays will occur in the project due to the significant increase in spearman's correlation.

7. Conclusion

There is a significant lack of knowledge in risk management in Lebanon where on average each Lebanese civil engineer is familiar with only half of the risk management stages. The latter signifies the importance of a third-party risk management consultant or training. Risk is perceived as a negative term although risks could also have positive impacts which would lead to the Lebanese civil engineers missing on the opportunity to exploit several risks.

The overall most important risks in the construction industry in Lebanon, as shown in the results of the survey, are the evaluation of tenders according to the lowest cost only, poor risk identification, and difficulty obtaining the completion certificate due to construction errors. The latter risks were allocated all to the owner which shows that Lebanese civil engineers are not willing to share risks. This could be solved through the implementation of efficient risk allocation models where the risk is allocated to the most competent party and the adoption of advanced forms of partnerships such as public-private partnerships. While the most important risks in each procurement phase are as follows: poor risk identification, lack of financial resources and under/over-statement of the needs in the preliminary phase, evaluation of tenders according to the lowest cost only, high competition between tenderers and inadequate tenders full of errors in the tendering phase.

While the most important risks in the project execution phase are unforeseen site conditions, defective design and communication barriers, and the most important risks in the project completion phase are difficulty obtaining the completion certificate due to construction errors, defective design, and communication barriers.

Besides, the most important risks varied according to the nature of the projects involved where it was revealed that corruption-related risks were vivid in infrastructure and geotechnical projects in Lebanon.

The latter most important risks that were chosen by the Lebanese civil engineers were then studied using in-depth interviews while taking into consideration design-bid-build lump sum projects. It was revealed that the most occurring and hardest to detect risk is poor risk identification, and the most severe risk is the defective design which is only high-level risks. Taking into consideration the ability to detect the risks, the most important risks become poor risk identification, defective design, and lack of financial resources. The latter shows the importance of the application of RPN in order to be able to efficiently manage and plan for unprecedented risks and avoid the occurrence of several moderately severe yet hard to detect risks together which could lead to the possible failure of construction projects.

After this, a quantitative risk analysis was implemented on a sample design-bid-build lump sum project while using primavera risk analysis. It was vivid that risk mitigation and risk avoidance are the most optimum risk response strategies since they cause the least impact on the duration and cost of the project. Moreover, the application of the case study resulted in a very high BCR and risks having only negligible impacts on the project's schedule and cost after the application of specific risk responses. Thus, highlighting the necessity for the application of risk management in the construction industry in Lebanon which could result in the sustainable and resilient construction industry especially with having several Lebanese families depending on its stability for their livelihood and Lebanon having a high-risk profile and facing several disruptions such as the Coronavirus of the year 2020 and the October Lebanese revolution in the year 2019.

On another hand, six sigma, lean, and lessons learned from the application of risk management in the enterprises and the IT industry should be explored and implemented in the construction industry in Lebanon in order to obtain continuous improvement and be able to apply risk management in construction more efficiently. For example, risk management in the construction industry can be automated like it is implemented in the IT industry (Fadlallah, 2018).

8. Limitations

This research of this thesis was executed during critical times in Lebanon witnessing the Lebanese October revolution and the spread of Coronavirus which have impacted the choice of the most important risks in each phase. The latter explains why environmental risks were not chosen by Lebanese civil engineers since EPA has ceased enforcing environmental laws during the occurrence of the Coronavirus (Associated Press, 2020). Moreover, the dwindling construction activity, as evident from the downward trend of the number of construction permits, might have also impacted the response rate.

9. Direction for Future Research

Corruption-related risks should be investigated in infrastructure and geotechnical projects in Lebanon in terms of the size and value of the projects involved. Moreover, qualitative and quantitative risk analyses could be done in other types of procurement for construction projects such as design-build or construction management projects in order to compare the results with design-bid-build lump sum projects.

References

- Abou Chakra, H. and Ashi, A. (2017) 'Evaluation of Risk Indicators and Techniques in Construction Project Management', Research Journal of Applied Sciences, Engineering and Technology, 14(5), pp. 170–175. doi: 10.19026/rjaset.14.4286.
- Adams, F. (2008) 'Construction Contract Risk Management: A Study of Practices in the United Kingdom', Cost Engineering, 50(1), pp. 22–33.
- Aderbag, M. A., Elmabrouk, S. K. and Sherif, M. A. (2018) 'Risk Analysis Related to Costing and Scheduling of Construction Projects', Proceedings of the International Conference on Industrial Engineering and Operations Management, 2018-March.
- Akinbile, B. F. et al. (2018) 'Risk Management and Its Influence on Construction Project in Nigeria.', Annals of the Faculty of Engineering Hunedoara - International Journal of Engineering, 16(3), pp. 169–174. Available at: http://search.ebscohost.com/login.aspx?direct=true&db=a9h&AN=131841582&site=ehost-live&scope=site.
- Al-Azemi, K. F., Bhamra, R. and F.M.Salman, A. (2014) 'Risk_management_framework_for.PDF', Journal of Civil Engineering and Management.
- Al-Sabah, R. (2012) Evaluating Significant Risks In The Middle East North Africa (Mena) Construction Projects From Perspective Of Multinational Firms.
- Aminbakhsh, S., Gunduz, M. and Sonmez, R. (2013) 'Safety Risk Assessment Using Analytic Hierarchy Process (AHP) During Planning and Budgeting of Construction Projects', Journal of Safety Research, 46, pp. 99–105. doi: 10.1016/j.jsr.2013.05.003.
- Andrea, S. (2020) T Test (Student's T-Test): Definition and Examples - Statistics How To. Available at: https://www.statisticshowto.com/probability-and-statistics/t-test/ (Accessed: 9 April 2020).
- Ankit Vishwakarma et al. (2016) 'Risk Assessment in Construction of Highway Project', International Journal of Engineering Research and, V5(02), pp. 637–641. doi: 10.17577/ijertv5is020515.
- Antoaneta Claudia Butuza, L. V. H. (2010) 'Contract Construction Activity', Annals of the University of Petrosani : Economics, 10(3), pp. 33–40.
- Ashmawi, K. et al. (2018) 'Risk Assessment and Allocation in the Contract for Public Works Used in Saudi Arabia Construction Industry', Cogent Engineering. Cogent, 5(1), pp. 1–21. doi: 10.1080/23311916.2018.1490148.
- Associated Press (2020) Citing coronavirus, EPA has stopped enforcing environmental laws - MarketWatch. Available at: https://www.marketwatch.com/story/citing-coronavirus-epa-has-stopped-enforcing-environmental-laws-2020-03-27 (Accessed: 27 April 2020).
- Aven, T. (2016) 'Risk Assessment and Risk Management: Review of Recent Advances on Their Foundation', European Journal of Operational Research.

Elsevier B.V., 253(1), pp. 1–13. doi: 10.1016/j.ejor.2015.12.023.

- Banaitienė, N., Banaitis, A. and Norkus, A. (2011) 'Risk Management in Projects: Peculiarities of Lithuanian Construction Companies / Rizikos Valdymas Projektuose: Lietuvos Statybos Įmonių Savitumai', International Journal of Strategic Property Management, 15(1), pp. 60–73. doi: 10.3846/1648715x.2011.568675.
- Bartlett, J., Kortlik, J. and Higgins, C. (1977) 'Determining Appropriate Sample Size in Survey Research'.
- Beirut, U.-H. (2011) The Construction Sector.
- Bernardez (2007) 'Should We Have a Universal Model for HPT', Performance Improvement, 46(9), pp. 9–16. doi: 10.1002/pfi.
- Bloomberg (2020) Coronavirus Could Cost the Global Economy $2.7 Trillion. Here's How. Available at: https://www.bloomberg.com/graphics/2020-coronavirus-pandemic-global-economic-risk/ (Accessed: 8 April 2020).
- Bloomfield, K. et al. (2019) 'Systemic Risk in Major Public Contracts', International Journal of Forecasting. Elsevier B.V., 35(2), pp. 667–676. doi: 10.1016/j.ijforecast.2018.10.005.
- Campo, S. (2012) 'Risk Aversion and Asymmetry in Procurement Auctions: Identification, Estimation and Application to Construction Procurements', Journal of Econometrics. Elsevier B.V., 168(1), pp. 96–107. doi: 10.1016/j.jeconom.2011.09.011.
- Chan, D. W. M. et al. (2011) 'Risk Ranking and Analysis in Target Cost Contracts: Empirical Evidence from The Construction Industry', International Journal of Project Management. Elsevier B.V., 29(6), pp. 751–763. doi: 10.1016/j.ijproman.2010.08.003.
- Chege, L. W. and Rwelamila, P. M. D. (2002) 'Risk Management and Procurement Systems'. Available at: https://www.semanticscholar.org/paper/risk-management-and-procurement-systems-—-an-chege-Rwelamila/2aec1f905af16949c1148fd722149e013282c91b.
- Chen, H. (2012) 'Procurement Risk Management of Engineering Materials Based on Uncertain Rising Prices', Applied Mechanics and Materials, 174–177, pp. 3219–3222. doi: 10.4028/www.scientific.net/amm.174-177.3219.
- Chipman, C. and Asklof, L. (2015) Construction Corner: Design-Bid-Build Project Delivery Method | School Law. Available at: https://www.ctschoollaw.com/2015/06/construction-corner-design-bid-build-project-delivery-method/ (Accessed: 8 April 2020).
- CIDB: South Africa (2004) 'Managing Construction Procurement Risks', Best Practice Guideline #a5, pp. 1–8.
- Dahiru, A. and Bashir, A. M. (2015) 'Risk Factors Influencing Construction Procurement Performance in Nigeria', Arid Zone Journal of Engineering, Technology and Environment. August, 11, pp. 77–88. Available at: www.azojete.com.ng.
- Darren, G. and Mallery, P. (2003) (4) SPSS for Windows Step-by-Step: A Simple Guide and Reference, 14.0 update (7th Edition) | Request PDF. Available at:

https://www.researchgate.net/publication/234827666_SPSS_for_Windows_Step-by-Step_A_Simple_Guide_and_Reference_140_update_7th_Edition (Accessed: 8 April 2020).

- Date, S. (2019) Testing for Normality using Skewness and Kurtosis - Towards Data Science. Available at: https://towardsdatascience.com/testing-for-normality-using-skewness-and-kurtosis-afd61be860 (Accessed: 8 April 2020).
- Deloitte (2017) The Case for Risk Management in The Middle East Construction Market | Deloitte Saudi Arabia | ME PoV issue 23. Available at: https://www2.deloitte.com/sa/en/pages/about-deloitte/articles/The-only-certainty-is/case-me-risk-management-construction-market.html (Accessed: 27 April 2020).
- Deneckere, R., de Palma, A. and Leruth, L. (2019) 'Risk Sharing in Procurement', International Journal of Industrial Organization. Elsevier B.V., 65, pp. 173–220. doi: 10.1016/j.ijindorg.2019.01.002.
- Devi, V. R. (2018) 'A Study on Risk Analysis in Construction Project', International Research Journal of Engineering and Technology, 05(05), pp. 4317–4321.
- Ding, J., Wang, N. and Hu, L. (2018) 'Framework for Designing Project Delivery and Contract Strategy in Chinese Construction Industry Based on Value-Added Analysis', Advances in Civil Engineering. Hindawi Limited, 2018. doi: 10.1155/2018/5810357.
- Dionne, G. (2013) Risk Management: History, Definition and Critique Bureaux de Montréal : Bureaux de Québec. Available at: www.cirrelt.ca (Accessed: 8 April 2020).
- Dziadosz, A. and Rejment, M. (2015) 'Risk Analysis in Construction Project - Chosen Methods', Procedia Engineering. Elsevier B.V., 122(Orsdce), pp. 258–265. doi: 10.1016/j.proeng.2015.10.034.
- Dziadosz, A., Tomczyk, A. and Kapliński, O. (2015) 'Financial Risk Estimation in Construction Contracts', Procedia Engineering, 122(Orsdce), pp. 120–128. doi: 10.1016/j.proeng.2015.10.015.
- Engel, A. R. and Wambach, A. (2019) 'Risk Management in Procurement Auctions Public procurement under Limited Liability ', (April).
- Eskander, R. F. A. (2018) 'Risk Assessment Influencing Factors for Arabian Construction Projects Using Analytic Hierarchy Process', Alexandria Engineering Journal. Faculty of Engineering, Alexandria University, 57(4), pp. 4207–4218. doi: 10.1016/j.aej.2018.10.018.
- Fadlallah, H. (2018) How Information Technologies influenced Risk Management? Available at: https://towardsdatascience.com/how-information-technologies-influenced-risk-management-7eb3a38d253 (Accessed: 11 April 2020).
- Field Chat (2020) FieldChat. Available at: https://www.fieldchat.com/ (Accessed: 6 March 2020).
- Floor, F. (1993) 'Ipsas 11—construction contracts', 11(Revised), pp. 305–333.
- Frédéric BLANC-BRUDE, E.-R. I. (2013) 'An Example From Uk Primary and

Secondary Risk Transfer , Self-Selection and Ex Post Efficiency'.

- Garshasb Khazaeni, Mostafa Khanzadi, and A. A. (2012) 'Optimum_risk_allocation_mode.PDF'.
- GDP at Current Prices: Construction (% of GDP) - GDP by Economic Activity, Current Prices (% of GDP) - National Accounts - Lebanon - BRITE (2018). Available at: https://brite.blominvestbank.com/series/GDP-at-Current-Prices-Construction-of-GDP-10572/ (Accessed: 8 April 2020).
- Ghaeli, M. R. (2018) 'The Advantage of Project Risk Management Tools', Journal of Project Management, 3, pp. 121–124. doi: 10.5267/j.jpm.2018.1.002.
- Goldsworthy, J. S. et al. (no date) Measuring the Risk of Geotechnical Site Investigations.
- Government of Canada (2018) Risk management. Available at: https://www.international.gc.ca/world-monde/funding-financement/risk_management-gestion_risques.aspx?lang=eng (Accessed: 6 March 2020).
- Guo, Z. L., Hu, Y. Z. and Liu, J. E. (2014) 'The Analysis of Contractor's Risk Clause Based on the FIDIC Construction Contract', Applied Mechanics and Materials, 687–691, pp. 4815–4818. doi: 10.4028/www.scientific.net/amm.687-691.4815.
- Gupat, Divya and sharma, M. (2017) 'Risk Management in Construction Projects', Procedia Engineering, 208(14), pp. 174–182. doi: 10.1016/J.PROENG.2017.11.036.
- Gupta, V. K. and Thakkar, J. J. (2018) 'A Quantitative Risk Assessment Methodology for Construction Project', Sadhana - Academy Proceedings in Engineering Sciences, 43(7). doi: 10.1007/s12046-018-0846-6.
- Gyamf, T. A. (2016) 'Risk Analysis of Procurement Options: Implications for Construction Firms in Ghana', International Journal of Sciences: Basic and Applied Research (IJSBAR), 28(1), pp. 90–102.
- Gyamfi, T. A. and Boateng, V. (2016) 'Open Access Risk Management of Procurement Challenges : The Implication To Construction Firms In Ghana American Journal Of Engineering Research (AJER)', (8), pp. 164–172.
- Halpin, D. W. and Senior, B. A. (2011) Construction management. Wiley.
- Hawkes, I. (2017) Managing Contingency in Construction Cost Estimates | Faithful+Gould | Middle East. Available at: https://www.fgould.com/middle-east/articles/managing-contingency-construction-cost-estimates/ (Accessed: 6 March 2020).
- Hilson, D. (2014) Managing Overall Project Risk. Available at: https://www.pmi.org/learning/library/overall-project-risk-assessment-models-1386 (Accessed: 8 April 2020).
- HWANG, B.-G. and CHEN, M. (2015) 'Sustainable Risk Management in the Construction Industry: Lessons Learned From the It Industry', Technological and Economic Development of Economy, 21(2), pp. 216–231. doi: 10.3846/20294913.2014.979455.
- Hwang, B. G., Zhao, X. and Toh, L. P. (2014) 'Risk Management in Small

Construction Projects in Singapore: Status, Barriers and Impact', International Journal of Project Management. Elsevier Ltd and APM IPMA, 32(1), pp. 116–124. doi: 10.1016/j.ijproman.2013.01.007.

- Ignatius, J. and Buertey, T. (2016) Procurement of Developmental Projects in Ghana: A Literature Review of the Designer-Led System Verses the Producer-Led Systems :: Science Publishing Group. Available at: http://article.sciencepublishinggroup.com/html/10.11648.j.ajce.20160404.12.html#reference_3 (Accessed: 26 November 2019).
- Ironmonger, R. S. (1989) 'An Analysis of Construction Contracts : Types , Characteristics , and ...', Cost Engineering, 31(12), pp. 13–18.
- Jarkas, A. M. and Haupt, T. C. (2015) 'Major Construction Risk Factors Considered by General Contractors in Qatar', Journal of Engineering, Design and Technology, 13(1), pp. 165–194. doi: 10.1108/JEDT-03-2014-0012.
- Jim Hall (2010) Best Practices for Design Build Procurement - ppt video online download. Available at: https://slideplayer.com/slide/8703918/ (Accessed: 26 November 2019).
- Kalvet, T. (2010) 'Risks Management in Public Procurement for Innovation: The Case of Nordic-Baltic Sea Cities Tarmo Kalvet and Veiko Lember'. Available at: http://www.ippa.org/IPPC4/Proceedings/17SupplyChainManagement/Paper17-4.pdf.
- Khumpaisal, S. (2010) 'Risks in the Construction Project Procurement Process and the Mitigation Methods', Academic Articles on Housing and Real Estate Development, (January 2007), pp. 133–146.
- Kim, S. and Bejaj, D. (2000) 'Risk Management in Construction: An Approach for Contractors in South Korea', Cost Engineering, 42(1), pp. 38–44. Available at: http://search.proquest.com/docview/220447469?accountid=25704.
- Kordas, D. (2015) 'Risk Sharing in Traditional Construction Contracts for Building Projects', p. 279. Available at: https://essay.utwente.nl/68505/1/Kordas D. (2015).pdf.
- Kotb, M H et al. (2018) Risk Identification Barriers in Construction Projects in MENA 1, PM World Journal Risk Identification Barriers in Construction Projects. Available at: www.pmworldlibrary.net (Accessed: 27 April 2020).
- Koulinas, G. K. et al. (2019) 'Risk Analysis and Assessment In The Worksites Using The Fuzzy-Analytical Hierarchy Process and A Quantitative Technique – A Case Study for The Greek Construction Sector', Safety Science. Elsevier, 112(June 2018), pp. 96–104. doi: 10.1016/j.ssci.2018.10.017.
- Kululanga, G. and Kuotcha, W. (2010) 'Measuring Project Risk Management Process for Construction Contractors with Statement Indicators Linked To Numerical Scores', Engineering, Construction and Architectural Management, 17(4), pp. 336–351. doi: 10.1108/09699981011056556.
- L. Tsipouri et al. (2010) Risk Management in The Procurement of Innovation, Risk Management in The Procurement of Innovation. Concepts and Empirical Evidence in The European Union. doi: 10.2777/92030.
- Lam, K. C. et al. (2007) 'Modelling Risk Allocation Decision in Construction

Contracts', International Journal of Project Management, 25(5), pp. 485–493. doi: 10.1016/j.ijproman.2006.11.005.

- Landage, A. (2016) 'Risk Management in Construction Industry', International Journal of Engineering Research.
- Leimeister, S. (2009) IT Outsourcing Governance: Client Types and Their Management Strategies - Stefanie Leimeister - Google Books. Available at: https://books.google.com.lb/books?id=IYet2D3mH7wC&pg=PA140&lpg=PA140&dq=cronbach+alpha+0.6+for+exploratory+study&source=bl&ots=9Ne8NU4jlD&sig=ACfU3U2VlAp4nvVs4w8y45vJHJwbjXhrbg&hl=en&sa=X&ved=2ahUKEwi1pLTpvv7nAhXL7eAKHTVqC20Q6AEwDXoECAgQAQ#v=onepage&q=cro (Accessed: 3 March 2020).
- Li, W. F. (2013) 'The Study on Risk and Countermeasure of Highway Engineering Construction Contract', Applied Mechanics and Materials, 438–439, pp. 1940–1943. doi: 10.4028/www.scientific.net/amm.438-439.1940.
- Lin, Y. H., Lin, C. C. and Tyan, Y. Y. (2011) 'An Integrated Quantitative Risk Analysis Method for Major Construction Accidents Using Fuzzy Concepts and Influence Diagram', Journal of Marine Science and Technology, 19(4), pp. 383–391.
- Liu, M. (2013) 'Program Evaluation and Review Technique (PERT) in Construction Risk Analysis', Applied Mechanics and Materials, 357–360, pp. 2334–2337. doi: 10.4028/www.scientific.net/amm.357-360.2334.
- Liu, Y. and Li, Y. (2014) 'Risk Management of Construction Schedule by PERT with Monte Carlo Simulation', Applied Mechanics and Materials, 548–549, pp. 1646–1650. doi: 10.4028/www.scientific.net/amm.548-549.1646.
- Lund, A. and Lund, M. (2018) Kendall's Tau-b using SPSS Statistics - A How-To Statistical Guide by Laerd Statistics. Available at: https://statistics.laerd.com/spss-tutorials/kendalls-tau-b-using-spss-statistics.php (Accessed: 9 April 2020).
- Lyons, T. and Skitmore, M. (2004) 'Project Risk Management in The Queensland Engineering Construction Industry: A survey', International Journal of Project Management, 22(1), pp. 51–61. doi: 10.1016/S0263-7863(03)00005-X.
- MacLeod, M. J. and Akintoye, A. S. (1997) 'Risk Analysis and Management in Construction', International Journal of Project Management, 15(1), pp. 31–38. doi: 10.1016/S0263-7863(96)00035-X.
- Majumder, D., Debnath, J. and Biswas, A. (2014) 'Risk Analysis in Construction Sites Using Fuzzy Reasoning and Fuzzy Analytic Hierarchy Process', Procedia Technology. Elsevier B.V., 10, pp. 604–614. doi: 10.1016/j.protcy.2013.12.401.
- Marco, A. De et al. (2012) 'A Framework Methodology for Selection of Risk Analysis Techniques in Construction Projects', Creative Construction Conference, pp. 142–151.
- De Marco, A. and Jamaluddin Thaheem, M. (2014) 'Risk Analysis in Construction Projects: A Practical Selection Methodology', American Journal of Applied Sciences, 11(1), pp. 74–84. doi: 10.3844/ajassp.2014.74.84.
- Martin, S. (2006) 'Risk Management in Construction Project Management', Journal of Business Economics and Management, VII(2), pp. 77–83. doi:

10.1080/16111699.2006.9636126.

- McGoey-Smith, A. ., Poschmann, A. . and Campbell, L. . (2007) ‘Quantitative Risk Assessment and Risk Management of A Large Transportation Project’, TAC/ATC 2007 - 2007 Annual Conference and Exhibition of the Transportation Association of Canada: Transportation - An Economic Enabler, pp. 1–18. Available at: https://www.scopus.com/inward/record.uri?eid=2-s2.0-84898488657&partnerID=40&md5=aba3e951a3bdfbe71831cab0d1d4f37a.
- Mcnichol, D. (2013) Construction Goes Global: Infrastructure and Project Delivery Across Borders. Available at: http://www.mckinsey.com/insights/americas/us_game_changers (Accessed: 8 April 2020).
- Motiar Rahman, M. (2015) ‘Cost of Prequalification: A Pilot Study’, in Proceedings of the 19th International Symposium on Advancement of Construction Management and Real Estate. Springer Berlin Heidelberg, pp. 1219–1229. doi: 10.1007/978-3-662-46994-1_102.
- Mubin, S., Jahan, S. and Gavrishyk, E. (2019) ‘Monte Carlo Simulation and Modeling of Schedule, Cost and Risks of Dasu Hydropower Project’, Journal of Engineering & Technology, 38(3), pp. 557–570. doi: 10.22581/muet1982.1903.03.
- Murdoch, J. and Hughes, W. (no date) Construction Contracts: Law and Management, Third Edition.
- Murray, J. G. (2013) ‘Debate: The Need for Procurement Risk Management’, Public Money and Management, 33(4), pp. 285–287. doi: 10.1080/09540962.2013.799834.
- Nadaf, J. et al. (2018) ‘Qualitative Risk Analysis for Construction Projects’.
- Naoum, S. and Egbu, C. (2015) ‘Critical Review of Procurement Method Research in Construction Journals’, Procedia Economics and Finance. Elsevier B.V., 21(5), pp. 6–13. doi: 10.1016/s2212-5671(15)00144-6.
- Nawaz, A. et al. (2019) ‘An Innovative Framework for Risk Management in Construction Projects in Developing Countries: Evidence from Pakistan’, Risks, 7(1), p. 24. doi: 10.3390/risks7010024.
- Nicał, A. K. and Wodyński, W. A. (2015) ‘Procuring Governmental Megaprojects: Case Study’, in Procedia Engineering. Elsevier Ltd, pp. 342–351. doi: 10.1016/j.proeng.2015.10.045.
- Nieto-Morote, A. and Ruz-Vila, F. (2011) ‘A Fuzzy Approach to Construction Project Risk Assessment’, International Journal of Project Management. Elsevier Ltd and IPMA, 29(2), pp. 220–231. doi: 10.1016/j.ijproman.2010.02.002.
- OEA (2019) بحث عن مهندس | نقابة المهندسين بيروت. Available at: https://www.oea.org.lb/Arabic/MembersSearch.aspx?PageID=112&pagesize=20&RadCurrentPage=1&Code=0&HRSpecialty=503&Familyname=&Name= (Accessed: 3 October 2019).
- OEA (2020) إحصاءات الرخص | نقابة المهندسين بيروت. Available at: https://oea.org.lb/Arabic/Listing-Files.aspx?pageid=1729&FolderID=73 (Accessed: 13 April 2020).

- Olalekan Mumuni Ogunbayo (2014) ‘Assessment of Risk Analysis Processes in The Nigerian Constuction Industry’, International Journal of Advancements in Research & Technology, 3(1), pp. 36–42.
- Osipova, E. (2008) ‘Risk Management in Construction Projects : A Comparative Study of The Different Procurement Options in Sweden’, pp. 1–138.
- Osipova, E. and Eriksson, P. E. (2011a) ‘How Procurement Options Influence Risk Management in Construction Projects’, Construction Management and Economics, 29(11), pp. 1149–1158. doi: 10.1080/01446193.2011.639379.
- Osipova, E. and Eriksson, P. E. (2011b) ‘The Effects of Cooperative Procurement Procedures on Joint Risk Management in Swedish Construction Projects’, International Journal of Project Organisation and Management, 3(3/4), p. 209. doi: 10.1504/ijpom.2011.042029.
- Oyegoke, A. S. et al. (2009) ‘Construction Project Procurement Routes: An In-Depth Critique’, International Journal of Managing Projects in Business, 2(3), pp. 338–354. doi: 10.1108/17538370910971018.
- Öztaş, A. and Ökmen, Ö. (2004) ‘Risk Analysis in Fixed-Price Design-Build Construction Projects’, Building and Environment, 39(2), pp. 229–237. doi: 10.1016/j.buildenv.2003.08.018.
- Park, K., Lee, S. and Ahn, Y. (2017) ‘Construction Management Risk System (CMRS) for Construction Management (CM) Firms’, Future Internet, 9(1), p. 5. doi: 10.3390/fi9010005.
- Pawar, C. S., Jain, S. S. and Gaikwad, A. M. (2015) ‘Contract Documents Is Effective Tool for Risk’, International Journal of Engineering Research and General Science, 3(3), pp. 678–682.
- Pawar, S. P., Bajad, M. N. and Shinde, P. R. D. (2017) ‘Risk Analysis and Strategic Evaluation of Procurement Process in Construction’, International Research Journal of Engineering and Technology(IRJET), 4(6), pp. 1892–1898. Available at: https://irjet.net/archives/V4/i6/IRJET-V4I6594.pdf.
- Peckiene, A., Komarovska, A. and Ustinovicius, L. (2013) ‘Overview of Risk Allocation between Construction Parties’, Procedia Engineering. Elsevier B.V., 57, pp. 889–894. doi: 10.1016/j.proeng.2013.04.113.
- Perera, B. A. K. . (2009) ‘Risk Management in Road Construction: the Case of Sri Lanka’, International Journal of Strategic Property Management, 13(2), pp. 87–102. doi: 10.3846/1648-715x.2009.13.87-102.
- Perrenoud, A. et al. (2017) ‘Using Best-Value Procurement to Measure the Impact of Initial Risk-Management Capability on Qualitative Construction Performance’, Journal of Management in Engineering, 33(5), p. 04017019. doi: 10.1061/(asce)me.1943-5479.0000535.
- PMI (2014) Understanding Project Risks - Cognitive Approach. Available at: https://www.pmi.org/learning/library/understanding-project-risk-cognitive-approach-8305 (Accessed: 2 March 2020).
- Procurement, M. I. N. (2017) ‘Risk Management In Pocurement of Construction Project- A Context of Pwd In partial fulfillment of the requirements for the degree of January 2017 Masters in Procurement and Supply Management BRAC Institute

of Governance and Development (BIGD) RISK MANAG', (16382027).

- Proenca, D. et al. (2017) 'Risk management: A Maturity Model based on ISO 31000', Proceedings - 2017 IEEE 19th Conference on Business Informatics, CBI 2017, 1(July), pp. 99–108. doi: 10.1109/CBI.2017.40.
- R.A., J. et al. (2016) 'Managing Pre-Construction and Construction Risks on Project Sites in Abuja-Nigeria', Civil Engineering Dimension, 18(1), pp. 1–7. doi: 10.9744/ced.18.1.1-7.
- Rached, F. et al. (2014) (5) (PDF) Implementation of IPD in the Middle East and its Challenges. Available at: https://www.researchgate.net/publication/265122240_Implementation_of_IPD_in_the_Middle_East_and_its_Challenges (Accessed: 27 April 2020).
- Ramshaw, A. (2018) How to Analyze Survey Data in Excel. Available at: https://www.genroe.com/blog/analyze-survey-data-in-excel/11483 (Accessed: 7 October 2019).
- Rauzana, A. (2016) 'Identification and Assessment of Risk Factors Affecting Construction Projects in North Aceh, Indonesia', IOSR Journal of Business and Management, 18(09), pp. 72–77. doi: 10.9790/487x-1809047277.
- Reilly, J., Dc, W. and Eng, C. P. (2017) 'A Short History of Risk Management' Risk Management in Underground Construction Conference. Available at: www.JohnReilly.us (Accessed: 8 April 2020).
- Renault, B. Y. and Agumba, J. N. (2016) 'Risk Management in The Construction Industry: A New Literature Review', MATEC Web of Conferences, 66, p. 00008. doi: 10.1051/matecconf/20166600008.
- Rezakhani, P. (2013) 'A Review of Fuzzy Risk Assessment Models for Construction Projects', Slovak Journal of Civil Engineering, 20(3), pp. 35–40. doi: 10.2478/v10189-012-0016-5.
- Ruparathna, R. and Hewage, K. (2015) 'Review of Contemporary Construction Procurement Practices', Journal of Management in Engineering, 31(3), pp. 1–11. doi: 10.1061/(ASCE)ME.1943-5479.0000279.
- Sahu, Y. K. and Dudhe, N. (2016) 'Analysis of Risk Management in Construction Industries', IJSTE -International Journal of Science Technology & Engineering, 3(03), pp. 66–72. Available at: www.ijste.org.
- Sato, Y., Kitazume, K. and Miyamoto, K. (2005) 'Quantitative Risk Analysis of Road Projects Based on Empirical Data in Japan Yukiya', Journal of the Eastern Asia Society for Transportation Studies, 6, pp. 3971–3984.
- Serpell, A. et al. (2015) 'Evaluating Risk Management Practices in Construction Organizations', Procedia - Social and Behavioral Sciences. Elsevier B.V., 194(October 2014), pp. 201–210. doi: 10.1016/j.sbspro.2015.06.135.
- Serpella, A. F. et al. (2014) 'Risk Management in Construction Projects: A Knowledge-based Approach', Procedia - Social and Behavioral Sciences. Elsevier B.V., 119, pp. 653–662. doi: 10.1016/j.sbspro.2014.03.073.
- Sharma, S. K. (2013) 'Risk Management in Construction Projects Using Combined Analytic Hierarchy Process and Risk Map Framework.', IUP Journal of Operations Management, 12(4), pp. 23–53. Available at:

https://search.ebscohost.com/login.aspx?direct=true&db=bth&AN=92605540&site=ehost-live.

- Sunday, O. (2016) '930 Impact of Risks on Tendering and Procurement of Building Projects in Lagos State', (930), pp. 21–24.
- Syed M. Ahmed, Riaz Ahmad, D. D. D. S. (1999) 'Risk Management Trends in the Hong Kong Construction Industry'.
- Szymański, P. (2017a) 'Risk Management in Construction Projects', Procedia Engineering. Elsevier B.V., 208, pp. 174–182. doi: 10.1016/j.proeng.2017.11.036.
- Szymański, P. (2017b) 'Risk Management in Construction Poland Projects Paweł in Risk Management Construction Projects', Procedia Engineering, 208, pp. 174–182. doi: 10.1016/j.proeng.2017.11.036.
- Taghipour, M. et al. (2015) 'Risk Analysis In The Management of Urban Construction Projects from The Perspective of The Employer and The Contractor', International Journal of Organizational Leadership, 4(4), pp. 356–373. doi: 10.33844/ijol.2015.60284.
- Tamošaitienė, J., Zavadskas, E. K. and Turskis, Z. (2013) 'Multi-Criteria Risk Assessment of A Construction Project', Procedia Computer Science, 17(Itqm), pp. 129–133. doi: 10.1016/j.procs.2013.05.018.
- Taylan, O. et al. (2014) 'Construction Projects Selection and Risk Assessment by Fuzzy AHP and Fuzzy TOPSIS Methodologies', Applied Soft Computing Journal. Elsevier B.V., 17, pp. 105–116. doi: 10.1016/j.asoc.2014.01.003.
- Terra et Aqua (2005) - IADC Dredging. Available at: https://www.iadc-dredging.com/ul/cms/terraetaqua/document/2/3/9/239/239/1/terra-et-aqua-111-complete-issue.pdf (Accessed: 26 November 2019).
- Thaheem, M. J., Marco, A. De and Barlish, K. (2012) 'A Review of Quantitative Analysis Techniques for Construction Project Riks Management', Creative Construction Conference, (January), pp. 656–666.
- Titarenko, B. et al. (2018) 'Project Risk Management in The Construction of High-Rise Buildings', E3S Web of Conferences, 33, p. 03074. doi: 10.1051/e3sconf/20183303074.
- Tsai, T. C. and Yang, M. L. (2010) 'Risk Assessment of Design-Bid-Build and Design-Build Building Projects', Journal of the Operations Research Society of Japan, 53(1), pp. 20–39. doi: 10.15807/jorsj.53.20.
- Turner & Townsend (2018) Risk Management - Tendering and Contract Negotiations | Turner & Townsend. Available at: https://www.turnerandtownsend.com/en/perspectives/an-effective-approach-to-risk-management-during-tendering-and-contract-negotiations-stage/ (Accessed: 27 April 2020).
- Usmani, F. (2019) Risk vs Uncertainty in Project Management | PM Study Circle. Available at: https://pmstudycircle.com/2012/02/risk-vs-uncertainty/ (Accessed: 8 April 2020).
- Vidivelli, K. J. B. and Surjith, E. R. G. (2014) 'Risk Assessment and Management in Construction Projects', International Journal of Scientific & Engineering Research, 5(8).

- Wang, Z. Z. and Shi, B. (2014) ‘Probabilistic Risk Analysis for Highway Construction Management’, Applied Mechanics and Materials, 584–586, pp. 2363–2367. doi: 10.4028/www.scientific.net/amm.584-586.2363.
- Weaver, P. (2008) The Meaning of Risk in An Uncertain World. Available at: https://www.pmi.org/learning/library/project-risks-uncertain-world-8392 (Accessed: 8 April 2020).
- Wehbe, F. A. and Hamzeh, F. (2013) ‘Failure Mode and Effect Analysis as A Tool for Risk Management in Construction Planning Conference’, Proceedings for the 21st Annual Conference of the International Group for Lean Construction, (January). doi: 10.13140/RG.2.1.3935.4409.
- Weisstein, E. W. (2020) ‘Fisher’s Exact Test’. Wolfram Research, Inc.
- Wiley (2015) ‘Research Methods for Construction, 4th Edition’.
- Wilson, P. (2012) Professional Consultant Costs in Building Projects. Available at: https://www.mrfixitbali.com/building-construction/quantity-surveying-and-cost-control/building-consultant-costs-143.html (Accessed: 6 March 2020).
- Works, G. (2013) Comparison of Project Delivery Methods Integrated Services, Customized Solutions.
- Xia, N. et al. (2018) ‘Towards Integrating Construction Risk Management and Stakeholder Management: A Systematic Literature Review and Future Research Agendas’, International Journal of Project Management, 36(5), pp. 701–715. doi: 10.1016/j.ijproman.2018.03.006.
- Yeager, K. (2020) ‘LibGuides: SPSS Tutorials: One Sample t Test’.
- Younis, G. and Wood, G. (2010) ‘Minimizing Construction Disputes the Relationship.pdf’, pp. 728–740.
- Zhang, H. Y. and Zhao, J. W. (2013) ‘Explore and Analyse Construction Project Risk Management’, Applied Mechanics and Materials, 357–360, pp. 2550–2554. doi: 10.4028/www.scientific.net/amm.357-360.2550.
- Zhao, X., Hwang, B. G. and Phng, W. (2014) ‘Construction Project Risk Management in Singapore: Resources, Effectiveness, Impact, And Understanding’, KSCE Journal of Civil Engineering, 18(1), pp. 27–36. doi: 10.1007/s12205-014-0045-x.

Appendix

Questionnaire

1) What is your age?
- 24-34
- 34-44
- 44-54
- 54-64

2) What profession did you practice the most? *
- Consultant
- Procurement Engineer
- Project Manager
- Contractor
- Design Engineer
- Estimation Engineer
- Others

3) What is the highest level of education that you have acquired? *
- High School
- Technical School
- Bachelors Degree
- Masters Degree
- PhD
- Postgraduate Studies

4) How many years of experience do you have?
- 0-2
- 2-5
- 5-10
- 10-15
- >15

5) In addition to Lebanon, in which country did you also practice your profession?

6) What was the nature(s) of the projects that you were involved in?
- Environmental
- Transportation
- Structural
- Geotechnical
- Others

7) What How did you hear about this survey?
- LinkedIn
- Whatsapp
- Email
- SMS
- Others

8) What stage(s) in risk management process are you familiar with? (You can choose more than one)
- Risk identification (Brainstorming, checklist, documentation, meetings, etc.)
- Qualitative Risk Analysis (Survey, interview, expert judgement, SWOT analysis, etc.)
- Quantitative Risk Analysis (Simulation, decision tree analysis, analytical hierarchy process, etc.)
- Risk Response (Risk mitigation, risk acceptance, risk reduction, risk sharing, etc.)
- None

9) Which of the following step(s) in the risk management process do you apply in the procurement of construction? (You can choose more than one)
- Risk identification (Brainstorming, checklist, documentation, meetings, etc.)
- Qualitative Risk Analysis (Survey, interview, expert judgement, etc.)
- Quantitative Risk Analysis (Simulation, decision tree analysis, analytical hierarchy process, etc.)
- Risk Response (Risk mitigation, risk acceptance, risk reduction, risk sharing, etc.)
- None

10) In which stage in the procurement process is the application of risk management mostly effective?
- Preliminary (Defining needs, planning procurement process, bid solicitation)
- Tendering (Bidder selection, tender evaluation, purchase order)
- Project Execution (Contract amendments, project execution, progress payments)
- Completion (Project closeout, financial audits, final contract amendment)

11) In the projects you've worked on, which party(ies) was applying risk management? (You can choose more than one)

- Contractor
- Engineering Consultant
- Client
- Project Engineer
- Project Management Office
- Others

None

12) In your opinion, how do you perceive/consider risks in procurement of construction?

- Threats
- Opportunities
- Neutral

13) With respect to your work/profession, what is the most important risk that can occur during the preliminary phase?

- Corruption-related risks
- Exchange rate fluctuations
- Poor risk identification
- Inadequate financial provisions for risks
- Lack of financial resources
- Under/Over estimation of the budget

14) With respect to your work/profession, what is the most important risk that can occur during the tendering phase?

- Discrimination of tenderers
- High competition between tenderers
- Evaluation of tenders according to the lowest cost only
- Impact of contract type
- Impact of project delivery method
- Obtaining building permit (duration, preparation of documents, etc.)
- Inadequate tenders full of errors
- Experience of selected contractor
- Lack of procurement experts

15) With respect to your work/profession, what is the important risk that can occur during the project execution phase?

- Team conflicts
- Unforeseen site conditions
- Changes in government acts and regulations
- Communication barriers
- Defective design
- Third party delay
- Contract termination as a result of the main contractor's default
- Country - Specific risks (Social, economic, etc.)
- Force majeure
- Safety and accidents
- Delay in the release of progress payments
- Change orders

16) With respect to your work/profession, what is the most important risk that can occur during the project completion phase?

- Disputes/Need for arbitration
- Projectitis (Prolongation of the project due to deep attachment)
- Difficulty obtaining completion certificate due to construction errors
- Defective warranty
- Delay in the release of final payment and retention
- Difficulty agreeing on signoff on remaining punch-list issues

17) Which risk response strategy(ies) do you prefer/choose to use if you had to deal with a certain risk in the procurement of construction? (You can choose more than one)

- Risk Acceptance (i.e. to assume responsibility of the risk)
- Risk Transfer(i.e. to shift the responsibility of the risk from one party to another)
- Risk Mitigation(i.e. to reduce the exposure to a certain risk and/or its likelihood of occurrence)
- Risk Exploitation(i.e. to turn the risk into your own advantage)
- Risk Avoidance(i.e. to eliminate activities and exposures that can negatively affect the project)
- Risk Sharing(i.e. to distribute a risk's contractual responsibility among several parties)

18) Which tool do you use to monitor the risks in the procurement of construction?

- Reports (daily, weekly, special, etc.)
- Earned value management (cost & schedule variances or indexes)
- Meetings
- Others

19) Which project delivery method do you prefer taking into consideration the different risks in the procurement of construction?

- Design Build
- Design Bid Build
- Partnership/ Consortium
- Public Private Partnership
- Construction Management
- Others

20) Which contract type do you prefer taking into consideration the different risks in the procurement of construction?

- Fixed price contract
- Unit price contract
- Cost + % Cost
- Cost + Fixed Fee
- Cost + Sliding Fee
- Guaranteed Maximum Price
- Others

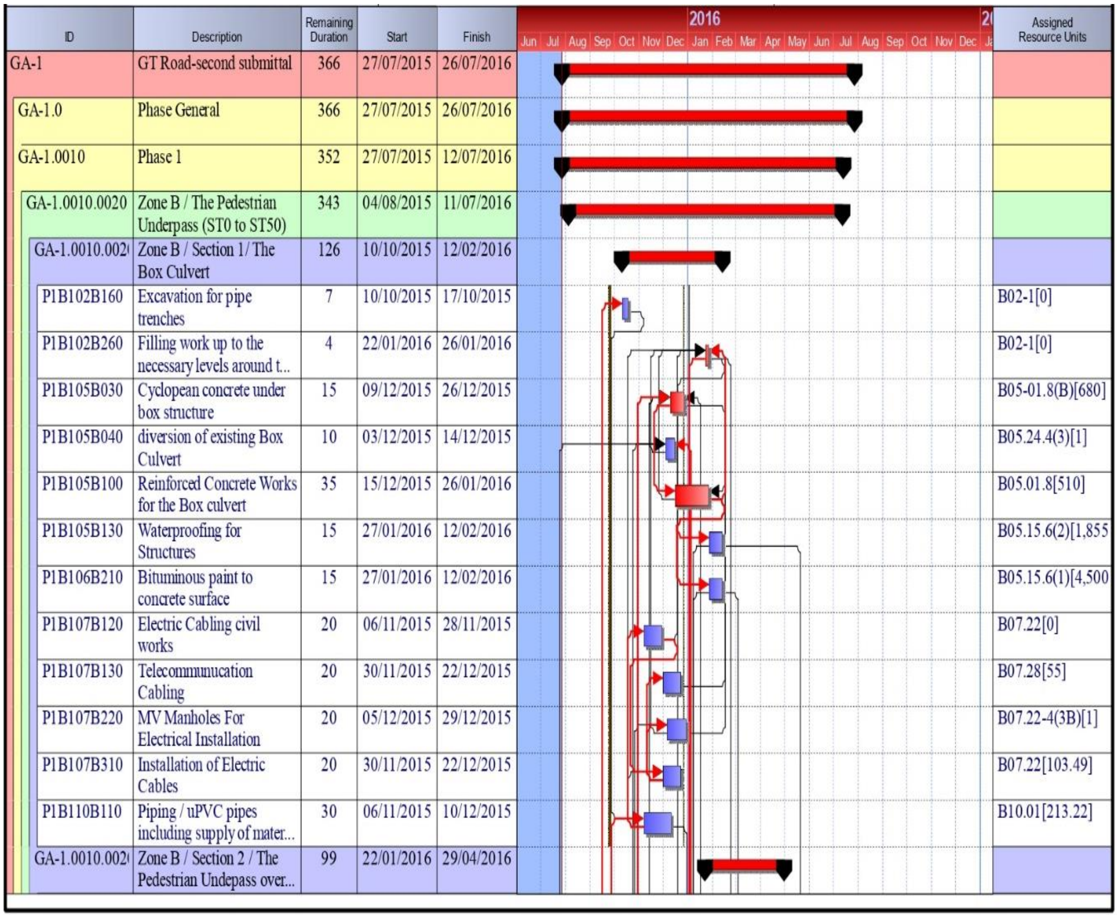
21) What is the main obstacle of applying effective risk management in procurement of construction?

- Lack of experts in risk management
- Management does not require the application of risk management
- No time
- Lack of awareness of the benefits of risk management
- Lack of knowledge in risk management
- Others

Case Study

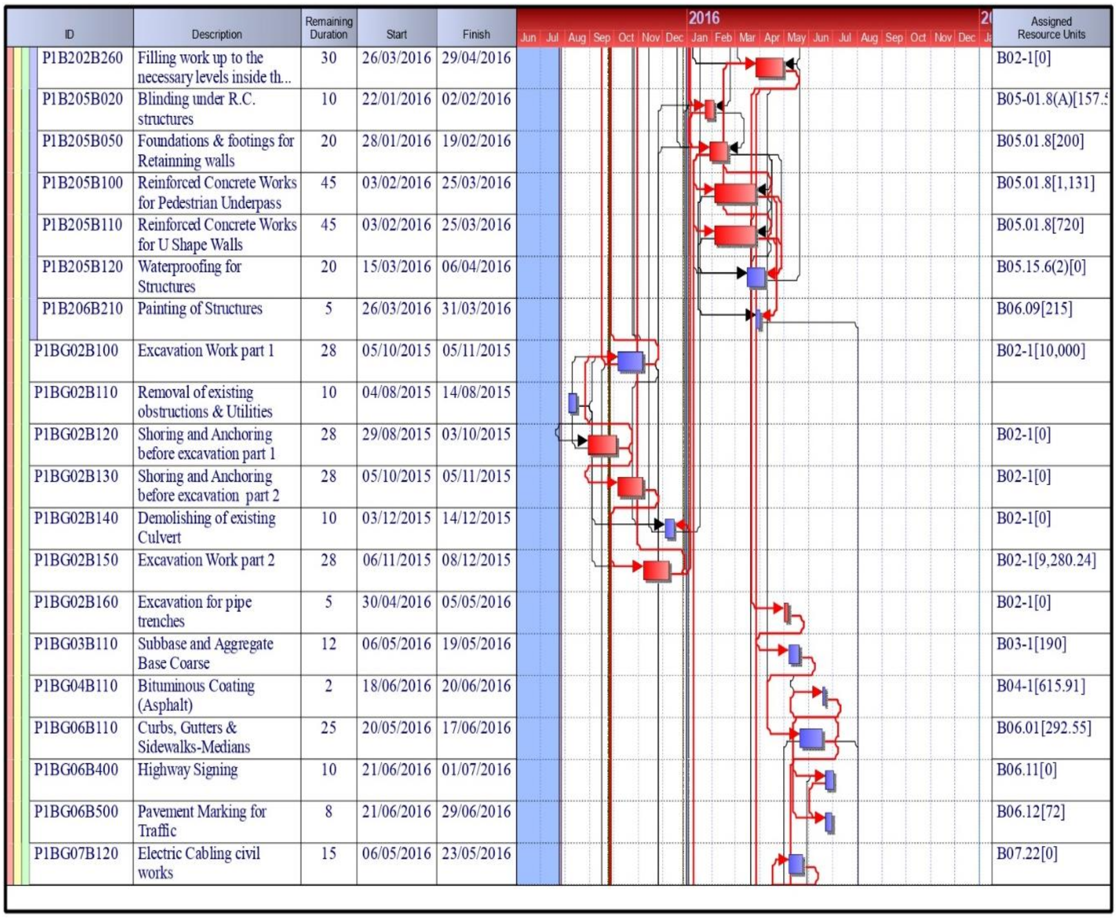
Table 35: Unit Cost of Resources

Description	Type	Unit Cost
Preliminaries	Materials	$279,120
Provisional Sum for Day works	Labor	$28,250
Excavation /Clearing/ Removal of obstruction	Labor	$15
Aggregate base course & Sub-Base Course	Materials	$27
Bituminous Construction	Materials	$31
Blinding beds	Materials	$103
Cyclopean concrete under box structure	Materials	$114
Concrete, Steel and Structures	Materials	$340
Membrane waterproofing	Labor	$26
Bridge Expansion Joints	Materials	$248
Bridge Bearings	Materials	$402
Concrete bridge parapet	Materials	$246
One rail aluminum parapet	Materials	$89
Inspection of existing box culvert by approved team	Labor	$4,513
CFRP to strengthen existing box culvert & painting	Materials	$111
Diversion of existing box culvert	Materials	$30,685
Concrete Curbs, Gutters, Sidewalks and Paved Medians	Materials	$72
Highway Signing	Materials	$266
Pavement Markings for traffic	Materials	$11
Handrails and Guards	Materials	$82
Power supply to L.V. feeder pillar. FP-KT/fees to EDL +civil works	Materials	$6,585
Dismantling and relocation of existing street lighting columns	Materials	$412
Low Voltage Feeder Pillars/ FP-KT	Materials	$9,157
Lighting Installation	Materials	$2,470
Earthing system	Materials	$925
Traffic Signals	Materials	$102,073
Electric Cabling	Materials	$111
Reinforced concrete base for 11m column	Materials	$603
Cable draw pit detail 18	Materials	$697
MV Manhole	Materials	$9,810
Telecommunications Cabling	Materials	$73
Telephone manhole, type A	Materials	$8,036
PVC pipes including supply of materials, installation and testing	Materials	$72
Manholes and Gullies	Materials	$645
Gully complete as specified and shown on drawing 10 m deep	Materials	$37,369



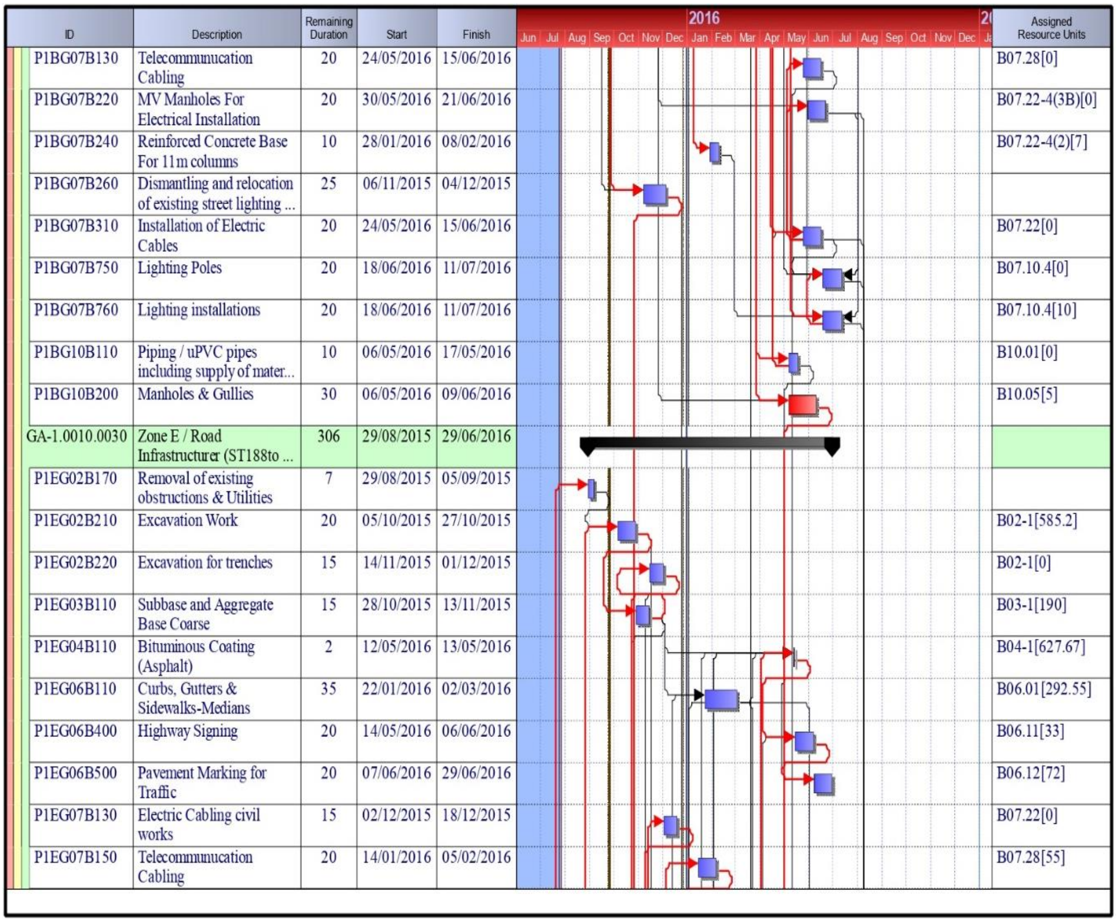
ID	Description	Remaining Duration	Start	Finish	Assigned Resource Units
GA-1	GT Road-second submittal	366	27/07/2015	26/07/2016	
GA-1.0	Phase General	366	27/07/2015	26/07/2016	
GA-1.0010	Phase 1	352	27/07/2015	12/07/2016	
GA-1.0010.0020	Zone B / The Pedestrian Underpass (ST0 to ST50)	343	04/08/2015	11/07/2016	
GA-1.0010.002(	Zone B / Section 1 / The Box Culvert	126	10/10/2015	12/02/2016	
P1B102B160	Excavation for pipe trenches	7	10/10/2015	17/10/2015	B02-1[0]
P1B102B260	Filling work up to the necessary levels around t...	4	22/01/2016	26/01/2016	B02-1[0]
P1B105B030	Cyclopean concrete under box structure	15	09/12/2015	26/12/2015	B05-01.8(B)[680]
P1B105B040	diversion of existing Box Culvert	10	03/12/2015	14/12/2015	B05.24.4(3)[1]
P1B105B100	Reinforced Concrete Works for the Box culvert	35	15/12/2015	26/01/2016	B05.01.8[510]
P1B105B130	Waterproofing for Structures	15	27/01/2016	12/02/2016	B05.15.6(2)[1,855
P1B106B210	Bituminous paint to concrete surface	15	27/01/2016	12/02/2016	B05.15.6(1)[4,500
P1B107B120	Electric Cabling civil works	20	06/11/2015	28/11/2015	B07.22[0]
P1B107B130	Telecommmunucation Cabling	20	30/11/2015	22/12/2015	B07.28[55]
P1B107B220	MV Manholes For Electrical Installation	20	05/12/2015	29/12/2015	B07.22-4(3B)[1]
P1B107B310	Installation of Electric Cables	20	30/11/2015	22/12/2015	B07.22[103.49]
P1B110B110	Piping / uPVC pipes including supply of mater...	30	06/11/2015	10/12/2015	B10.01[213.22]
GA-1.0010.002(	Zone B / Section 2 / The Pedestrian Undepass over...	99	22/01/2016	29/04/2016	

Figure 50: Full Gantt Chart of the Deterministic Case Study (1)



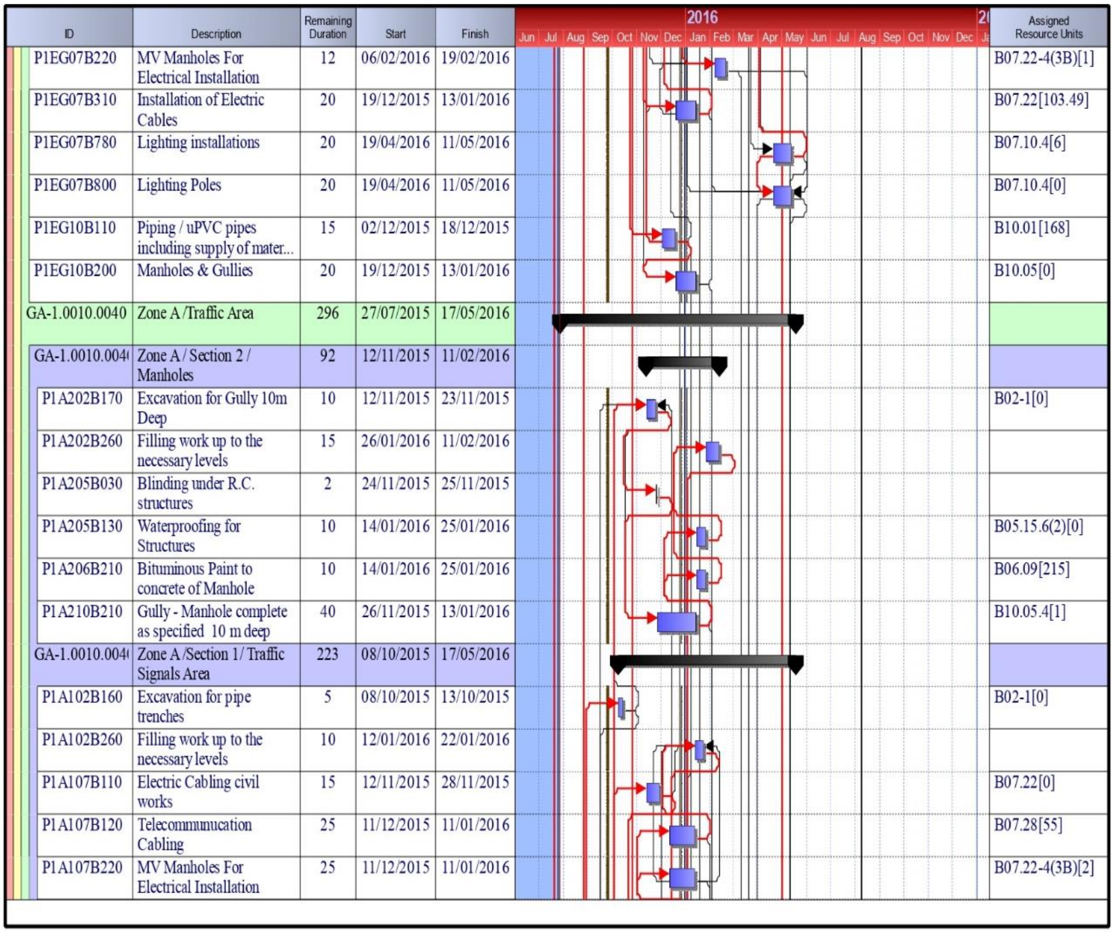
ID	Description	Remaining Duration	Start	Finish	Assigned Resource Units
P1B202B260	Filling work up to the necessary levels inside th...	30	26/03/2016	29/04/2016	B02-1[0]
P1B205B020	Blinding under R.C. structures	10	22/01/2016	02/02/2016	B05-01.8(A)[157.5
P1B205B050	Foundations & footings for Retainning walls	20	28/01/2016	19/02/2016	B05.01.8[200]
P1B205B100	Reinforced Concrete Works for Pedestrian Underpass	45	03/02/2016	25/03/2016	B05.01.8[1,131]
P1B205B110	Reinforced Concrete Works for U Shape Walls	45	03/02/2016	25/03/2016	B05.01.8[720]
P1B205B120	Waterproofing for Structures	20	15/03/2016	06/04/2016	B05.15.6(2)[0]
P1B206B210	Painting of Structures	5	26/03/2016	31/03/2016	B06.09[215]
P1BG02B100	Excavation Work part 1	28	05/10/2015	05/11/2015	B02-1[10,000]
P1BG02B110	Removal of existing obstructions & Utilities	10	04/08/2015	14/08/2015	
P1BG02B120	Shoring and Anchoring before excavation part 1	28	29/08/2015	03/10/2015	B02-1[0]
P1BG02B130	Shoring and Anchoring before excavation part 2	28	05/10/2015	05/11/2015	B02-1[0]
P1BG02B140	Demolishing of existing Culvert	10	03/12/2015	14/12/2015	B02-1[0]
P1BG02B150	Excavation Work part 2	28	06/11/2015	08/12/2015	B02-1[9,280.24]
P1BG02B160	Excavation for pipe trenches	5	30/04/2016	05/05/2016	B02-1[0]
P1BG03B110	Subbase and Aggregate Base Coarse	12	06/05/2016	19/05/2016	B03-1[190]
P1BG04B110	Bituminous Coating (Asphalt)	2	18/06/2016	20/06/2016	B04-1[615.91]
P1BG06B110	Curbs, Gutters & Sidewalks-Medians	25	20/05/2016	17/06/2016	B06.01[292.55]
P1BG06B400	Highway Signing	10	21/06/2016	01/07/2016	B06.11[0]
P1BG06B500	Pavement Marking for Traffic	8	21/06/2016	29/06/2016	B06.12[72]
P1BG07B120	Electric Cabling civil works	15	06/05/2016	23/05/2016	B07.22[0]

Figure 51: Full Gantt Chart of the Deterministic Case Study (2)



ID	Description	Remaining Duration	Start	Finish	Assigned Resource Units
P1BG07B130	Telecommunucation Cabling	20	24/05/2016	15/06/2016	B07.28[0]
P1BG07B220	MV Manholes For Electrical Installation	20	30/05/2016	21/06/2016	B07.22-4(3B)[0]
P1BG07B240	Reinforced Concrete Base For 11m columns	10	28/01/2016	08/02/2016	B07.22-4(2)[7]
P1BG07B260	Dismantling and relocation of existing street lighting ...	25	06/11/2015	04/12/2015	
P1BG07B310	Installation of Electric Cables	20	24/05/2016	15/06/2016	B07.22[0]
P1BG07B750	Lighting Poles	20	18/06/2016	11/07/2016	B07.10.4[0]
P1BG07B760	Lighting installations	20	18/06/2016	11/07/2016	B07.10.4[10]
P1BG10B110	Piping / uPVC pipes including supply of mater...	10	06/05/2016	17/05/2016	B10.01[0]
P1BG10B200	Manholes & Gullies	30	06/05/2016	09/06/2016	B10.05[5]
GA-1.0010.0030	Zone E / Road Infrastructurer (ST188to ...	306	29/08/2015	29/06/2016	
P1EG02B170	Removal of existing obstructions & Utilities	7	29/08/2015	05/09/2015	
P1EG02B210	Excavation Work	20	05/10/2015	27/10/2015	B02-1[585.2]
P1EG02B220	Excavation for trenches	15	14/11/2015	01/12/2015	B02-1[0]
P1EG03B110	Subbase and Aggregate Base Coarse	15	28/10/2015	13/11/2015	B03-1[190]
P1EG04B110	Bituminous Coating (Asphalt)	2	12/05/2016	13/05/2016	B04-1[627.67]
P1EG06B110	Curbs, Gutters & Sidewalks-Medians	35	22/01/2016	02/03/2016	B06.01[292.55]
P1EG06B400	Highway Signing	20	14/05/2016	06/06/2016	B06.11[33]
P1EG06B500	Pavement Marking for Traffic	20	07/06/2016	29/06/2016	B06.12[72]
P1EG07B130	Electric Cabling civil works	15	02/12/2015	18/12/2015	B07.22[0]
P1EG07B150	Telecommunucation Cabling	20	14/01/2016	05/02/2016	B07.28[55]

Figure 52: Full Gantt Chart of the Deterministic Case Study (3)



ID	Description	Remaining Duration	Start	Finish	Assigned Resource Units
P1EG07B220	MV Manholes For Electrical Installation	12	06/02/2016	19/02/2016	B07.22-4(3B)[1]
P1EG07B310	Installation of Electric Cables	20	19/12/2015	13/01/2016	B07.22[103.49]
P1EG07B780	Lighting installations	20	19/04/2016	11/05/2016	B07.10.4[6]
P1EG07B800	Lighting Poles	20	19/04/2016	11/05/2016	B07.10.4[0]
P1EG10B110	Piping / uPVC pipes including supply of mater...	15	02/12/2015	18/12/2015	B10.01[168]
P1EG10B200	Manholes & Gullies	20	19/12/2015	13/01/2016	B10.05[0]
GA-1.0010.0040	Zone A /Traffic Area	296	27/07/2015	17/05/2016	
GA-1.0010.004(	Zone A / Section 2 / Manholes	92	12/11/2015	11/02/2016	
P1A202B170	Excavation for Gully 10m Deep	10	12/11/2015	23/11/2015	B02-1[0]
P1A202B260	Filling work up to the necessary levels	15	26/01/2016	11/02/2016	
P1A205B030	Blinding under R.C. structures	2	24/11/2015	25/11/2015	
P1A205B130	Waterproofing for Structures	10	14/01/2016	25/01/2016	B05.15.6(2)[0]
P1A206B210	Bituminous Paint to concrete of Manhole	10	14/01/2016	25/01/2016	B06.09[215]
P1A210B210	Gully - Manhole complete as specified 10 m deep	40	26/11/2015	13/01/2016	B10.05.4[1]
GA-1.0010.004(	Zone A /Section 1/ Traffic Signals Area	223	08/10/2015	17/05/2016	
P1A102B160	Excavation for pipe trenches	5	08/10/2015	13/10/2015	B02-1[0]
P1A102B260	Filling work up to the necessary levels	10	12/01/2016	22/01/2016	
P1A107B110	Electric Cabling civil works	15	12/11/2015	28/11/2015	B07.22[0]
P1A107B120	Telecommunucation Cabling	25	11/12/2015	11/01/2016	B07.28[55]
P1A107B220	MV Manholes For Electrical Installation	25	11/12/2015	11/01/2016	B07.22-4(3B)[2]

Figure 53: Full Gantt Chart of the Deterministic Case Study (4)

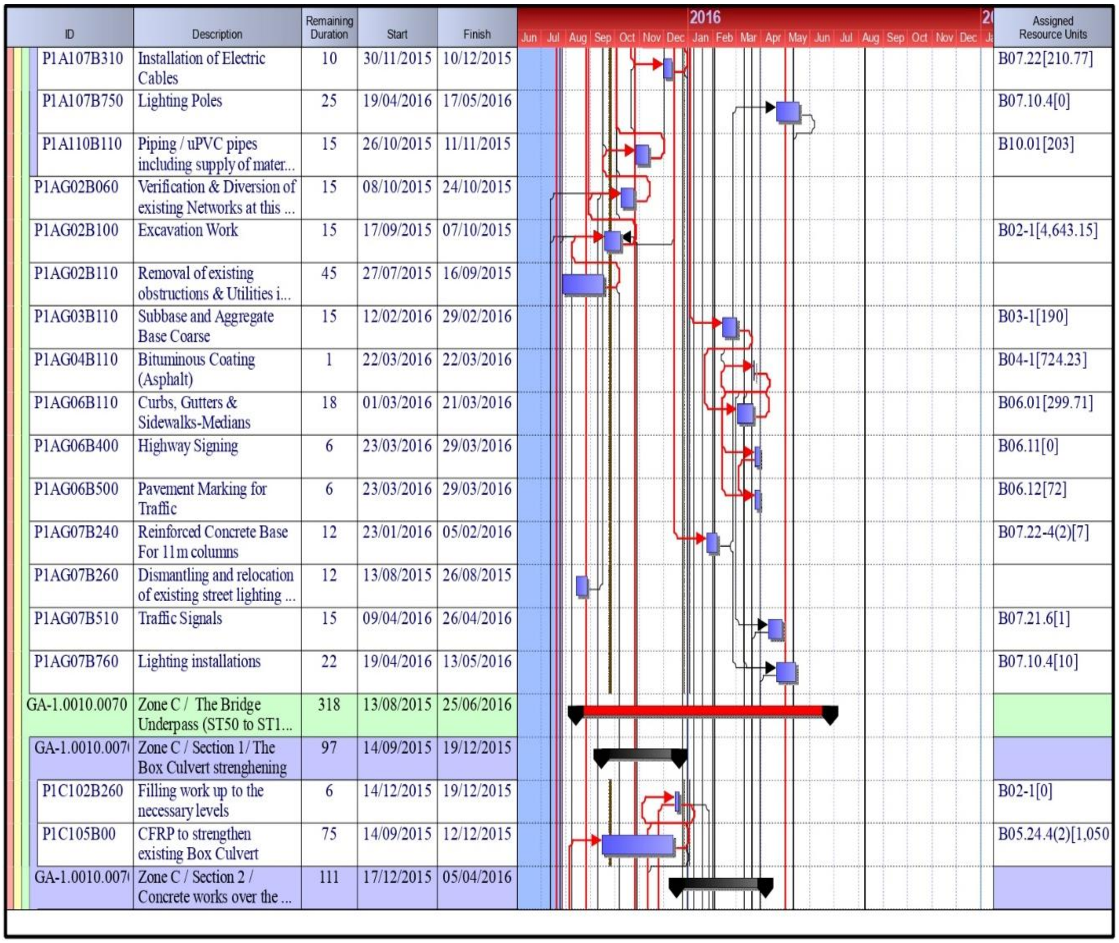
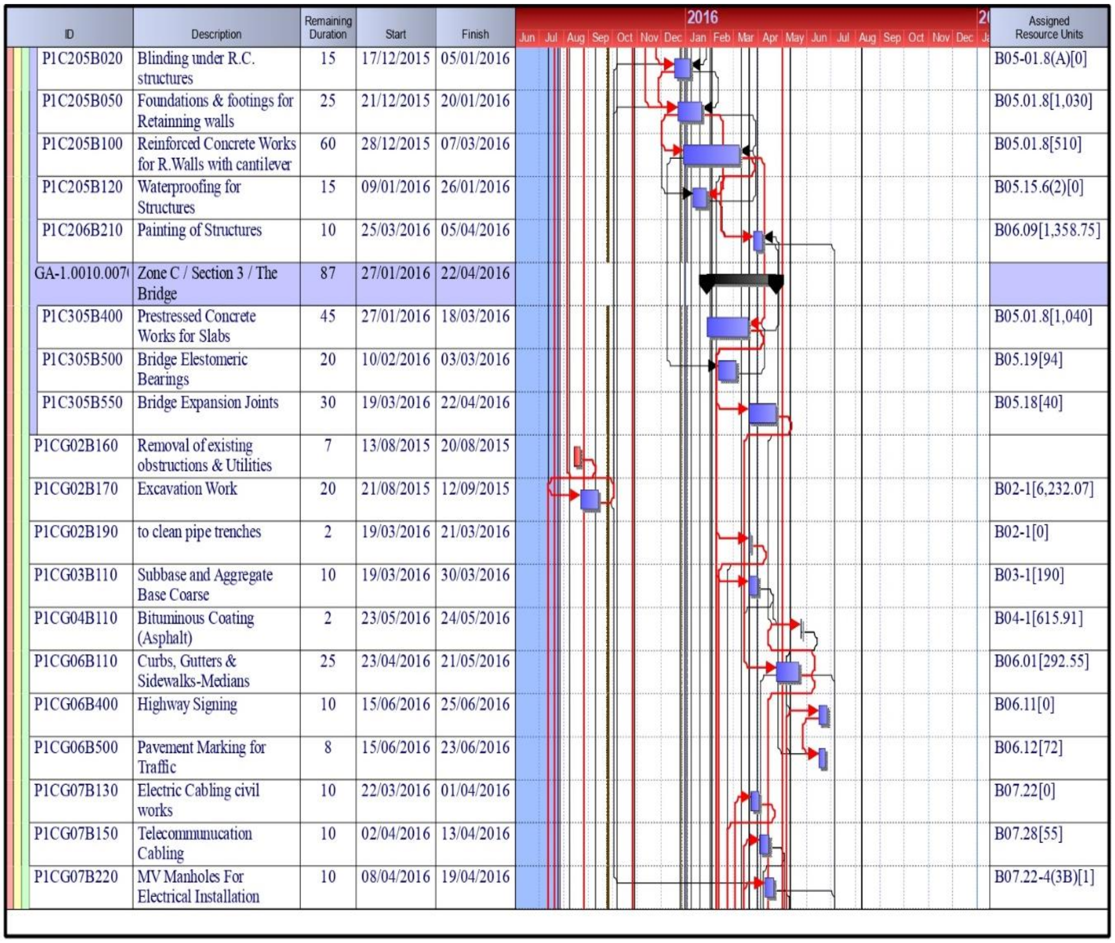
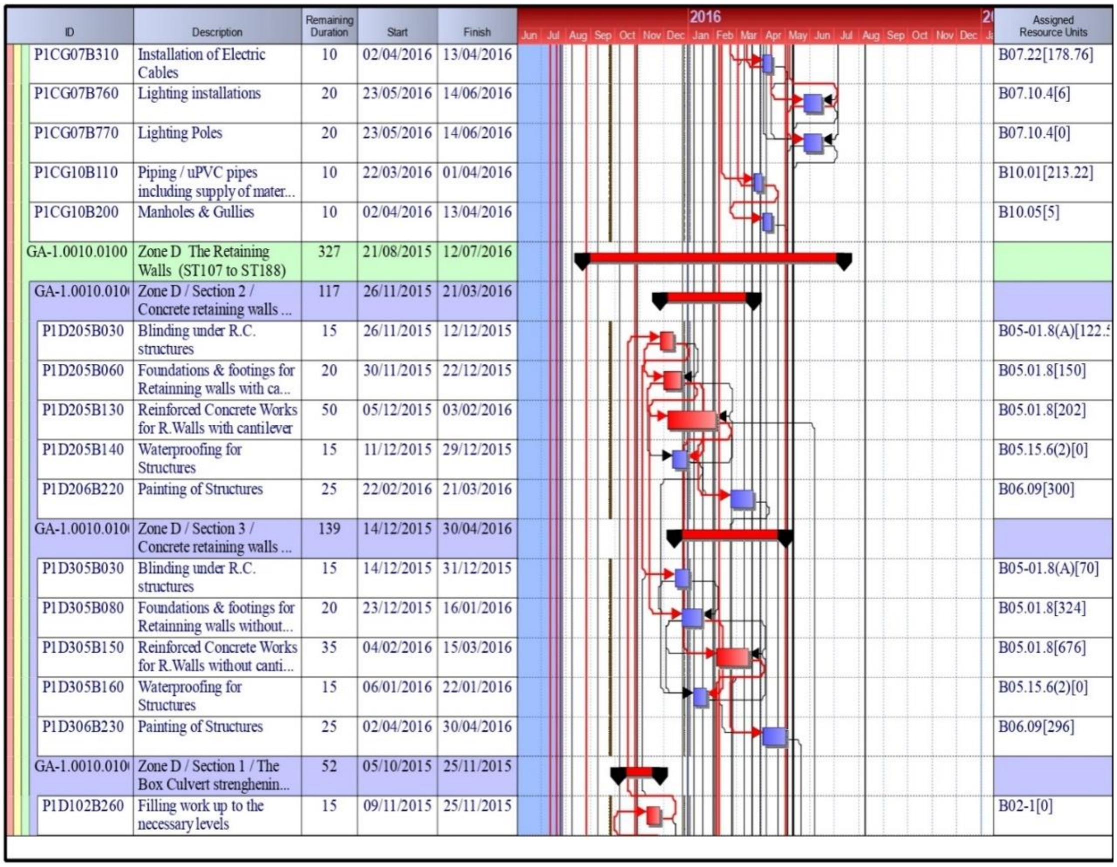


Figure 54: Full Gantt Chart of the Deterministic Case Study (5)



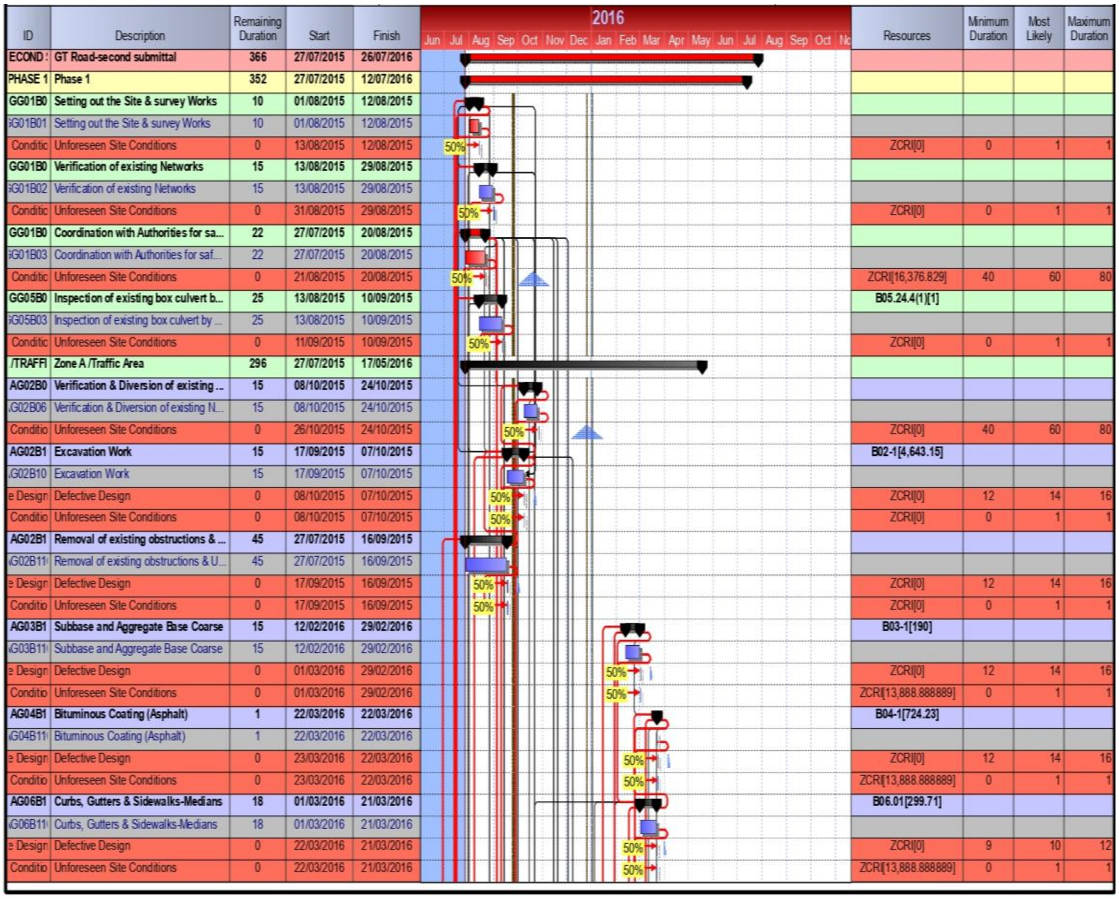
ID	Description	Remaining Duration	Start	Finish	Assigned Resource Units
P1C205B020	Blinding under R.C. structures	15	17/12/2015	05/01/2016	B05-01.8(A)[0]
P1C205B050	Foundations & footings for Retainning walls	25	21/12/2015	20/01/2016	B05.01.8[1,030]
P1C205B100	Reinforced Concrete Works for R.Walls with cantilever	60	28/12/2015	07/03/2016	B05.01.8[510]
P1C205B120	Waterproofing for Structures	15	09/01/2016	26/01/2016	B05.15.6(2)[0]
P1C206B210	Painting of Structures	10	25/03/2016	05/04/2016	B06.09[1,358.75]
GA-1.0010.007	Zone C / Section 3 / The Bridge	87	27/01/2016	22/04/2016	
P1C305B400	Prestressed Concrete Works for Slabs	45	27/01/2016	18/03/2016	B05.01.8[1,040]
P1C305B500	Bridge Elestomeric Bearings	20	10/02/2016	03/03/2016	B05.19[94]
P1C305B550	Bridge Expansion Joints	30	19/03/2016	22/04/2016	B05.18[40]
P1CG02B160	Removal of existing obstructions & Utilities	7	13/08/2015	20/08/2015	
P1CG02B170	Excavation Work	20	21/08/2015	12/09/2015	B02-1[6,232.07]
P1CG02B190	to clean pipe trenches	2	19/03/2016	21/03/2016	B02-1[0]
P1CG03B110	Subbase and Aggregate Base Coarse	10	19/03/2016	30/03/2016	B03-1[190]
P1CG04B110	Bituminous Coating (Asphalt)	2	23/05/2016	24/05/2016	B04-1[615.91]
P1CG06B110	Curbs, Gutters & Sidewalks-Medians	25	23/04/2016	21/05/2016	B06.01[292.55]
P1CG06B400	Highway Signing	10	15/06/2016	25/06/2016	B06.11[0]
P1CG06B500	Pavement Marking for Traffic	8	15/06/2016	23/06/2016	B06.12[72]
P1CG07B130	Electric Cabling civil works	10	22/03/2016	01/04/2016	B07.22[0]
P1CG07B150	Telecommunucation Cabling	10	02/04/2016	13/04/2016	B07.28[55]
P1CG07B220	MV Manholes For Electrical Installation	10	08/04/2016	19/04/2016	B07.22-4(3B)[1]

Figure 55: Full Gantt Chart of the Deterministic Case Study (6)



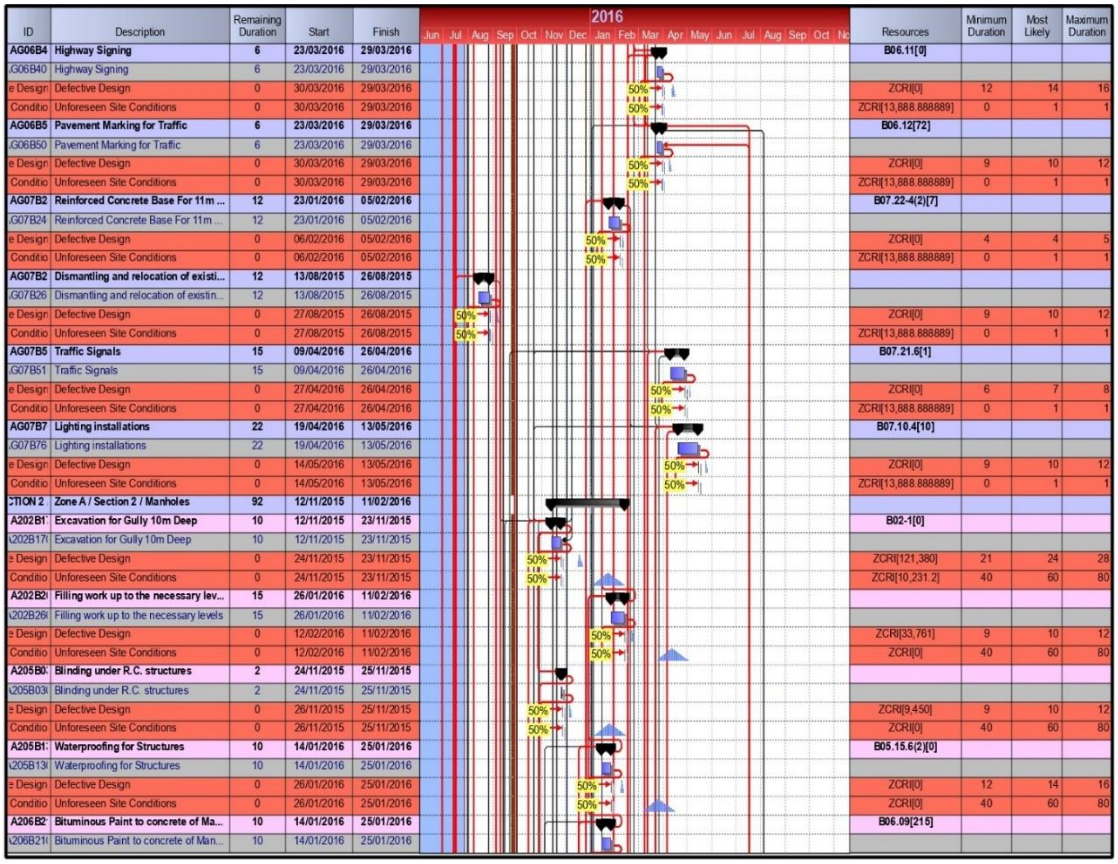
ID	Description	Remaining Duration	Start	Finish	Assigned Resource Units
P1CG07B310	Installation of Electric Cables	10	02/04/2016	13/04/2016	B07.22[178.76]
P1CG07B760	Lighting installations	20	23/05/2016	14/06/2016	B07.10.4[6]
P1CG07B770	Lighting Poles	20	23/05/2016	14/06/2016	B07.10.4[0]
P1CG10B110	Piping / uPVC pipes including supply of mater...	10	22/03/2016	01/04/2016	B10.01[213.22]
P1CG10B200	Manholes & Gullies	10	02/04/2016	13/04/2016	B10.05[5]
GA-1.0010.0100	Zone D The Retaining Walls (ST107 to ST188)	327	21/08/2015	12/07/2016	
GA-1.0010.010(	Zone D / Section 2 / Concrete retaining walls ...	117	26/11/2015	21/03/2016	
P1D205B030	Blinding under R.C. structures	15	26/11/2015	12/12/2015	B05-01.8(A)[122.5
P1D205B060	Foundations & footings for Retainning walls with ca...	20	30/11/2015	22/12/2015	B05.01.8[150]
P1D205B130	Reinforced Concrete Works for R.Walls with cantilever	50	05/12/2015	03/02/2016	B05.01.8[202]
P1D205B140	Waterproofing for Structures	15	11/12/2015	29/12/2015	B05.15.6(2)[0]
P1D206B220	Painting of Structures	25	22/02/2016	21/03/2016	B06.09[300]
GA-1.0010.010(	Zone D / Section 3 / Concrete retaining walls ...	139	14/12/2015	30/04/2016	
P1D305B030	Blinding under R.C. structures	15	14/12/2015	31/12/2015	B05-01.8(A)[70]
P1D305B080	Foundations & footings for Retainning walls without...	20	23/12/2015	16/01/2016	B05.01.8[324]
P1D305B150	Reinforced Concrete Works for R.Walls without canti...	35	04/02/2016	15/03/2016	B05.01.8[676]
P1D305B160	Waterproofing for Structures	15	06/01/2016	22/01/2016	B05.15.6(2)[0]
P1D306B230	Painting of Structures	25	02/04/2016	30/04/2016	B06.09[296]
GA-1.0010.010(	Zone D / Section 1 / The Box Culvert strenghenin...	52	05/10/2015	25/11/2015	
P1D102B260	Filling work up to the necessary levels	15	09/11/2015	25/11/2015	B02-1[0]

Figure 56: Full Gantt Chart of the Deterministic Case Study (7)



ID	Description	Remaining Duration	Start	Finish	Resources	Minimum Duration	Most Likely	Maximum Duration
ECOND :	GT Road-second submittal	366	27/07/2015	26/07/2016				
PHASE 1	Phase 1	352	27/07/2015	12/07/2016				
GG01B0	Setting out the Site & survey Works	10	01/08/2015	12/08/2015				
;G01B01	Setting out the Site & survey Works	10	01/08/2015	12/08/2015				
Conditic	Unforeseen Site Conditions	0	13/08/2015	12/08/2015	ZCRI[0]	0	1	1
GG01B0	Verification of existing Networks	15	13/08/2015	29/08/2015				
;G01B02	Verification of existing Networks	15	13/08/2015	29/08/2015				
Conditic	Unforeseen Site Conditions	0	31/08/2015	29/08/2015	ZCRI[0]	0	1	1
GG01B0	Coordination with Authorities for sa...	22	27/07/2015	20/08/2015				
;G01B03	Coordination with Authorities for saf...	22	27/07/2015	20/08/2015				
Conditic	Unforeseen Site Conditions	0	21/08/2015	20/08/2015	ZCRI[16,376.829]	40	60	80
GG05B0	Inspection of existing box culvert b...	25	13/08/2015	10/09/2015	B05.24.4(1)[1]			
;G05B03	Inspection of existing box culvert by ...	25	13/08/2015	10/09/2015				
Conditic	Unforeseen Site Conditions	0	11/09/2015	10/09/2015	ZCRI[0]	0	1	1
/TRAFFI	Zone A /Traffic Area	296	27/07/2015	17/05/2016				
AG02B0	Verification & Diversion of existing ...	15	08/10/2015	24/10/2015				
.G02B06	Verification & Diversion of existing N...	15	08/10/2015	24/10/2015				
Conditio	Unforeseen Site Conditions	0	26/10/2015	24/10/2015	ZCRI[0]	40	60	80
AG02B1	Excavation Work	15	17/09/2015	07/10/2015	B02-1[4,643.15]			
.G02B10	Excavation Work	15	17/09/2015	07/10/2015				
e Design	Defective Design	0	08/10/2015	07/10/2015	ZCRI[0]	12	14	16
Conditio	Unforeseen Site Conditions	0	08/10/2015	07/10/2015	ZCRI[0]	0	1	1
AG02B1	Removal of existing obstructions & ...	45	27/07/2015	16/09/2015				
.G02B11	Removal of existing obstructions & U...	45	27/07/2015	16/09/2015				
e Design	Defective Design	0	17/09/2015	16/09/2015	ZCRI[0]	12	14	16
Conditio	Unforeseen Site Conditions	0	17/09/2015	16/09/2015	ZCRI[0]	0	1	1
AG03B1	Subbase and Aggregate Base Coarse	15	12/02/2016	29/02/2016	B03-1[190]			
.G03B11	Subbase and Aggregate Base Coarse	15	12/02/2016	29/02/2016				
e Design	Defective Design	0	01/03/2016	29/02/2016	ZCRI[0]	12	14	16
Conditio	Unforeseen Site Conditions	0	01/03/2016	29/02/2016	ZCRI[13,888.888889]	0	1	1
AG04B1	Bituminous Coating (Asphalt)	1	22/03/2016	22/03/2016	B04-1[724.23]			
.G04B11	Bituminous Coating (Asphalt)	1	22/03/2016	22/03/2016				
e Design	Defective Design	0	23/03/2016	22/03/2016	ZCRI[0]	12	14	16
Conditio	Unforeseen Site Conditions	0	23/03/2016	22/03/2016	ZCRI[13,888.888889]	0	1	1
AG06B1	Curbs, Gutters & Sidewalks-Medians	18	01/03/2016	21/03/2016	B06.01[299.71]			
.G06B11	Curbs, Gutters & Sidewalks-Medians	18	01/03/2016	21/03/2016				
e Design	Defective Design	0	22/03/2016	21/03/2016	ZCRI[0]	9	10	12
Conditio	Unforeseen Site Conditions	0	22/03/2016	21/03/2016	ZCRI[13,888.888889]	0	1	1

Figure 57: Full Gantt Chart of the Optimized Case Study (1)



ID	Description	Remaining Duration	Start	Finish	Resources	Minimum Duration	Most Likely	Maximum Duration
AG06B4	Highway Signing	6	23/03/2016	29/03/2016	B06.11[0]			
.G06B40	Highway Signing	6	23/03/2016	29/03/2016				
e Design	Defective Design	0	30/03/2016	29/03/2016	ZCRI[0]	12	14	16
Conditio	Unforeseen Site Conditions	0	30/03/2016	29/03/2016	ZCRI[13,888.888889]	0	1	1
AG06B5	Pavement Marking for Traffic	6	23/03/2016	29/03/2016	B06.12[72]			
.G06B50	Pavement Marking for Traffic	6	23/03/2016	29/03/2016				
e Design	Defective Design	0	30/03/2016	29/03/2016	ZCRI[0]	9	10	12
Conditio	Unforeseen Site Conditions	0	30/03/2016	29/03/2016	ZCRI[13,888.888889]	0	1	1
AG07B2	Reinforced Concrete Base For 11m ...	12	23/01/2016	05/02/2016	B07.22-4(2)[7]			
.G07B24	Reinforced Concrete Base For 11m ...	12	23/01/2016	05/02/2016				
e Design	Defective Design	0	06/02/2016	05/02/2016	ZCRI[0]	4	4	5
Conditio	Unforeseen Site Conditions	0	06/02/2016	05/02/2016	ZCRI[13,888.888889]	0	1	1
AG07B2	Dismantling and relocation of existi...	12	13/08/2015	26/08/2015				
.G07B26	Dismantling and relocation of existin...	12	13/08/2015	26/08/2015				
e Design	Defective Design	0	27/08/2015	26/08/2015	ZCRI[0]	9	10	12
Conditio	Unforeseen Site Conditions	0	27/08/2015	26/08/2015	ZCRI[13,888.888889]	0	1	1
AG07B5	Traffic Signals	15	09/04/2016	26/04/2016	B07.21.6[1]			
.G07B51	Traffic Signals	15	09/04/2016	26/04/2016				
e Design	Defective Design	0	27/04/2016	26/04/2016	ZCRI[0]	6	7	8
Conditio	Unforeseen Site Conditions	0	27/04/2016	26/04/2016	ZCRI[13,888.888889]	0	1	1
AG07B7	Lighting installations	22	19/04/2016	13/05/2016	B07.10.4[10]			
.G07B76	Lighting installations	22	19/04/2016	13/05/2016				
e Design	Defective Design	0	14/05/2016	13/05/2016	ZCRI[0]	9	10	12
Conditio	Unforeseen Site Conditions	0	14/05/2016	13/05/2016	ZCRI[13,888.888889]	0	1	1
CTION 2	Zone A / Section 2 / Manholes	92	12/11/2015	11/02/2016				
A202B1	Excavation for Gully 10m Deep	10	12/11/2015	23/11/2015	B02-1[0]			
A202B17	Excavation for Gully 10m Deep	10	12/11/2015	23/11/2015				
e Design	Defective Design	0	24/11/2015	23/11/2015	ZCRI[121,380]	21	24	28
Conditio	Unforeseen Site Conditions	0	24/11/2015	23/11/2015	ZCRI[10,231.2]	40	60	80
A202B2	Filling work up to the necessary lev...	15	26/01/2016	11/02/2016				
A202B26	Filling work up to the necessary levels	15	26/01/2016	11/02/2016				
e Design	Defective Design	0	12/02/2016	11/02/2016	ZCRI[33,761]	9	10	12
Conditio	Unforeseen Site Conditions	0	12/02/2016	11/02/2016	ZCRI[0]	40	60	80
A205B0	Blinding under R.C. structures	2	24/11/2015	25/11/2015				
A205B03	Blinding under R.C. structures	2	24/11/2015	25/11/2015				
e Design	Defective Design	0	26/11/2015	25/11/2015	ZCRI[9,450]	9	10	12
Conditio	Unforeseen Site Conditions	0	26/11/2015	25/11/2015	ZCRI[0]	40	60	80
A205B1	Waterproofing for Structures	10	14/01/2016	25/01/2016	B05.15.6(2)[0]			
A205B13	Waterproofing for Structures	10	14/01/2016	25/01/2016				
e Design	Defective Design	0	26/01/2016	25/01/2016	ZCRI[0]	12	14	16
Conditio	Unforeseen Site Conditions	0	26/01/2016	25/01/2016	ZCRI[0]	40	60	80
A206B2	Bituminous Paint to concrete of Ma...	10	14/01/2016	25/01/2016	B06.09[215]			
A206B21	Bituminous Paint to concrete of Man...	10	14/01/2016	25/01/2016				

Figure 58: Full Gantt Chart of the Optimized Case Study (2)

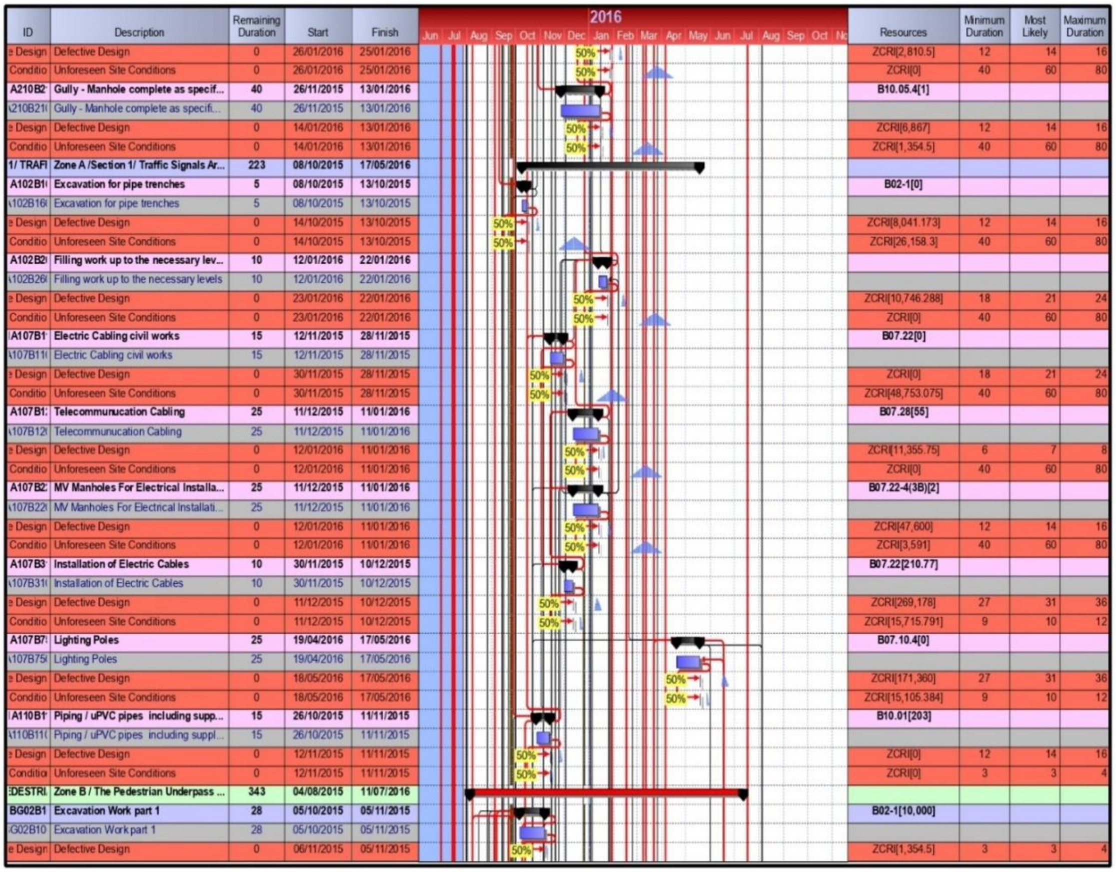
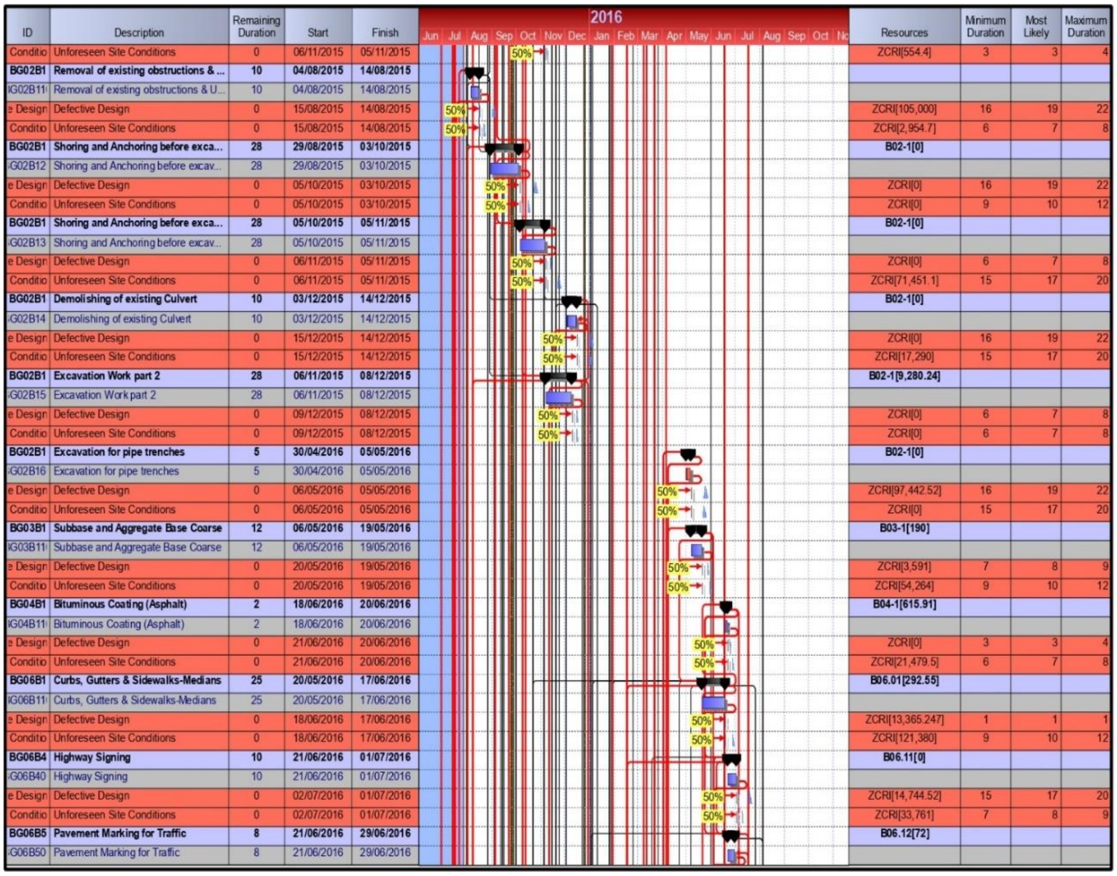
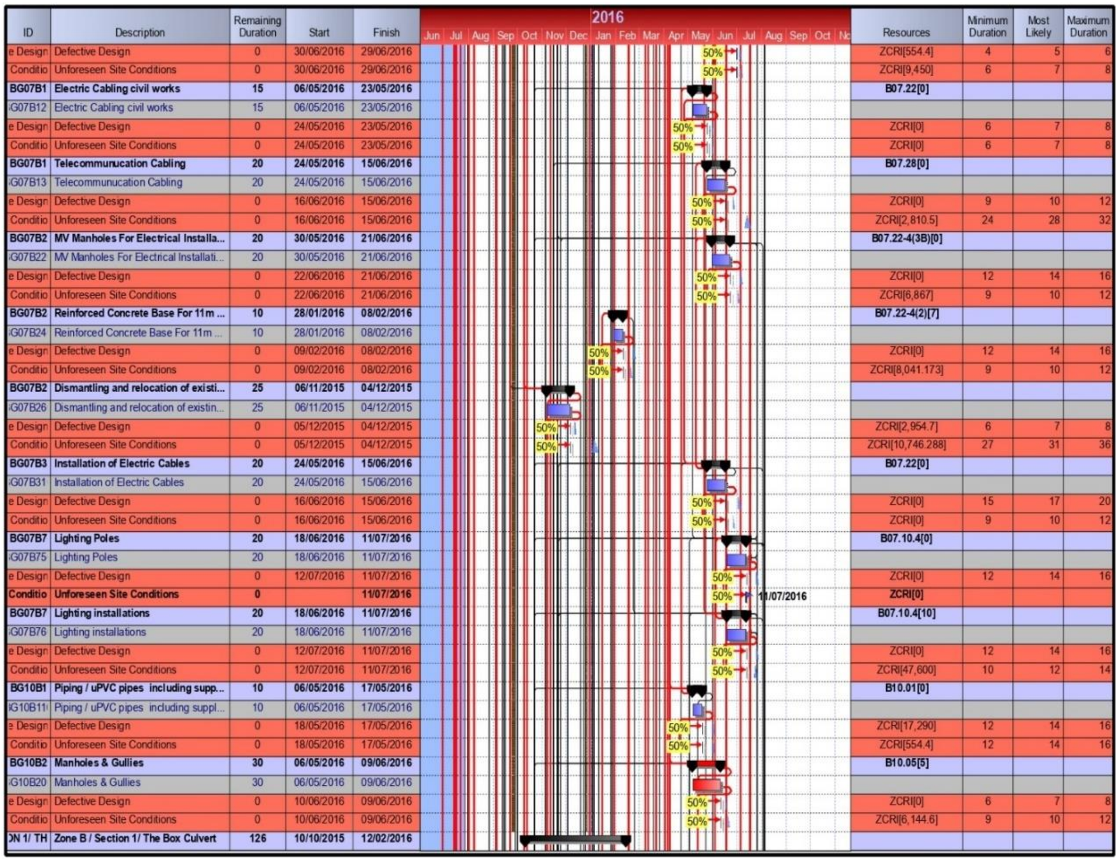


Figure 59: Full Gantt Chart of the Optimized Case Study (3)



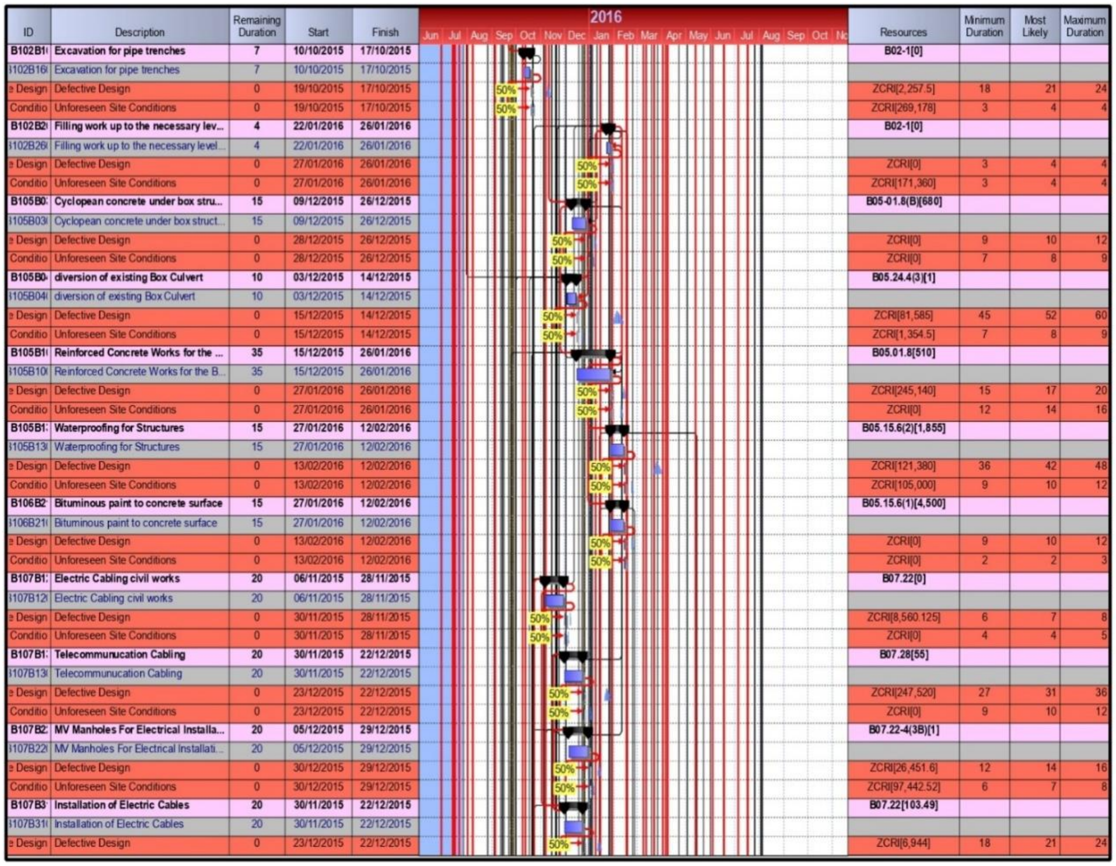
ID	Description	Remaining Duration	Start	Finish	Resources	Minimum Duration	Most Likely	Maximum Duration
Conditio	Unforeseen Site Conditions	0	06/11/2015	05/11/2015	ZCRI[554.4]	3	3	4
BG02B1	Removal of existing obstructions & ...	10	04/08/2015	14/08/2015				
G02B11	Removal of existing obstructions & U...	10	04/08/2015	14/08/2015				
e Design	Defective Design	0	15/08/2015	14/08/2015	ZCRI[105,000]	16	19	22
Conditio	Unforeseen Site Conditions	0	15/08/2015	14/08/2015	ZCRI[2,954.7]	6	7	8
BG02B1	Shoring and Anchoring before exca...	28	29/08/2015	03/10/2015	B02-1[0]			
G02B12	Shoring and Anchoring before excav...	28	29/08/2015	03/10/2015				
e Design	Defective Design	0	05/10/2015	03/10/2015	ZCRI[0]	16	19	22
Conditio	Unforeseen Site Conditions	0	05/10/2015	03/10/2015	ZCRI[0]	9	10	12
BG02B1	Shoring and Anchoring before exca...	28	05/10/2015	05/11/2015	B02-1[0]			
G02B13	Shoring and Anchoring before excav...	28	05/10/2015	05/11/2015				
e Design	Defective Design	0	06/11/2015	05/11/2015	ZCRI[0]	6	7	8
Conditio	Unforeseen Site Conditions	0	06/11/2015	05/11/2015	ZCRI[71,451.1]	15	17	20
BG02B1	Demolishing of existing Culvert	10	03/12/2015	14/12/2015	B02-1[0]			
G02B14	Demolishing of existing Culvert	10	03/12/2015	14/12/2015				
e Design	Defective Design	0	15/12/2015	14/12/2015	ZCRI[0]	16	19	22
Conditio	Unforeseen Site Conditions	0	15/12/2015	14/12/2015	ZCRI[17,290]	15	17	20
BG02B1	Excavation Work part 2	28	06/11/2015	08/12/2015	B02-1[9,280.24]			
G02B15	Excavation Work part 2	28	06/11/2015	08/12/2015				
e Design	Defective Design	0	09/12/2015	08/12/2015	ZCRI[0]	6	7	8
Conditio	Unforeseen Site Conditions	0	09/12/2015	08/12/2015	ZCRI[0]	6	7	8
BG02B1	Excavation for pipe trenches	5	30/04/2016	05/05/2016	B02-1[0]			
G02B16	Excavation for pipe trenches	5	30/04/2016	05/05/2016				
e Design	Defective Design	0	06/05/2016	05/05/2016	ZCRI[97,442.52]	16	19	22
Conditio	Unforeseen Site Conditions	0	06/05/2016	05/05/2016	ZCRI[0]	15	17	20
BG03B1	Subbase and Aggregate Base Coarse	12	06/05/2016	19/05/2016	B03-1[190]			
G03B11	Subbase and Aggregate Base Coarse	12	06/05/2016	19/05/2016				
e Design	Defective Design	0	20/05/2016	19/05/2016	ZCRI[3,591]	7	8	9
Conditio	Unforeseen Site Conditions	0	20/05/2016	19/05/2016	ZCRI[54,264]	9	10	12
BG04B1	Bituminous Coating (Asphalt)	2	18/06/2016	20/06/2016	B04-1[615.91]			
G04B11	Bituminous Coating (Asphalt)	2	18/06/2016	20/06/2016				
e Design	Defective Design	0	21/06/2016	20/06/2016	ZCRI[0]	3	3	4
Conditio	Unforeseen Site Conditions	0	21/06/2016	20/06/2016	ZCRI[21,479.5]	6	7	8
BG06B1	Curbs, Gutters & Sidewalks-Medians	25	20/05/2016	17/06/2016	B06.01[292.55]			
G06B11	Curbs, Gutters & Sidewalks-Medians	25	20/05/2016	17/06/2016				
e Design	Defective Design	0	18/06/2016	17/06/2016	ZCRI[13,365.247]	1	1	1
Conditio	Unforeseen Site Conditions	0	18/06/2016	17/06/2016	ZCRI[121,380]	9	10	12
BG06B4	Highway Signing	10	21/06/2016	01/07/2016	B06.11[0]			
G06B40	Highway Signing	10	21/06/2016	01/07/2016				
e Design	Defective Design	0	02/07/2016	01/07/2016	ZCRI[14,744.52]	15	17	20
Conditio	Unforeseen Site Conditions	0	02/07/2016	01/07/2016	ZCRI[33,761]	7	8	9
BG06B5	Pavement Marking for Traffic	8	21/06/2016	29/06/2016	B06.12[72]			
G06B50	Pavement Marking for Traffic	8	21/06/2016	29/06/2016				

Figure 60: Full Gantt Chart of the Optimized Case Study (4)



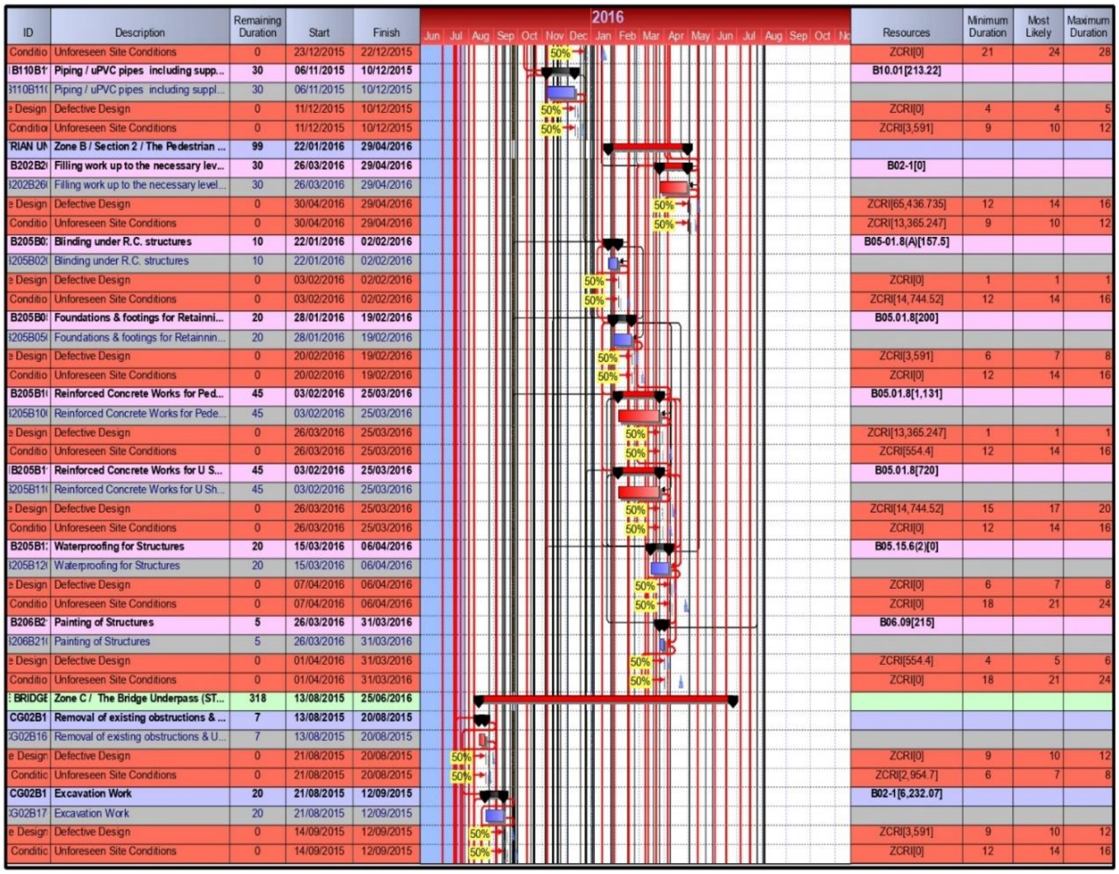
ID	Description	Remaining Duration	Start	Finish	Resources	Minimum Duration	Most Likely	Maximum Duration
e Design	Defective Design	0	30/06/2016	29/06/2016	ZCRI[554.4]	4	5	6
Conditio	Unforeseen Site Conditions	0	30/06/2016	29/06/2016	ZCRI[9,450]	6	7	8
BG07B1	**Electric Cabling civil works**	**15**	**06/05/2016**	**23/05/2016**	**B07.22[0]**			
G07B12	Electric Cabling civil works	15	06/05/2016	23/05/2016				
e Design	Defective Design	0	24/05/2016	23/05/2016	ZCRI[0]	6	7	8
Conditio	Unforeseen Site Conditions	0	24/05/2016	23/05/2016	ZCRI[0]	6	7	8
BG07B1	**Telecommunucation Cabling**	**20**	**24/05/2016**	**15/06/2016**	**B07.28[0]**			
G07B13	Telecommunucation Cabling	20	24/05/2016	15/06/2016				
e Design	Defective Design	0	16/06/2016	15/06/2016	ZCRI[0]	9	10	12
Conditio	Unforeseen Site Conditions	0	16/06/2016	15/06/2016	ZCRI[2,810.5]	24	28	32
BG07B2	**MV Manholes For Electrical Installa...**	**20**	**30/05/2016**	**21/06/2016**	**B07.22-4(3B)[0]**			
G07B22	MV Manholes For Electrical Installati...	20	30/05/2016	21/06/2016				
e Design	Defective Design	0	22/06/2016	21/06/2016	ZCRI[0]	12	14	16
Conditio	Unforeseen Site Conditions	0	22/06/2016	21/06/2016	ZCRI[6,867]	9	10	12
BG07B2	**Reinforced Concrete Base For 11m ...**	**10**	**28/01/2016**	**08/02/2016**	**B07.22-4(2)[7]**			
G07B24	Reinforced Concrete Base For 11m ...	10	28/01/2016	08/02/2016				
e Design	Defective Design	0	09/02/2016	08/02/2016	ZCRI[0]	12	14	16
Conditio	Unforeseen Site Conditions	0	09/02/2016	08/02/2016	ZCRI[8,041.173]	9	10	12
BG07B2	**Dismantling and relocation of existi...**	**25**	**06/11/2015**	**04/12/2015**				
G07B26	Dismantling and relocation of existin...	25	06/11/2015	04/12/2015				
e Design	Defective Design	0	05/12/2015	04/12/2015	ZCRI[2,954.7]	6	7	8
Conditio	Unforeseen Site Conditions	0	05/12/2015	04/12/2015	ZCRI[10,746.288]	27	31	36
BG07B3	**Installation of Electric Cables**	**20**	**24/05/2016**	**15/06/2016**	**B07.22[0]**			
G07B31	Installation of Electric Cables	20	24/05/2016	15/06/2016				
e Design	Defective Design	0	16/06/2016	15/06/2016	ZCRI[0]	15	17	20
Conditio	Unforeseen Site Conditions	0	16/06/2016	15/06/2016	ZCRI[0]	9	10	12
BG07B7	**Lighting Poles**	**20**	**18/06/2016**	**11/07/2016**	**B07.10.4[0]**			
G07B75	Lighting Poles	20	18/06/2016	11/07/2016				
e Design	Defective Design	0	12/07/2016	11/07/2016	ZCRI[0]	12	14	16
Conditio	**Unforeseen Site Conditions**	**0**		**11/07/2016**	**ZCRI[0]**			
BG07B7	**Lighting installations**	**20**	**18/06/2016**	**11/07/2016**	**B07.10.4[10]**			
G07B76	Lighting installations	20	18/06/2016	11/07/2016				
e Design	Defective Design	0	12/07/2016	11/07/2016	ZCRI[0]	12	14	16
Conditio	Unforeseen Site Conditions	0	12/07/2016	11/07/2016	ZCRI[47,600]	10	12	14
BG10B1	**Piping / uPVC pipes including supp...**	**10**	**06/05/2016**	**17/05/2016**	**B10.01[0]**			
G10B11	Piping / uPVC pipes including suppl...	10	06/05/2016	17/05/2016				
e Design	Defective Design	0	18/05/2016	17/05/2016	ZCRI[17,290]	12	14	16
Conditio	Unforeseen Site Conditions	0	18/05/2016	17/05/2016	ZCRI[554.4]	12	14	16
BG10B2	**Manholes & Gullies**	**30**	**06/05/2016**	**09/06/2016**	**B10.05[5]**			
G10B20	Manholes & Gullies	30	06/05/2016	09/06/2016				
e Design	Defective Design	0	10/06/2016	09/06/2016	ZCRI[0]	6	7	8
Conditio	Unforeseen Site Conditions	0	10/06/2016	09/06/2016	ZCRI[6,144.6]	9	10	12
ON 1/ TH	**Zone B / Section 1/ The Box Culvert**	**126**	**10/10/2015**	**12/02/2016**				

Figure 61: Full Gantt Chart of the Optimized Case Study (5)



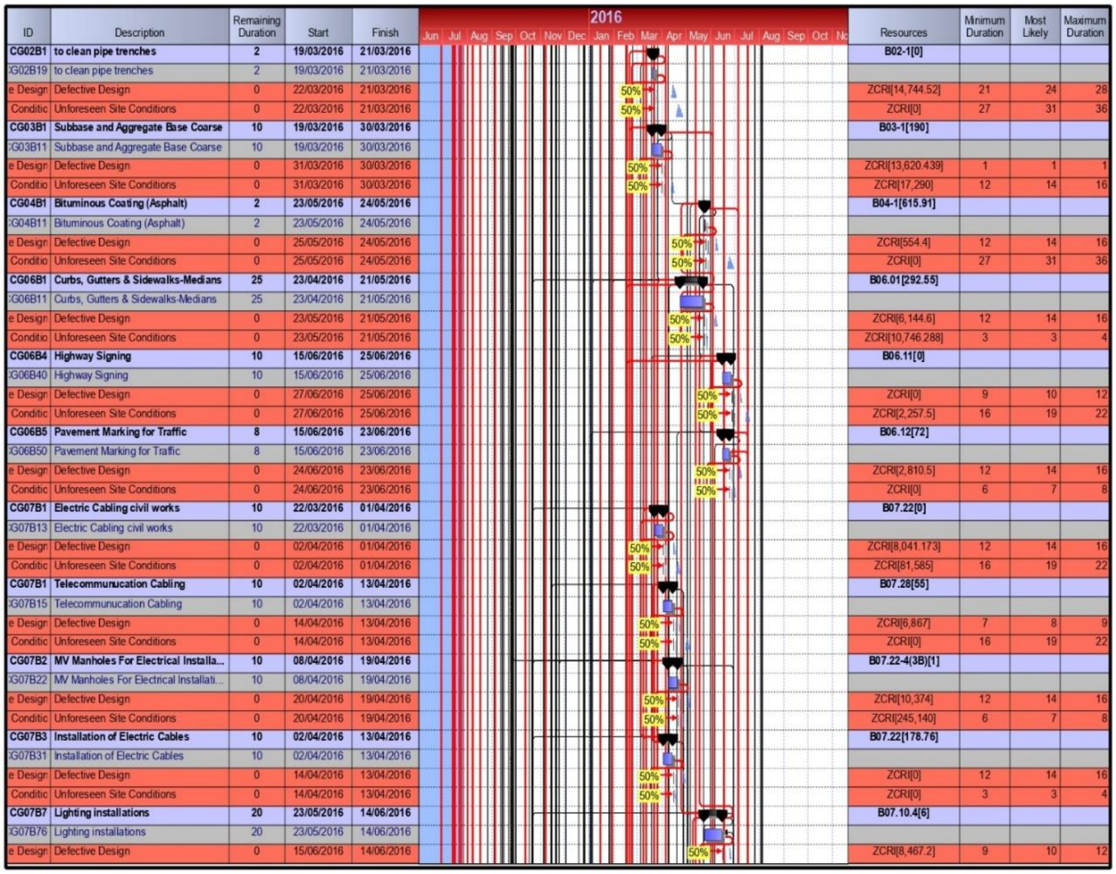
ID	Description	Remaining Duration	Start	Finish	Resources	Minimum Duration	Most Likely	Maximum Duration
B102B1(	Excavation for pipe trenches	7	10/10/2015	17/10/2015	B02-1[0]			
3102B16(	Excavation for pipe trenches	7	10/10/2015	17/10/2015				
e Design	Defective Design	0	19/10/2015	17/10/2015	ZCRI[2,257.5]	18	21	24
Conditio	Unforeseen Site Conditions	0	19/10/2015	17/10/2015	ZCRI[269,178]	3	4	4
B102B2(	Filling work up to the necessary lev...	4	22/01/2016	26/01/2016	B02-1[0]			
3102B26(	Filling work up to the necessary level...	4	22/01/2016	26/01/2016				
e Design	Defective Design	0	27/01/2016	26/01/2016	ZCRI[0]	3	4	4
Conditio	Unforeseen Site Conditions	0	27/01/2016	26/01/2016	ZCRI[171,360]	3	4	4
B105B0:	Cyclopean concrete under box stru...	15	09/12/2015	26/12/2015	B05-01.8(B)[680]			
3105B03(	Cyclopean concrete under box struct...	15	09/12/2015	26/12/2015				
e Design	Defective Design	0	28/12/2015	26/12/2015	ZCRI[0]	9	10	12
Conditio	Unforeseen Site Conditions	0	28/12/2015	26/12/2015	ZCRI[0]	7	8	9
B105B0-	diversion of existing Box Culvert	10	03/12/2015	14/12/2015	B05.24.4(3)[1]			
3105B04(	diversion of existing Box Culvert	10	03/12/2015	14/12/2015				
e Design	Defective Design	0	15/12/2015	14/12/2015	ZCRI[81,585]	45	52	60
Conditio	Unforeseen Site Conditions	0	15/12/2015	14/12/2015	ZCRI[1,354.5]	7	8	9
B105B1(	Reinforced Concrete Works for the ...	35	15/12/2015	26/01/2016	B05.01.8[510]			
3105B10(	Reinforced Concrete Works for the B...	35	15/12/2015	26/01/2016				
e Design	Defective Design	0	27/01/2016	26/01/2016	ZCRI[245,140]	15	17	20
Conditio	Unforeseen Site Conditions	0	27/01/2016	26/01/2016	ZCRI[0]	12	14	16
B105B1:	Waterproofing for Structures	15	27/01/2016	12/02/2016	B05.15.6(2)[1,855]			
3105B13(	Waterproofing for Structures	15	27/01/2016	12/02/2016				
e Design	Defective Design	0	13/02/2016	12/02/2016	ZCRI[121,380]	36	42	48
Conditio	Unforeseen Site Conditions	0	13/02/2016	12/02/2016	ZCRI[105,000]	9	10	12
B106B2'	Bituminous paint to concrete surface	15	27/01/2016	12/02/2016	B05.15.6(1)[4,500]			
3106B21(	Bituminous paint to concrete surface	15	27/01/2016	12/02/2016				
e Design	Defective Design	0	13/02/2016	12/02/2016	ZCRI[0]	9	10	12
Conditio	Unforeseen Site Conditions	0	13/02/2016	12/02/2016	ZCRI[0]	2	2	3
B107B1:	Electric Cabling civil works	20	06/11/2015	28/11/2015	B07.22[0]			
3107B12(	Electric Cabling civil works	20	06/11/2015	28/11/2015				
e Design	Defective Design	0	30/11/2015	28/11/2015	ZCRI[8,560.125]	6	7	8
Conditio	Unforeseen Site Conditions	0	30/11/2015	28/11/2015	ZCRI[0]	4	4	5
B107B1:	Telecommunucation Cabling	20	30/11/2015	22/12/2015	B07.28[55]			
3107B13(	Telecommunucation Cabling	20	30/11/2015	22/12/2015				
e Design	Defective Design	0	23/12/2015	22/12/2015	ZCRI[247,520]	27	31	36
Conditio	Unforeseen Site Conditions	0	23/12/2015	22/12/2015	ZCRI[0]	9	10	12
B107B2:	MV Manholes For Electrical Installa...	20	05/12/2015	29/12/2015	B07.22-4(3B)[1]			
3107B22(	MV Manholes For Electrical Installati...	20	05/12/2015	29/12/2015				
e Design	Defective Design	0	30/12/2015	29/12/2015	ZCRI[26,451.6]	12	14	16
Conditio	Unforeseen Site Conditions	0	30/12/2015	29/12/2015	ZCRI[97,442.52]	6	7	8
B107B3'	Installation of Electric Cables	20	30/11/2015	22/12/2015	B07.22[103.49]			
3107B31(	Installation of Electric Cables	20	30/11/2015	22/12/2015				
e Design	Defective Design	0	23/12/2015	22/12/2015	ZCRI[6,944]	18	21	24

Figure 62: Full Gantt Chart of the Optimized Case Study (6)



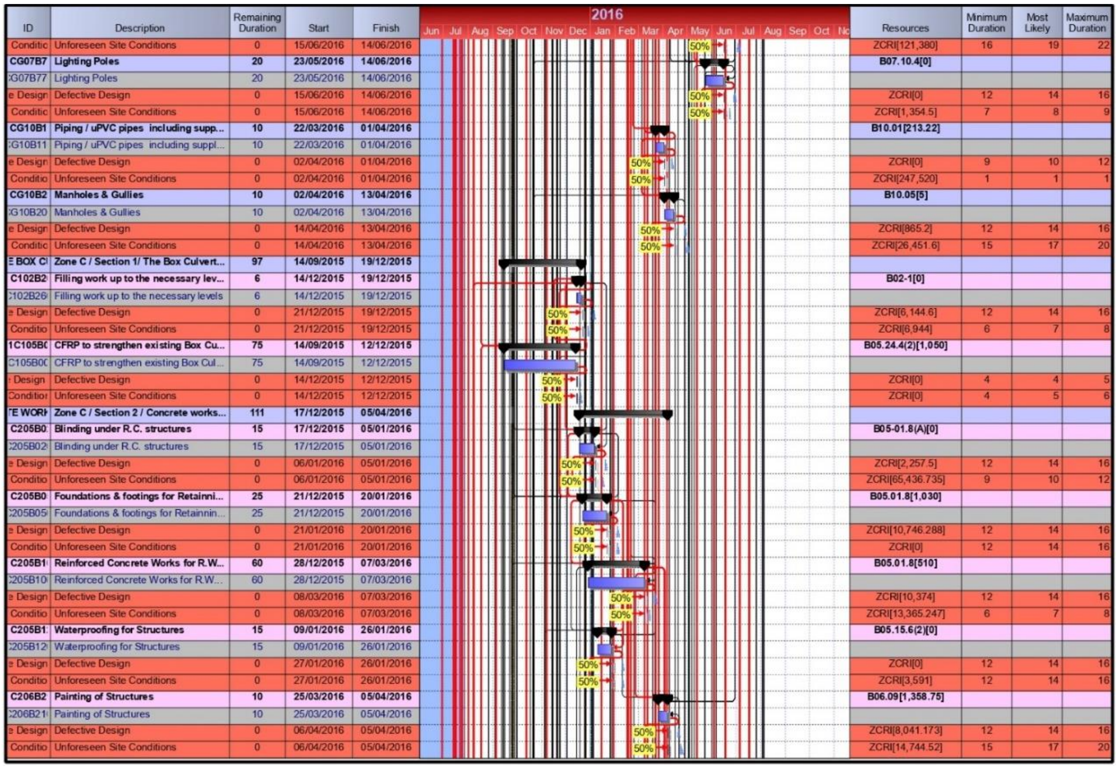
ID	Description	Remaining Duration	Start	Finish	Resources	Minimum Duration	Most Likely	Maximum Duration
Conditio	Unforeseen Site Conditions	0	23/12/2015	22/12/2015	ZCRI[0]	21	24	28
B110B1	**Piping / uPVC pipes including supp...**	**30**	**06/11/2015**	**10/12/2015**	**B10.01[213.22]**			
3110B11(	Piping / uPVC pipes including suppl...	30	06/11/2015	10/12/2015				
e Design	Defective Design	0	11/12/2015	10/12/2015	ZCRI[0]	4	4	5
Conditio	Unforeseen Site Conditions	0	11/12/2015	10/12/2015	ZCRI[3,591]	9	10	12
RIAN UN	**Zone B / Section 2 / The Pedestrian ...**	**99**	**22/01/2016**	**29/04/2016**				
B202B2	**Filling work up to the necessary lev...**	**30**	**26/03/2016**	**29/04/2016**	**B02-1[0]**			
3202B26	Filling work up to the necessary level...	30	26/03/2016	29/04/2016				
e Design	Defective Design	0	30/04/2016	29/04/2016	ZCRI[65,436.735]	12	14	16
Conditio	Unforeseen Site Conditions	0	30/04/2016	29/04/2016	ZCRI[13,365.247]	9	10	12
B205B0	**Blinding under R.C. structures**	**10**	**22/01/2016**	**02/02/2016**	**B05-01.8(A)[157.5]**			
3205B02	Blinding under R.C. structures	10	22/01/2016	02/02/2016				
e Design	Defective Design	0	03/02/2016	02/02/2016	ZCRI[0]	1	1	1
Conditio	Unforeseen Site Conditions	0	03/02/2016	02/02/2016	ZCRI[14,744.52]	12	14	16
B205B0	**Foundations & footings for Retainni...**	**20**	**28/01/2016**	**19/02/2016**	**B05.01.8[200]**			
3205B05	Foundations & footings for Retainnin...	20	28/01/2016	19/02/2016				
e Design	Defective Design	0	20/02/2016	19/02/2016	ZCRI[3,591]	6	7	8
Conditio	Unforeseen Site Conditions	0	20/02/2016	19/02/2016	ZCRI[0]	12	14	16
B205B1	**Reinforced Concrete Works for Ped...**	**45**	**03/02/2016**	**25/03/2016**	**B05.01.8[1,131]**			
3205B10	Reinforced Concrete Works for Pede...	45	03/02/2016	25/03/2016				
e Design	Defective Design	0	26/03/2016	25/03/2016	ZCRI[13,365.247]	1	1	1
Conditio	Unforeseen Site Conditions	0	26/03/2016	25/03/2016	ZCRI[554.4]	12	14	16
B205B1	**Reinforced Concrete Works for U S...**	**45**	**03/02/2016**	**25/03/2016**	**B05.01.8[720]**			
3205B11	Reinforced Concrete Works for U Sh...	45	03/02/2016	25/03/2016				
e Design	Defective Design	0	26/03/2016	25/03/2016	ZCRI[14,744.52]	15	17	20
Conditio	Unforeseen Site Conditions	0	26/03/2016	25/03/2016	ZCRI[0]	12	14	16
B205B1	**Waterproofing for Structures**	**20**	**15/03/2016**	**06/04/2016**	**B05.15.6(2)[0]**			
3205B12	Waterproofing for Structures	20	15/03/2016	06/04/2016				
e Design	Defective Design	0	07/04/2016	06/04/2016	ZCRI[0]	6	7	8
Conditio	Unforeseen Site Conditions	0	07/04/2016	06/04/2016	ZCRI[0]	18	21	24
B206B2	**Painting of Structures**	**5**	**26/03/2016**	**31/03/2016**	**B06.09[215]**			
3206B21	Painting of Structures	5	26/03/2016	31/03/2016				
e Design	Defective Design	0	01/04/2016	31/03/2016	ZCRI[554.4]	4	5	6
Conditio	Unforeseen Site Conditions	0	01/04/2016	31/03/2016	ZCRI[0]	18	21	24
BRIDGE	**Zone C / The Bridge Underpass (ST...**	**318**	**13/08/2015**	**25/06/2016**				
CG02B1	**Removal of existing obstructions & ...**	**7**	**13/08/2015**	**20/08/2015**				
G02B16	Removal of existing obstructions & U...	7	13/08/2015	20/08/2015				
e Design	Defective Design	0	21/08/2015	20/08/2015	ZCRI[0]	9	10	12
Conditic	Unforeseen Site Conditions	0	21/08/2015	20/08/2015	ZCRI[2,954.7]	6	7	8
CG02B1	**Excavation Work**	**20**	**21/08/2015**	**12/09/2015**	**B02-1[6,232.07]**			
G02B17	Excavation Work	20	21/08/2015	12/09/2015				
e Design	Defective Design	0	14/09/2015	12/09/2015	ZCRI[3,591]	9	10	12
Conditic	Unforeseen Site Conditions	0	14/09/2015	12/09/2015	ZCRI[0]	12	14	16

Figure 63: Full Gantt Chart of the Optimized Case Study (7)



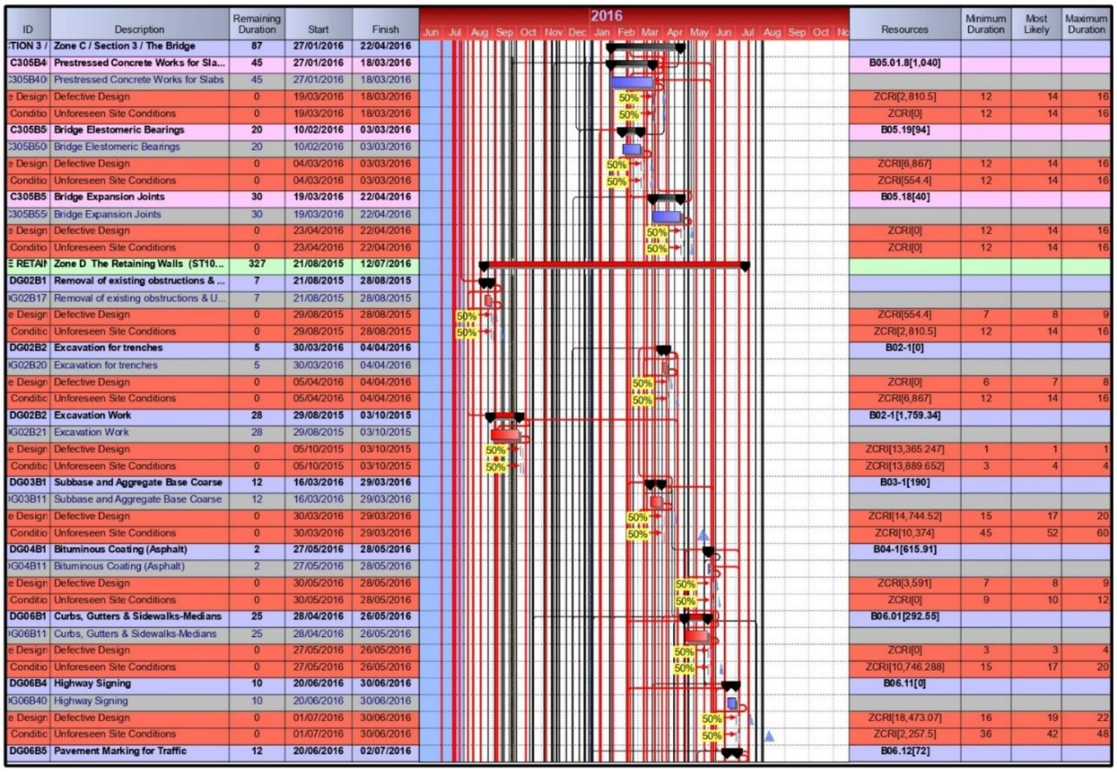
ID	Description	Remaining Duration	Start	Finish	Resources	Minimum Duration	Most Likely	Maximum Duration
CG02B1	to clean pipe trenches	2	19/03/2016	21/03/2016	B02-1[0]			
:G02B19	to clean pipe trenches	2	19/03/2016	21/03/2016				
e Design	Defective Design	0	22/03/2016	21/03/2016	ZCRI[14,744.52]	21	24	28
Conditic	Unforeseen Site Conditions	0	22/03/2016	21/03/2016	ZCRI[0]	27	31	36
CG03B1	Subbase and Aggregate Base Coarse	10	19/03/2016	30/03/2016	B03-1[190]			
:G03B11	Subbase and Aggregate Base Coarse	10	19/03/2016	30/03/2016				
e Design	Defective Design	0	31/03/2016	30/03/2016	ZCRI[13,620.439]	1	1	1
Conditio	Unforeseen Site Conditions	0	31/03/2016	30/03/2016	ZCRI[17,290]	12	14	16
CG04B1	Bituminous Coating (Asphalt)	2	23/05/2016	24/05/2016	B04-1[615.91]			
:G04B11	Bituminous Coating (Asphalt)	2	23/05/2016	24/05/2016				
e Design	Defective Design	0	25/05/2016	24/05/2016	ZCRI[554.4]	12	14	16
Conditio	Unforeseen Site Conditions	0	25/05/2016	24/05/2016	ZCRI[0]	27	31	36
CG06B1	Curbs, Gutters & Sidewalks-Medians	25	23/04/2016	21/05/2016	B06.01[292.55]			
:G06B11	Curbs, Gutters & Sidewalks-Medians	25	23/04/2016	21/05/2016				
e Design	Defective Design	0	23/05/2016	21/05/2016	ZCRI[6,144.6]	12	14	16
Conditio	Unforeseen Site Conditions	0	23/05/2016	21/05/2016	ZCRI[10,746.288]	3	3	4
CG06B4	Highway Signing	10	15/06/2016	25/06/2016	B06.11[0]			
:G06B40	Highway Signing	10	15/06/2016	25/06/2016				
e Design	Defective Design	0	27/06/2016	25/06/2016	ZCRI[0]	9	10	12
Conditic	Unforeseen Site Conditions	0	27/06/2016	25/06/2016	ZCRI[2,257.5]	16	19	22
CG06B5	Pavement Marking for Traffic	8	15/06/2016	23/06/2016	B06.12[72]			
:G06B50	Pavement Marking for Traffic	8	15/06/2016	23/06/2016				
e Design	Defective Design	0	24/06/2016	23/06/2016	ZCRI[2,810.5]	12	14	16
Conditic	Unforeseen Site Conditions	0	24/06/2016	23/06/2016	ZCRI[0]	6	7	8
CG07B1	Electric Cabling civil works	10	22/03/2016	01/04/2016	B07.22[0]			
:G07B13	Electric Cabling civil works	10	22/03/2016	01/04/2016				
e Design	Defective Design	0	02/04/2016	01/04/2016	ZCRI[8,041.173]	12	14	16
Conditic	Unforeseen Site Conditions	0	02/04/2016	01/04/2016	ZCRI[81,585]	16	19	22
CG07B1	Telecommunucation Cabling	10	02/04/2016	13/04/2016	B07.28[55]			
:G07B15	Telecommunucation Cabling	10	02/04/2016	13/04/2016				
e Design	Defective Design	0	14/04/2016	13/04/2016	ZCRI[6,867]	7	8	9
Conditic	Unforeseen Site Conditions	0	14/04/2016	13/04/2016	ZCRI[0]	16	19	22
CG07B2	MV Manholes For Electrical Installa...	10	08/04/2016	19/04/2016	B07.22-4(3B)[1]			
:G07B22	MV Manholes For Electrical Installati...	10	08/04/2016	19/04/2016				
e Design	Defective Design	0	20/04/2016	19/04/2016	ZCRI[10,374]	12	14	16
Conditic	Unforeseen Site Conditions	0	20/04/2016	19/04/2016	ZCRI[245,140]	6	7	8
CG07B3	Installation of Electric Cables	10	02/04/2016	13/04/2016	B07.22[178.76]			
:G07B31	Installation of Electric Cables	10	02/04/2016	13/04/2016				
e Design	Defective Design	0	14/04/2016	13/04/2016	ZCRI[0]	12	14	16
Conditic	Unforeseen Site Conditions	0	14/04/2016	13/04/2016	ZCRI[0]	3	3	4
CG07B7	Lighting installations	20	23/05/2016	14/06/2016	B07.10.4[6]			
:G07B76	Lighting installations	20	23/05/2016	14/06/2016				
e Design	Defective Design	0	15/06/2016	14/06/2016	ZCRI[8,467.2]	9	10	12

Figure 64: Full Gantt Chart of the Optimized Case Study (8)



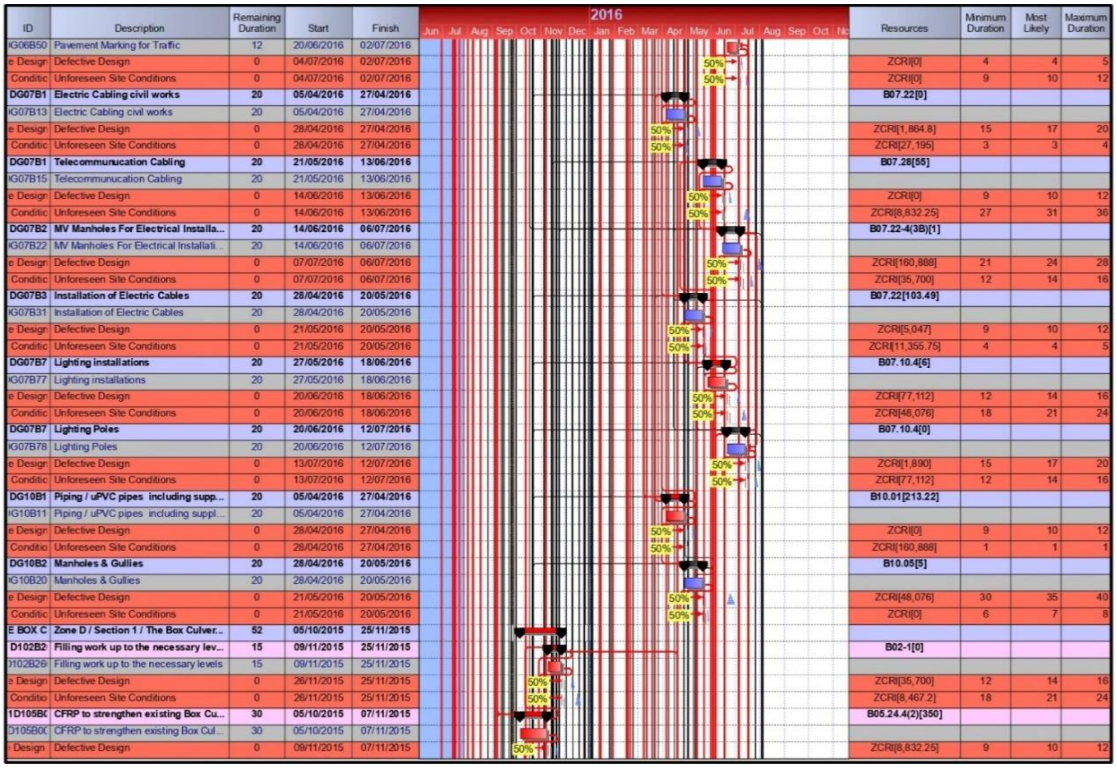
ID	Description	Remaining Duration	Start	Finish	Resources	Minimum Duration	Most Likely	Maximum Duration
Conditic	Unforeseen Site Conditions	0	15/06/2016	14/06/2016	ZCRI[121,380]	16	19	22
CG07B7	**Lighting Poles**	**20**	**23/05/2016**	**14/06/2016**	**B07.10.4[0]**			
:G07B77	Lighting Poles	20	23/05/2016	14/06/2016				
e Design	Defective Design	0	15/06/2016	14/06/2016	ZCRI[0]	12	14	16
Conditic	Unforeseen Site Conditions	0	15/06/2016	14/06/2016	ZCRI[1,354.5]	7	8	9
CG10B1	**Piping / uPVC pipes including supp...**	**10**	**22/03/2016**	**01/04/2016**	**B10.01[213.22]**			
:G10B11	Piping / uPVC pipes including suppl...	10	22/03/2016	01/04/2016				
e Design	Defective Design	0	02/04/2016	01/04/2016	ZCRI[0]	9	10	12
Conditio	Unforeseen Site Conditions	0	02/04/2016	01/04/2016	ZCRI[247,520]	1	1	1
CG10B2	**Manholes & Gullies**	**10**	**02/04/2016**	**13/04/2016**	**B10.05[5]**			
:G10B20	Manholes & Gullies	10	02/04/2016	13/04/2016				
e Design	Defective Design	0	14/04/2016	13/04/2016	ZCRI[865.2]	12	14	16
Conditic	Unforeseen Site Conditions	0	14/04/2016	13/04/2016	ZCRI[26,451.6]	15	17	20
E BOX C	**Zone C / Section 1/ The Box Culvert...**	**97**	**14/09/2015**	**19/12/2015**				
C102B2	**Filling work up to the necessary lev...**	**6**	**14/12/2015**	**19/12/2015**	**B02-1[0]**			
:102B26	Filling work up to the necessary levels	6	14/12/2015	19/12/2015				
e Design	Defective Design	0	21/12/2015	19/12/2015	ZCRI[6,144.6]	12	14	16
Conditio	Unforeseen Site Conditions	0	21/12/2015	19/12/2015	ZCRI[6,944]	6	7	8
1C105B(	**CFRP to strengthen existing Box Cu...**	**75**	**14/09/2015**	**12/12/2015**	**B05.24.4(2)[1,050]**			
C105B0(	CFRP to strengthen existing Box Cul...	75	14/09/2015	12/12/2015				
Design	Defective Design	0	14/12/2015	12/12/2015	ZCRI[0]	4	4	5
Conditior	Unforeseen Site Conditions	0	14/12/2015	12/12/2015	ZCRI[0]	4	5	6
TE WORK	**Zone C / Section 2 / Concrete works...**	**111**	**17/12/2015**	**05/04/2016**				
C205B0	**Blinding under R.C. structures**	**15**	**17/12/2015**	**05/01/2016**	**B05-01.8(A)[0]**			
:205B02	Blinding under R.C. structures	15	17/12/2015	05/01/2016				
e Design	Defective Design	0	06/01/2016	05/01/2016	ZCRI[2,257.5]	12	14	16
Conditio	Unforeseen Site Conditions	0	06/01/2016	05/01/2016	ZCRI[65,436.735]	9	10	12
C205B0	**Foundations & footings for Retainni...**	**25**	**21/12/2015**	**20/01/2016**	**B05.01.8[1,030]**			
:205B05	Foundations & footings for Retainnin...	25	21/12/2015	20/01/2016				
e Design	Defective Design	0	21/01/2016	20/01/2016	ZCRI[10,746.288]	12	14	16
Conditio	Unforeseen Site Conditions	0	21/01/2016	20/01/2016	ZCRI[0]	12	14	16
C205B1	**Reinforced Concrete Works for R.W...**	**60**	**28/12/2015**	**07/03/2016**	**B05.01.8[510]**			
:205B10	Reinforced Concrete Works for R.W...	60	28/12/2015	07/03/2016				
e Design	Defective Design	0	08/03/2016	07/03/2016	ZCRI[10,374]	12	14	16
Conditio	Unforeseen Site Conditions	0	08/03/2016	07/03/2016	ZCRI[13,365.247]	6	7	8
C205B1	**Waterproofing for Structures**	**15**	**09/01/2016**	**26/01/2016**	**B05.15.6(2)[0]**			
:205B12	Waterproofing for Structures	15	09/01/2016	26/01/2016				
e Design	Defective Design	0	27/01/2016	26/01/2016	ZCRI[0]	12	14	16
Conditio	Unforeseen Site Conditions	0	27/01/2016	26/01/2016	ZCRI[3,591]	12	14	16
C206B2	**Painting of Structures**	**10**	**25/03/2016**	**05/04/2016**	**B06.09[1,358.75]**			
:206B21	Painting of Structures	10	25/03/2016	05/04/2016				
e Design	Defective Design	0	06/04/2016	05/04/2016	ZCRI[8,041.173]	12	14	16
Conditio	Unforeseen Site Conditions	0	06/04/2016	05/04/2016	ZCRI[14,744.52]	15	17	20

Figure 65: Full Gantt Chart of the Optimized Case Study (9)



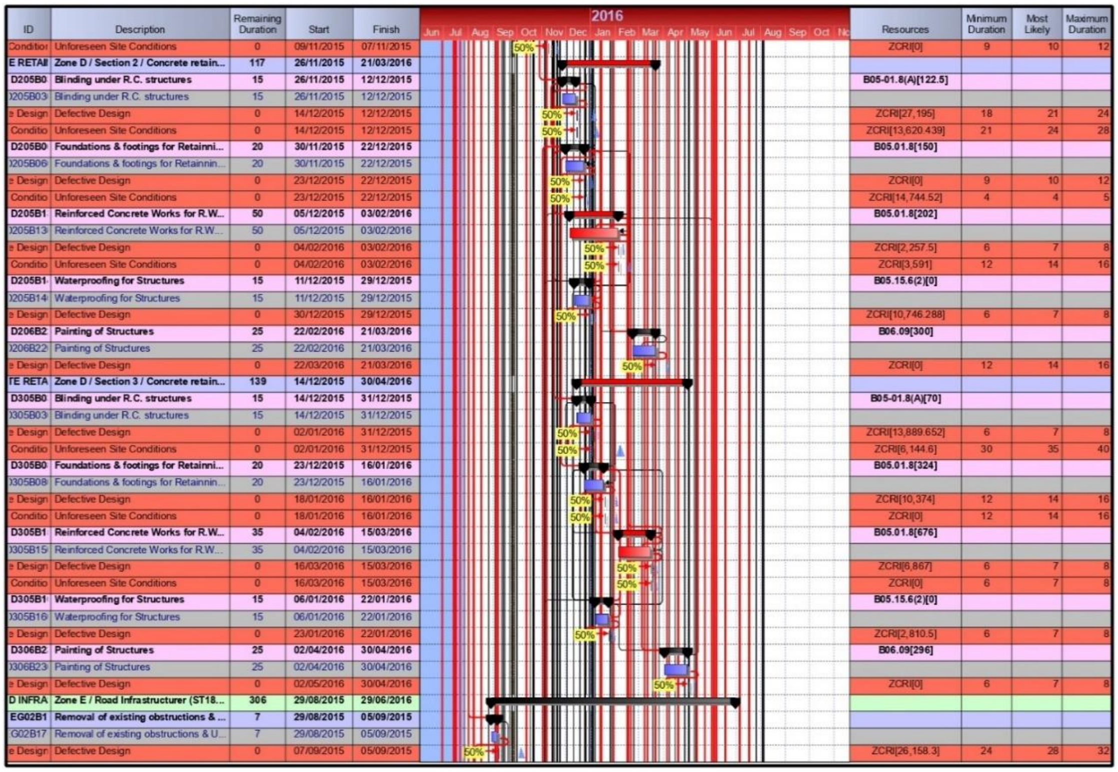
ID	Description	Remaining Duration	Start	Finish	Resources	Minimum Duration	Most Likely	Maximum Duration
:TION 3 /	**Zone C / Section 3 / The Bridge**	**87**	**27/01/2016**	**22/04/2016**				
C305B4	**Prestressed Concrete Works for Sla...**	**45**	**27/01/2016**	**18/03/2016**	**B05.01.8[1,040]**			
:305B40	Prestressed Concrete Works for Slabs	45	27/01/2016	18/03/2016				
e Design	Defective Design	0	19/03/2016	18/03/2016	ZCRI[2,810.5]	12	14	16
Conditio	Unforeseen Site Conditions	0	19/03/2016	18/03/2016	ZCRI[0]	12	14	16
C305B5	**Bridge Elestomeric Bearings**	**20**	**10/02/2016**	**03/03/2016**	**B05.19[94]**			
:305B50	Bridge Elestomeric Bearings	20	10/02/2016	03/03/2016				
e Design	Defective Design	0	04/03/2016	03/03/2016	ZCRI[6,867]	12	14	16
Conditio	Unforeseen Site Conditions	0	04/03/2016	03/03/2016	ZCRI[554.4]	12	14	16
C305B5	**Bridge Expansion Joints**	**30**	**19/03/2016**	**22/04/2016**	**B05.18[40]**			
:305B55	Bridge Expansion Joints	30	19/03/2016	22/04/2016				
e Design	Defective Design	0	23/04/2016	22/04/2016	ZCRI[0]	12	14	16
Conditio	Unforeseen Site Conditions	0	23/04/2016	22/04/2016	ZCRI[0]	12	14	16
E RETAIN	**Zone D The Retaining Walls (ST10...**	**327**	**21/08/2015**	**12/07/2016**				
DG02B1	**Removal of existing obstructions & ...**	**7**	**21/08/2015**	**28/08/2015**				
G02B17	Removal of existing obstructions & U...	7	21/08/2015	28/08/2015				
e Design	Defective Design	0	29/08/2015	28/08/2015	ZCRI[554.4]	7	8	9
Conditic	Unforeseen Site Conditions	0	29/08/2015	28/08/2015	ZCRI[2,810.5]	12	14	16
DG02B2	**Excavation for trenches**	**5**	**30/03/2016**	**04/04/2016**	**B02-1[0]**			
G02B20	Excavation for trenches	5	30/03/2016	04/04/2016				
e Design	Defective Design	0	05/04/2016	04/04/2016	ZCRI[0]	6	7	8
Conditic	Unforeseen Site Conditions	0	05/04/2016	04/04/2016	ZCRI[6,867]	12	14	16
DG02B2	**Excavation Work**	**28**	**29/08/2015**	**03/10/2015**	**B02-1[1,759.34]**			
G02B21	Excavation Work	28	29/08/2015	03/10/2015				
e Design	Defective Design	0	05/10/2015	03/10/2015	ZCRI[13,365.247]	1	1	1
Conditic	Unforeseen Site Conditions	0	05/10/2015	03/10/2015	ZCRI[13,889.652]	3	4	4
DG03B1	**Subbase and Aggregate Base Coarse**	**12**	**16/03/2016**	**29/03/2016**	**B03-1[190]**			
G03B11	Subbase and Aggregate Base Coarse	12	16/03/2016	29/03/2016				
e Design	Defective Design	0	30/03/2016	29/03/2016	ZCRI[14,744.52]	15	17	20
Conditio	Unforeseen Site Conditions	0	30/03/2016	29/03/2016	ZCRI[10,374]	45	52	60
DG04B1	**Bituminous Coating (Asphalt)**	**2**	**27/05/2016**	**28/05/2016**	**B04-1[615.91]**			
G04B11	Bituminous Coating (Asphalt)	2	27/05/2016	28/05/2016				
e Design	Defective Design	0	30/05/2016	28/05/2016	ZCRI[3,591]	7	8	9
Conditio	Unforeseen Site Conditions	0	30/05/2016	28/05/2016	ZCRI[0]	9	10	12
DG06B1	**Curbs, Gutters & Sidewalks-Medians**	**25**	**28/04/2016**	**26/05/2016**	**B06.01[292.55]**			
G06B11	Curbs, Gutters & Sidewalks-Medians	25	28/04/2016	26/05/2016				
e Design	Defective Design	0	27/05/2016	26/05/2016	ZCRI[0]	3	3	4
Conditio	Unforeseen Site Conditions	0	27/05/2016	26/05/2016	ZCRI[10,746.288]	15	17	20
DG06B4	**Highway Signing**	**10**	**20/06/2016**	**30/06/2016**	**B06.11[0]**			
G06B40	Highway Signing	10	20/06/2016	30/06/2016				
e Design	Defective Design	0	01/07/2016	30/06/2016	ZCRI[18,473.07]	16	19	22
Conditic	Unforeseen Site Conditions	0	01/07/2016	30/06/2016	ZCRI[2,257.5]	36	42	48
DG06B5	**Pavement Marking for Traffic**	**12**	**20/06/2016**	**02/07/2016**	**B06.12[72]**			

Figure 66: Full Gantt Chart of the Optimized Case Study (10)



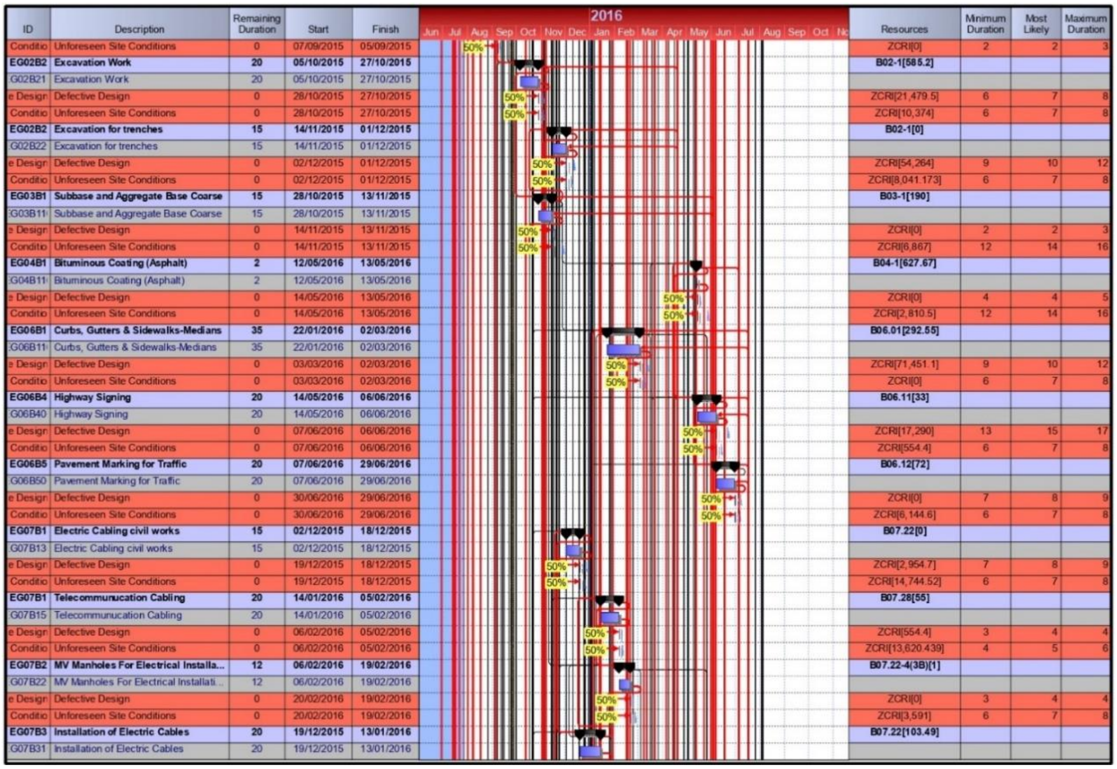
ID	Description	Remaining Duration	Start	Finish	Resources	Minimum Duration	Most Likely	Maximum Duration
IG06B50	Pavement Marking for Traffic	12	20/06/2016	02/07/2016				
e Design	Defective Design	0	04/07/2016	02/07/2016	ZCRI[0]	4	4	5
Conditic	Unforeseen Site Conditions	0	04/07/2016	02/07/2016	ZCRI[0]	9	10	12
DG07B1	**Electric Cabling civil works**	**20**	**05/04/2016**	**27/04/2016**	**B07.22[0]**			
IG07B13	Electric Cabling civil works	20	05/04/2016	27/04/2016				
e Design	Defective Design	0	28/04/2016	27/04/2016	ZCRI[1,864.8]	15	17	20
Conditic	Unforeseen Site Conditions	0	28/04/2016	27/04/2016	ZCRI[27,195]	3	3	4
DG07B1	**Telecommunucation Cabling**	**20**	**21/05/2016**	**13/06/2016**	**B07.28[55]**			
IG07B15	Telecommunucation Cabling	20	21/05/2016	13/06/2016				
e Design	Defective Design	0	14/06/2016	13/06/2016	ZCRI[0]	9	10	12
Conditic	Unforeseen Site Conditions	0	14/06/2016	13/06/2016	ZCRI[8,832.25]	27	31	36
DG07B2	**MV Manholes For Electrical Installa...**	**20**	**14/06/2016**	**06/07/2016**	**B07.22-4(3B)[1]**			
IG07B22	MV Manholes For Electrical Installati...	20	14/06/2016	06/07/2016				
e Design	Defective Design	0	07/07/2016	06/07/2016	ZCRI[160,888]	21	24	28
Conditic	Unforeseen Site Conditions	0	07/07/2016	06/07/2016	ZCRI[35,700]	12	14	16
DG07B3	**Installation of Electric Cables**	**20**	**28/04/2016**	**20/05/2016**	**B07.22[103.49]**			
IG07B31	Installation of Electric Cables	20	28/04/2016	20/05/2016				
e Design	Defective Design	0	21/05/2016	20/05/2016	ZCRI[5,047]	9	10	12
Conditic	Unforeseen Site Conditions	0	21/05/2016	20/05/2016	ZCRI[11,355.75]	4	4	5
DG07B7	**Lighting installations**	**20**	**27/05/2016**	**18/06/2016**	**B07.10.4[6]**			
IG07B77	Lighting installations	20	27/05/2016	18/06/2016				
e Design	Defective Design	0	20/06/2016	18/06/2016	ZCRI[77,112]	12	14	16
Conditic	Unforeseen Site Conditions	0	20/06/2016	18/06/2016	ZCRI[48,076]	18	21	24
DG07B7	**Lighting Poles**	**20**	**20/06/2016**	**12/07/2016**	**B07.10.4[0]**			
IG07B78	Lighting Poles	20	20/06/2016	12/07/2016				
e Design	Defective Design	0	13/07/2016	12/07/2016	ZCRI[1,890]	15	17	20
Conditic	Unforeseen Site Conditions	0	13/07/2016	12/07/2016	ZCRI[77,112]	12	14	16
DG10B1	**Piping / uPVC pipes including supp...**	**20**	**05/04/2016**	**27/04/2016**	**B10.01[213.22]**			
IG10B11	Piping / uPVC pipes including suppl...	20	05/04/2016	27/04/2016				
e Design	Defective Design	0	28/04/2016	27/04/2016	ZCRI[0]	9	10	12
Conditio	Unforeseen Site Conditions	0	28/04/2016	27/04/2016	ZCRI[160,888]	1	1	1
DG10B2	**Manholes & Gullies**	**20**	**28/04/2016**	**20/05/2016**	**B10.05[5]**			
IG10B20	Manholes & Gullies	20	28/04/2016	20/05/2016				
e Design	Defective Design	0	21/05/2016	20/05/2016	ZCRI[48,076]	30	35	40
Conditic	Unforeseen Site Conditions	0	21/05/2016	20/05/2016	ZCRI[0]	6	7	8
E BOX C	**Zone D / Section 1 / The Box Culver...**	**52**	**05/10/2015**	**25/11/2015**				
D102B2	**Filling work up to the necessary lev...**	**15**	**09/11/2015**	**25/11/2015**	**B02-1[0]**			
)102B26	Filling work up to the necessary levels	15	09/11/2015	25/11/2015				
e Design	Defective Design	0	26/11/2015	25/11/2015	ZCRI[35,700]	12	14	16
Conditio	Unforeseen Site Conditions	0	26/11/2015	25/11/2015	ZCRI[8,467.2]	18	21	24
1D105B(	**CFRP to strengthen existing Box Cu...**	**30**	**05/10/2015**	**07/11/2015**	**B05.24.4(2)[350]**			
D105B0(	CFRP to strengthen existing Box Cul...	30	05/10/2015	07/11/2015				
Design	Defective Design	0	09/11/2015	07/11/2015	ZCRI[8,832.25]	9	10	12

Figure 67: Full Gantt Chart of the Optimized Case Study (11)



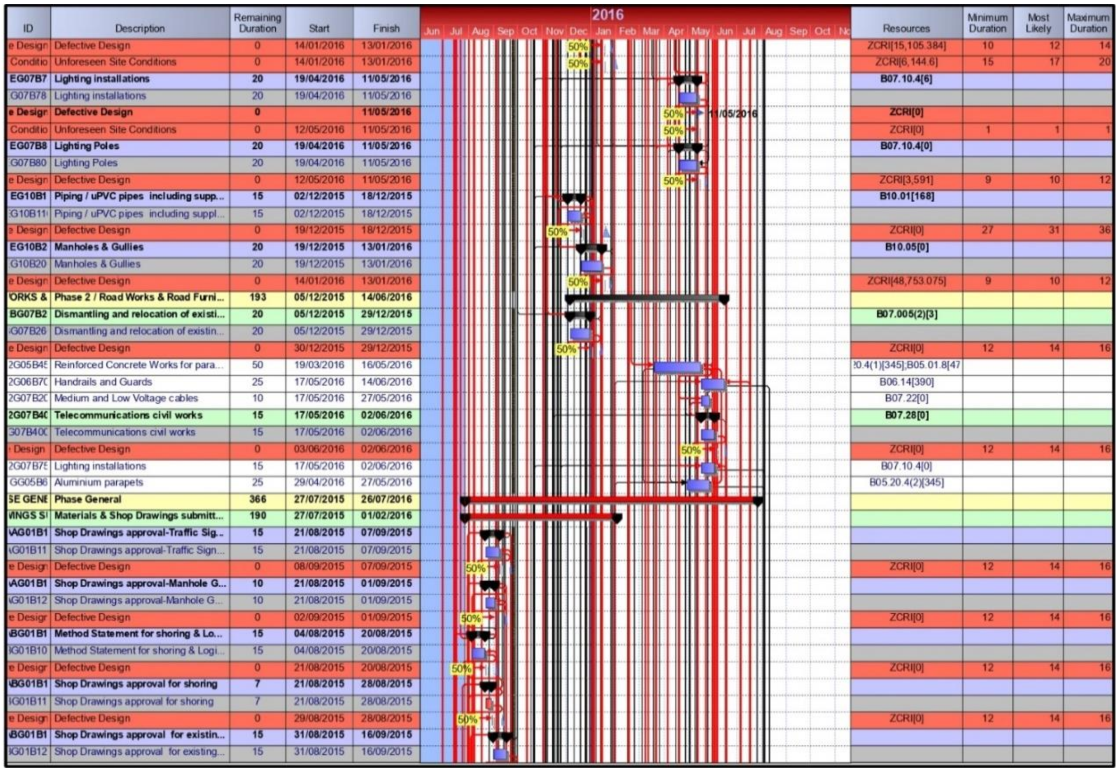
ID	Description	Remaining Duration	Start	Finish	Resources	Minimum Duration	Most Likely	Maximum Duration
Conditior	Unforeseen Site Conditions	0	09/11/2015	07/11/2015	ZCRI[0]	9	10	12
E RETAI	Zone D / Section 2 / Concrete retain...	117	26/11/2015	21/03/2016				
D205B0	Blinding under R.C. structures	15	26/11/2015	12/12/2015	B05-01.8(A)[122.5]			
)205B03	Blinding under R.C. structures	15	26/11/2015	12/12/2015				
e Design	Defective Design	0	14/12/2015	12/12/2015	ZCRI[27,195]	18	21	24
Conditio	Unforeseen Site Conditions	0	14/12/2015	12/12/2015	ZCRI[13,620.439]	21	24	28
D205B0	Foundations & footings for Retainni...	20	30/11/2015	22/12/2015	B05.01.8[150]			
)205B06	Foundations & footings for Retainnin...	20	30/11/2015	22/12/2015				
e Design	Defective Design	0	23/12/2015	22/12/2015	ZCRI[0]	9	10	12
Conditio	Unforeseen Site Conditions	0	23/12/2015	22/12/2015	ZCRI[14,744.52]	4	4	5
D205B1	Reinforced Concrete Works for R.W...	50	05/12/2015	03/02/2016	B05.01.8[202]			
)205B13	Reinforced Concrete Works for R.W...	50	05/12/2015	03/02/2016				
e Design	Defective Design	0	04/02/2016	03/02/2016	ZCRI[2,257.5]	6	7	8
Conditio	Unforeseen Site Conditions	0	04/02/2016	03/02/2016	ZCRI[3,591]	12	14	16
D205B1	Waterproofing for Structures	15	11/12/2015	29/12/2015	B05.15.6(2)[0]			
)205B14	Waterproofing for Structures	15	11/12/2015	29/12/2015				
e Design	Defective Design	0	30/12/2015	29/12/2015	ZCRI[10,746.288]	6	7	8
D206B2	Painting of Structures	25	22/02/2016	21/03/2016	B06.09[300]			
)206B22	Painting of Structures	25	22/02/2016	21/03/2016				
e Design	Defective Design	0	22/03/2016	21/03/2016	ZCRI[0]	12	14	16
TE RETA	Zone D / Section 3 / Concrete retain...	139	14/12/2015	30/04/2016				
D305B0	Blinding under R.C. structures	15	14/12/2015	31/12/2015	B05-01.8(A)[70]			
)305B03	Blinding under R.C. structures	15	14/12/2015	31/12/2015				
e Design	Defective Design	0	02/01/2016	31/12/2015	ZCRI[13,889.652]	6	7	8
Conditio	Unforeseen Site Conditions	0	02/01/2016	31/12/2015	ZCRI[6,144.6]	30	35	40
D305B0	Foundations & footings for Retainni...	20	23/12/2015	16/01/2016	B05.01.8[324]			
)305B08	Foundations & footings for Retainnin...	20	23/12/2015	16/01/2016				
e Design	Defective Design	0	18/01/2016	16/01/2016	ZCRI[10,374]	12	14	16
Conditio	Unforeseen Site Conditions	0	18/01/2016	16/01/2016	ZCRI[0]	12	14	16
D305B1	Reinforced Concrete Works for R.W...	35	04/02/2016	15/03/2016	B05.01.8[676]			
)305B15	Reinforced Concrete Works for R.W...	35	04/02/2016	15/03/2016				
e Design	Defective Design	0	16/03/2016	15/03/2016	ZCRI[6,867]	6	7	8
Conditio	Unforeseen Site Conditions	0	16/03/2016	15/03/2016	ZCRI[0]	6	7	8
D305B1	Waterproofing for Structures	15	06/01/2016	22/01/2016	B05.15.6(2)[0]			
)305B16	Waterproofing for Structures	15	06/01/2016	22/01/2016				
e Design	Defective Design	0	23/01/2016	22/01/2016	ZCRI[2,810.5]	6	7	8
D306B2	Painting of Structures	25	02/04/2016	30/04/2016	B06.09[296]			
)306B23	Painting of Structures	25	02/04/2016	30/04/2016				
e Design	Defective Design	0	02/05/2016	30/04/2016	ZCRI[0]	6	7	8
D INFRA	Zone E / Road Infrastructurer (ST18...	306	29/08/2015	29/06/2016				
EG02B1	Removal of existing obstructions & ...	7	29/08/2015	05/09/2015				
G02B17	Removal of existing obstructions & U...	7	29/08/2015	05/09/2015				
e Design	Defective Design	0	07/09/2015	05/09/2015	ZCRI[26,158.3]	24	28	32

Figure 68: Full Gantt Chart of the Optimized Case Study (12)



ID	Description	Remaining Duration	Start	Finish	Resources	Minimum Duration	Most Likely	Maximum Duration
Conditio	Unforeseen Site Conditions	0	07/09/2015	05/09/2015	ZCRI[0]	2	2	3
EG02B2	**Excavation Work**	**20**	**05/10/2015**	**27/10/2015**	**B02-1[585.2]**			
:G02B21	Excavation Work	20	05/10/2015	27/10/2015				
e Design	Defective Design	0	28/10/2015	27/10/2015	ZCRI[21,479.5]	6	7	8
Conditio	Unforeseen Site Conditions	0	28/10/2015	27/10/2015	ZCRI[10,374]	6	7	8
EG02B2	**Excavation for trenches**	**15**	**14/11/2015**	**01/12/2015**	**B02-1[0]**			
:G02B22	Excavation for trenches	15	14/11/2015	01/12/2015				
e Design	Defective Design	0	02/12/2015	01/12/2015	ZCRI[54,264]	9	10	12
Conditio	Unforeseen Site Conditions	0	02/12/2015	01/12/2015	ZCRI[8,041.173]	6	7	8
EG03B1	**Subbase and Aggregate Base Coarse**	**15**	**28/10/2015**	**13/11/2015**	**B03-1[190]**			
:G03B11	Subbase and Aggregate Base Coarse	15	28/10/2015	13/11/2015				
e Design	Defective Design	0	14/11/2015	13/11/2015	ZCRI[0]	2	2	3
Conditio	Unforeseen Site Conditions	0	14/11/2015	13/11/2015	ZCRI[6,867]	12	14	16
EG04B1	**Bituminous Coating (Asphalt)**	**2**	**12/05/2016**	**13/05/2016**	**B04-1[627.67]**			
:G04B11	Bituminous Coating (Asphalt)	2	12/05/2016	13/05/2016				
e Design	Defective Design	0	14/05/2016	13/05/2016	ZCRI[0]	4	4	5
Conditio	Unforeseen Site Conditions	0	14/05/2016	13/05/2016	ZCRI[2,810.5]	12	14	16
EG06B1	**Curbs, Gutters & Sidewalks-Medians**	**35**	**22/01/2016**	**02/03/2016**	**B06.01[292.55]**			
:G06B11	Curbs, Gutters & Sidewalks-Medians	35	22/01/2016	02/03/2016				
e Design	Defective Design	0	03/03/2016	02/03/2016	ZCRI[71,451.1]	9	10	12
Conditio	Unforeseen Site Conditions	0	03/03/2016	02/03/2016	ZCRI[0]	6	7	8
EG06B4	**Highway Signing**	**20**	**14/05/2016**	**06/06/2016**	**B06.11[33]**			
:G06B40	Highway Signing	20	14/05/2016	06/06/2016				
e Design	Defective Design	0	07/06/2016	06/06/2016	ZCRI[17,290]	13	15	17
Conditio	Unforeseen Site Conditions	0	07/06/2016	06/06/2016	ZCRI[554.4]	6	7	8
EG06B5	**Pavement Marking for Traffic**	**20**	**07/06/2016**	**29/06/2016**	**B06.12[72]**			
:G06B50	Pavement Marking for Traffic	20	07/06/2016	29/06/2016				
e Design	Defective Design	0	30/06/2016	29/06/2016	ZCRI[0]	7	8	9
Conditio	Unforeseen Site Conditions	0	30/06/2016	29/06/2016	ZCRI[6,144.6]	6	7	8
EG07B1	**Electric Cabling civil works**	**15**	**02/12/2015**	**18/12/2015**	**B07.22[0]**			
:G07B13	Electric Cabling civil works	15	02/12/2015	18/12/2015				
e Design	Defective Design	0	19/12/2015	18/12/2015	ZCRI[2,954.7]	7	8	9
Conditio	Unforeseen Site Conditions	0	19/12/2015	18/12/2015	ZCRI[14,744.52]	6	7	8
EG07B1	**Telecommunucation Cabling**	**20**	**14/01/2016**	**05/02/2016**	**B07.28[55]**			
:G07B15	Telecommunucation Cabling	20	14/01/2016	05/02/2016				
e Design	Defective Design	0	06/02/2016	05/02/2016	ZCRI[554.4]	3	4	4
Conditio	Unforeseen Site Conditions	0	06/02/2016	05/02/2016	ZCRI[13,620.439]	4	5	6
EG07B2	**MV Manholes For Electrical Installa...**	**12**	**06/02/2016**	**19/02/2016**	**B07.22-4(3B)[1]**			
:G07B22	MV Manholes For Electrical Installati...	12	06/02/2016	19/02/2016				
e Design	Defective Design	0	20/02/2016	19/02/2016	ZCRI[0]	3	4	4
Conditio	Unforeseen Site Conditions	0	20/02/2016	19/02/2016	ZCRI[3,591]	6	7	8
EG07B3	**Installation of Electric Cables**	**20**	**19/12/2015**	**13/01/2016**	**B07.22[103.49]**			
:G07B31	Installation of Electric Cables	20	19/12/2015	13/01/2016				

Figure 69: Full Gantt Chart of the Optimized Case Study (13)



ID	Description	Remaining Duration	Start	Finish	Resources	Minimum Duration	Most Likely	Maximum Duration
e Design	Defective Design	0	14/01/2016	13/01/2016	ZCRI[15,105.384]	10	12	14
Conditio	Unforeseen Site Conditions	0	14/01/2016	13/01/2016	ZCRI[6,144.6]	15	17	20
EG07B7	Lighting installations	20	19/04/2016	11/05/2016	B07.10.4[6]			
G07B78	Lighting installations	20	19/04/2016	11/05/2016				
e Design	Defective Design	0		11/05/2016	ZCRI[0]			
Conditio	Unforeseen Site Conditions	0	12/05/2016	11/05/2016	ZCRI[0]	1	1	1
EG07B8	Lighting Poles	20	19/04/2016	11/05/2016	B07.10.4[0]			
G07B80	Lighting Poles	20	19/04/2016	11/05/2016				
e Design	Defective Design	0	12/05/2016	11/05/2016	ZCRI[3,591]	9	10	12
EG10B1	Piping / uPVC pipes including supp...	15	02/12/2015	18/12/2015	B10.01[168]			
G10B11	Piping / uPVC pipes including suppl...	15	02/12/2015	18/12/2015				
e Design	Defective Design	0	19/12/2015	18/12/2015	ZCRI[0]	27	31	36
EG10B2	Manholes & Gullies	20	19/12/2015	13/01/2016	B10.05[0]			
G10B20	Manholes & Gullies	20	19/12/2015	13/01/2016				
e Design	Defective Design	0	14/01/2016	13/01/2016	ZCRI[48,753.075]	9	10	12
ORKS &	Phase 2 / Road Works & Road Furni...	193	05/12/2015	14/06/2016				
BG07B2	Dismantling and relocation of existi...	20	05/12/2015	29/12/2015	B07.005(2)[3]			
G07B26	Dismantling and relocation of existin...	20	05/12/2015	29/12/2015				
e Design	Defective Design	0	30/12/2015	29/12/2015	ZCRI[0]	12	14	16
2G05B4	Reinforced Concrete Works for para...	50	19/03/2016	16/05/2016	0.4(1)[345];B05.01.8[47			
2G06B7	Handrails and Guards	25	17/05/2016	14/06/2016	B06.14[390]			
2G07B2	Medium and Low Voltage cables	10	17/05/2016	27/05/2016	B07.22[0]			
2G07B4	Telecommunications civil works	15	17/05/2016	02/06/2016	B07.28[0]			
G07B40	Telecommunications civil works	15	17/05/2016	02/06/2016				
Design	Defective Design	0	03/06/2016	02/06/2016	ZCRI[0]	12	14	16
2G07B7	Lighting installations	15	17/05/2016	02/06/2016	B07.10.4[0]			
GG05B6	Aluminium parapets	25	29/04/2016	27/05/2016	B05.20.4(2)[345]			
SE GENE	Phase General	366	27/07/2015	26/07/2016				
INGS S	Materials & Shop Drawings submitt...	190	27/07/2015	01/02/2016				
AG01B1	Shop Drawings approval-Traffic Sig...	15	21/08/2015	07/09/2015				
G01B11	Shop Drawings approval-Traffic Sign...	15	21/08/2015	07/09/2015				
e Design	Defective Design	0	08/09/2015	07/09/2015	ZCRI[0]	12	14	16
AG01B1	Shop Drawings approval-Manhole G...	10	21/08/2015	01/09/2015				
G01B12	Shop Drawings approval-Manhole G...	10	21/08/2015	01/09/2015				
e Desigr	Defective Design	0	02/09/2015	01/09/2015	ZCRI[0]	12	14	16
BG01B1	Method Statement for shoring & Lo...	15	04/08/2015	20/08/2015				
G01B10	Method Statement for shoring & Logi...	15	04/08/2015	20/08/2015				
e Desigr	Defective Design	0	21/08/2015	20/08/2015	ZCRI[0]	12	14	16
BG01B1	Shop Drawings approval for shoring	7	21/08/2015	28/08/2015				
G01B11	Shop Drawings approval for shoring	7	21/08/2015	28/08/2015				
e Design	Defective Design	0	29/08/2015	28/08/2015	ZCRI[0]	12	14	16
BG01B1	Shop Drawings approval for existin...	15	31/08/2015	16/09/2015				
G01B12	Shop Drawings approval for existing...	15	31/08/2015	16/09/2015				

Figure 70: Full Gantt Chart of the Optimized Case Study (14)

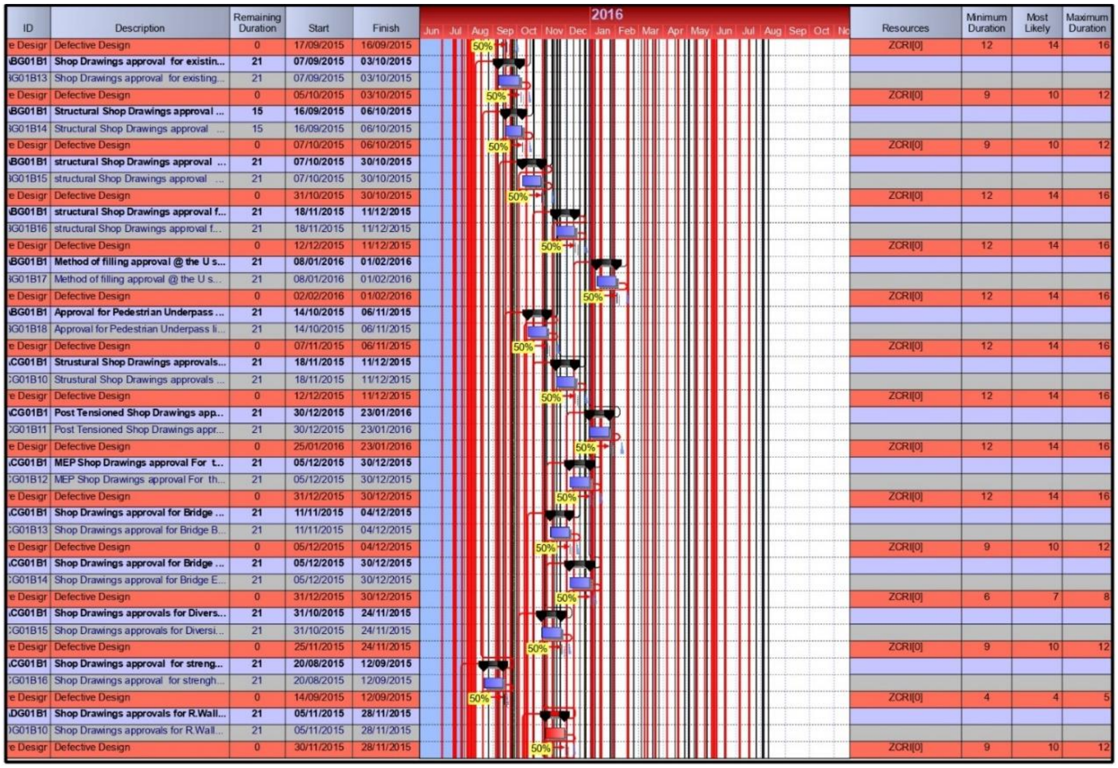
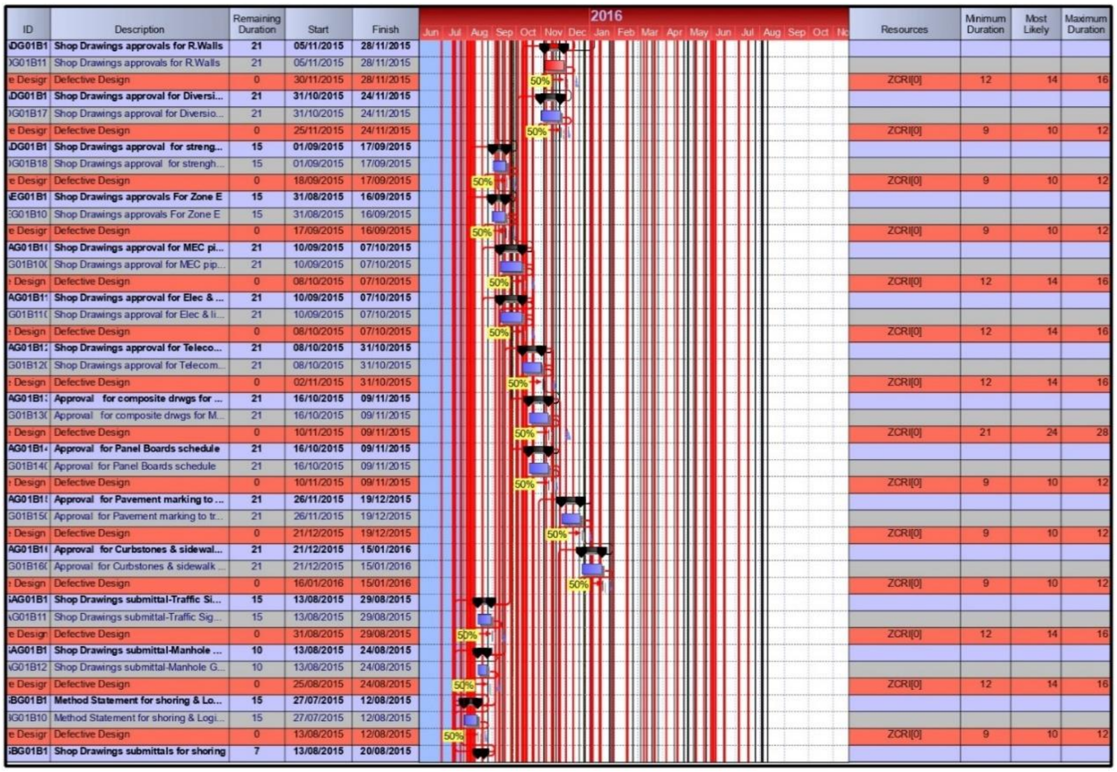


Figure 71: Full Gantt Chart of the Optimized Case Study (15)



ID	Description	Remaining Duration	Start	Finish	Resources	Minimum Duration	Most Likely	Maximum Duration
DG01B1	**Shop Drawings approvals for R.Walls**	21	05/11/2015	28/11/2015				
G01B11	Shop Drawings approvals for R.Walls	21	05/11/2015	28/11/2015				
e Desigr	Defective Design	0	30/11/2015	28/11/2015	ZCRI[0]	12	14	16
DG01B1	**Shop Drawings approval for Diversi...**	21	31/10/2015	24/11/2015				
G01B17	Shop Drawings approval for Diversio...	21	31/10/2015	24/11/2015				
e Desigr	Defective Design	0	25/11/2015	24/11/2015	ZCRI[0]	9	10	12
DG01B1	**Shop Drawings approval for streng...**	15	01/09/2015	17/09/2015				
G01B18	Shop Drawings approval for strengh...	15	01/09/2015	17/09/2015				
e Desigr	Defective Design	0	18/09/2015	17/09/2015	ZCRI[0]	9	10	12
EG01B1	**Shop Drawings approvals For Zone E**	15	31/08/2015	16/09/2015				
G01B10	Shop Drawings approvals For Zone E	15	31/08/2015	16/09/2015				
e Desigr	Defective Design	0	17/09/2015	16/09/2015	ZCRI[0]	9	10	12
AG01B1(	**Shop Drawings approval for MEC pi...**	21	10/09/2015	07/10/2015				
G01B10(	Shop Drawings approval for MEC pip...	21	10/09/2015	07/10/2015				
Design	Defective Design	0	08/10/2015	07/10/2015	ZCRI[0]	12	14	16
AG01B1	**Shop Drawings approval for Elec & ...**	21	10/09/2015	07/10/2015				
G01B11(	Shop Drawings approval for Elec & li...	21	10/09/2015	07/10/2015				
Design	Defective Design	0	08/10/2015	07/10/2015	ZCRI[0]	12	14	16
AG01B1	**Shop Drawings approval for Teleco...**	21	08/10/2015	31/10/2015				
G01B12(	Shop Drawings approval for Telecom...	21	08/10/2015	31/10/2015				
Design	Defective Design	0	02/11/2015	31/10/2015	ZCRI[0]	12	14	16
AG01B1	**Approval for composite drwgs for ...**	21	16/10/2015	09/11/2015				
G01B13(	Approval for composite drwgs for M...	21	16/10/2015	09/11/2015				
Design	Defective Design	0	10/11/2015	09/11/2015	ZCRI[0]	21	24	28
AG01B1	**Approval for Panel Boards schedule**	21	16/10/2015	09/11/2015				
G01B14(	Approval for Panel Boards schedule	21	16/10/2015	09/11/2015				
Design	Defective Design	0	10/11/2015	09/11/2015	ZCRI[0]	9	10	12
AG01B1	**Approval for Pavement marking to ...**	21	26/11/2015	19/12/2015				
G01B15(	Approval for Pavement marking to tr...	21	26/11/2015	19/12/2015				
Design	Defective Design	0	21/12/2015	19/12/2015	ZCRI[0]	9	10	12
AG01B1(	**Approval for Curbstones & sidewal...**	21	21/12/2015	15/01/2016				
G01B16(	Approval for Curbstones & sidewalk ...	21	21/12/2015	15/01/2016				
Design	Defective Design	0	16/01/2016	15/01/2016	ZCRI[0]	9	10	12
AG01B1	**Shop Drawings submittal-Traffic Si...**	15	13/08/2015	29/08/2015				
G01B11	Shop Drawings submittal-Traffic Sig...	15	13/08/2015	29/08/2015				
e Design	Defective Design	0	31/08/2015	29/08/2015	ZCRI[0]	12	14	16
AG01B1	**Shop Drawings submittal-Manhole ...**	10	13/08/2015	24/08/2015				
G01B12	Shop Drawings submittal-Manhole G...	10	13/08/2015	24/08/2015				
e Desigr	Defective Design	0	25/08/2015	24/08/2015	ZCRI[0]	12	14	16
BG01B1	**Method Statement for shoring & Lo...**	15	27/07/2015	12/08/2015				
G01B10	Method Statement for shoring & Logi...	15	27/07/2015	12/08/2015				
e Desigr	Defective Design	0	13/08/2015	12/08/2015	ZCRI[0]	9	10	12
BG01B1	**Shop Drawings submittals for shoring**	7	13/08/2015	20/08/2015				

Figure 72: Full Gantt Chart of the Optimized Case Study (16)

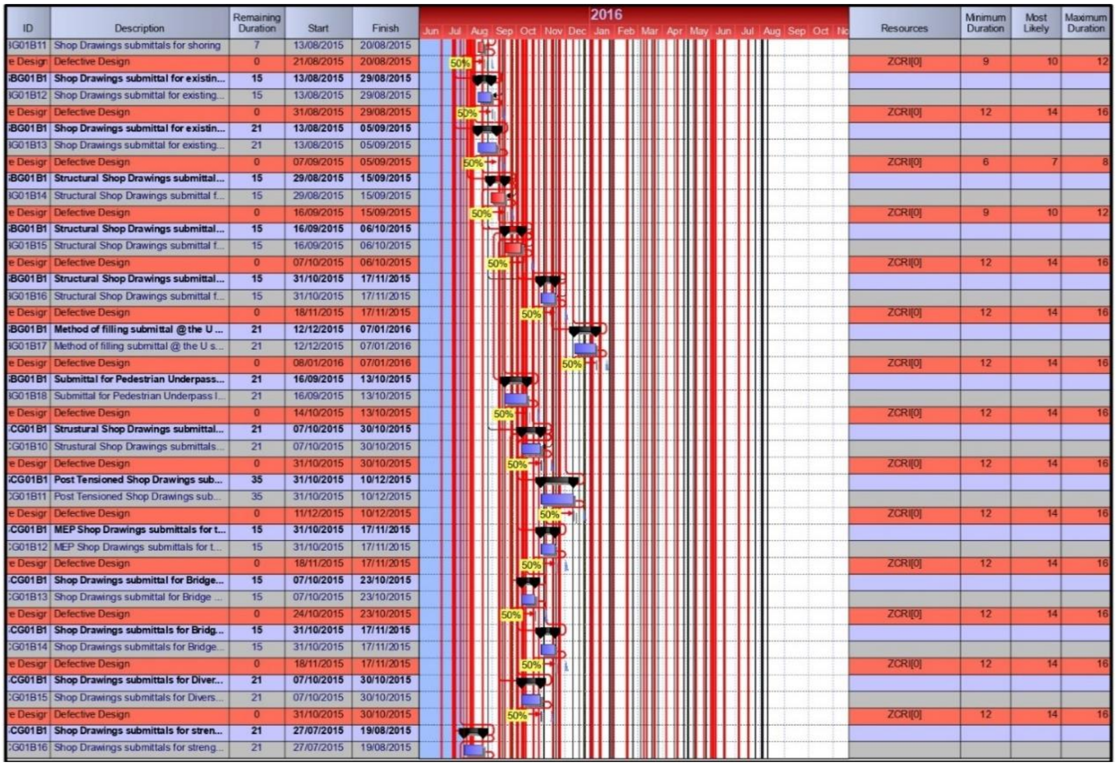
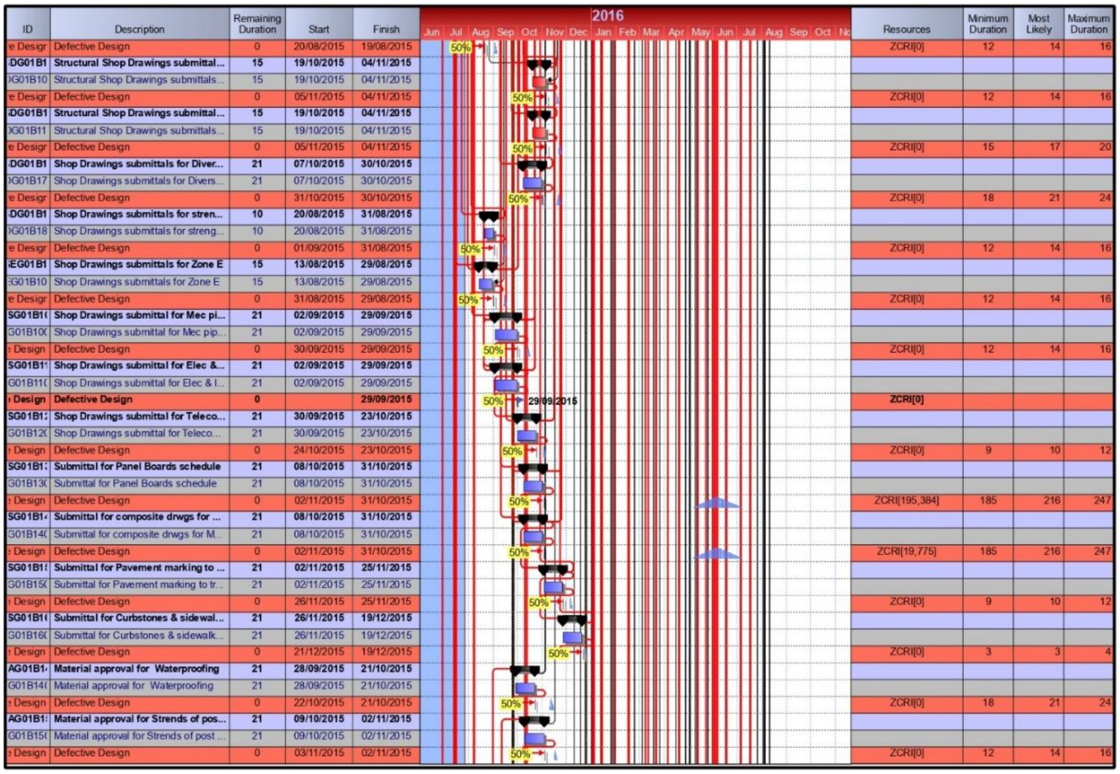
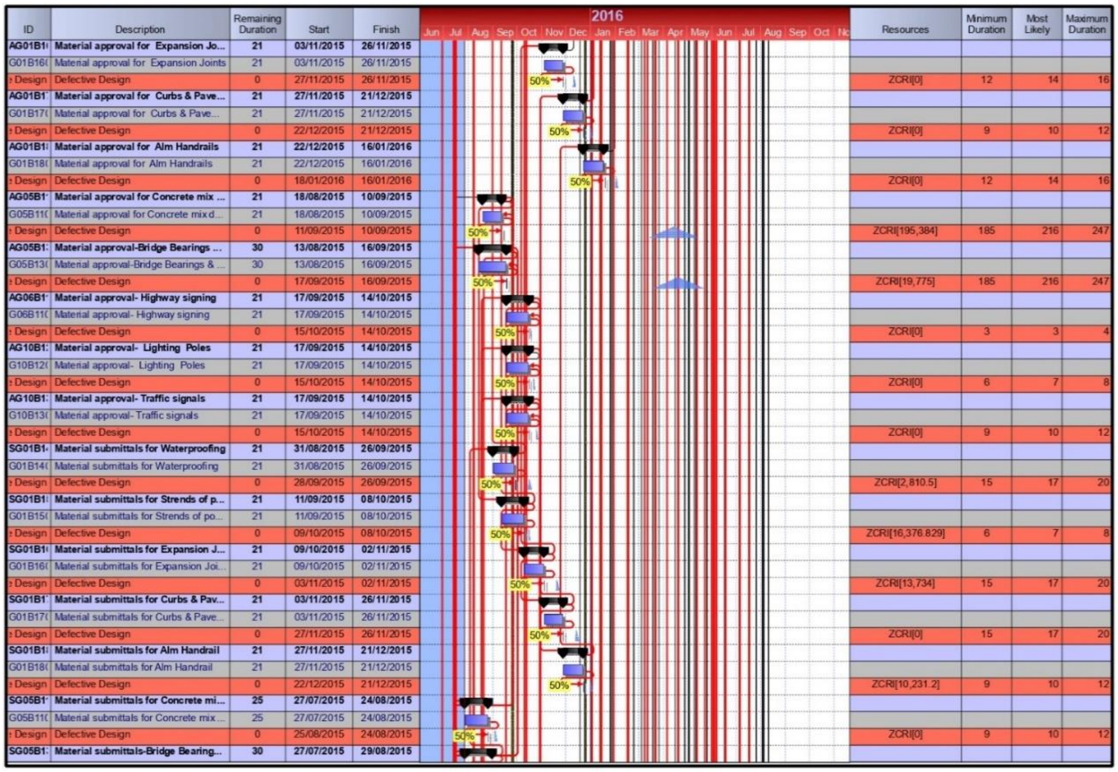


Figure 73: Full Gantt Chart of the Optimized Case Study (17)



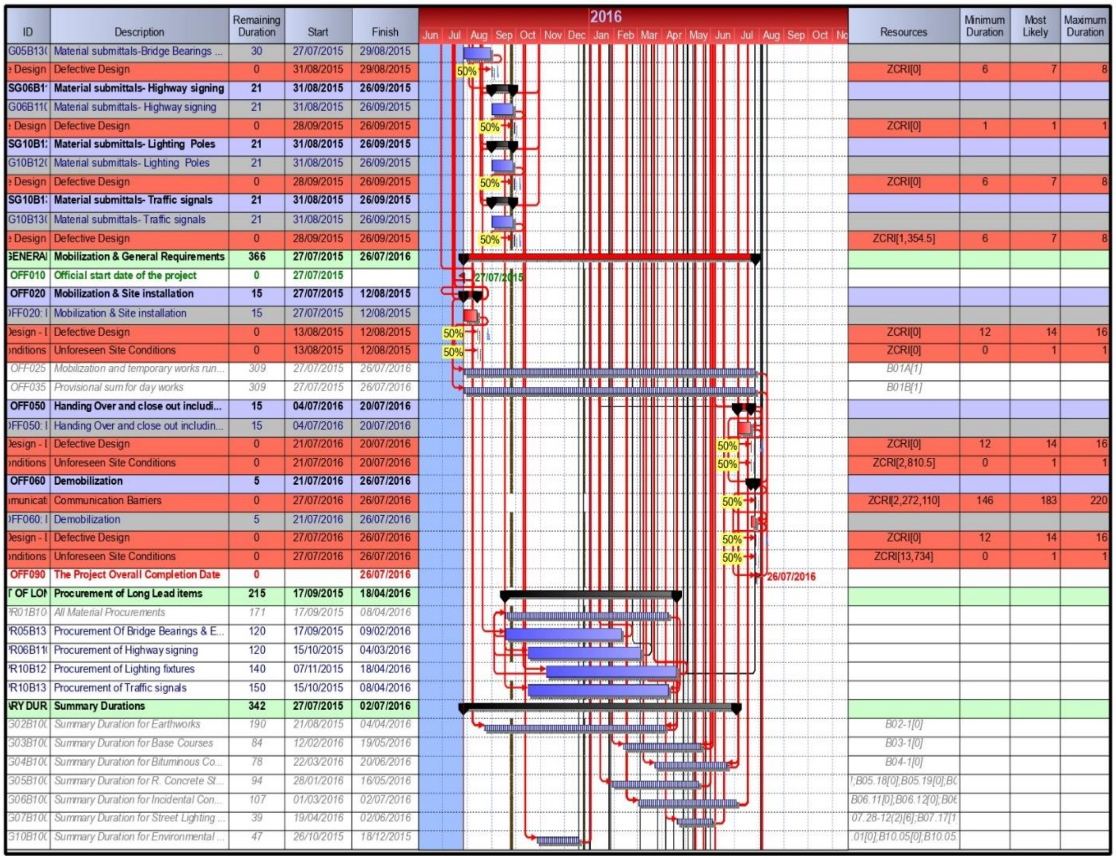
ID	Description	Remaining Duration	Start	Finish	Resources	Minimum Duration	Most Likely	Maximum Duration
e Desigr	Defective Design	0	20/08/2015	19/08/2015	ZCRI[0]	12	14	16
DG01B1	**Structural Shop Drawings submittal...**	**15**	**19/10/2015**	**04/11/2015**				
)G01B10	Structural Shop Drawings submittals...	15	19/10/2015	04/11/2015				
e Desigr	Defective Design	0	05/11/2015	04/11/2015	ZCRI[0]	12	14	16
DG01B1	**Structural Shop Drawings submittal...**	**15**	**19/10/2015**	**04/11/2015**				
)G01B11	Structural Shop Drawings submittals...	15	19/10/2015	04/11/2015				
e Desigr	Defective Design	0	05/11/2015	04/11/2015	ZCRI[0]	15	17	20
DG01B1	**Shop Drawings submittals for Diver...**	**21**	**07/10/2015**	**30/10/2015**				
)G01B17	Shop Drawings submittals for Divers...	21	07/10/2015	30/10/2015				
e Desigr	Defective Design	0	31/10/2015	30/10/2015	ZCRI[0]	18	21	24
DG01B1	**Shop Drawings submittals for stren...**	**10**	**20/08/2015**	**31/08/2015**				
)G01B18	Shop Drawings submittals for streng...	10	20/08/2015	31/08/2015				
e Desigr	Defective Design	0	01/09/2015	31/08/2015	ZCRI[0]	12	14	16
EG01B1	**Shop Drawings submittals for Zone E**	**15**	**13/08/2015**	**29/08/2015**				
:G01B10	Shop Drawings submittals for Zone E	15	13/08/2015	29/08/2015				
e Desigr	Defective Design	0	31/08/2015	29/08/2015	ZCRI[0]	12	14	16
SG01B1(	**Shop Drawings submittal for Mec pi...**	**21**	**02/09/2015**	**29/09/2015**				
G01B10(	Shop Drawings submittal for Mec pip...	21	02/09/2015	29/09/2015				
: Design	Defective Design	0	30/09/2015	29/09/2015	ZCRI[0]	12	14	16
SG01B1	**Shop Drawings submittal for Elec &...**	**21**	**02/09/2015**	**29/09/2015**				
G01B11(	Shop Drawings submittal for Elec & I...	21	02/09/2015	29/09/2015				
Design	**Defective Design**	**0**		**29/09/2015**	**ZCRI[0]**			
SG01B1:	**Shop Drawings submittal for Teleco...**	**21**	**30/09/2015**	**23/10/2015**				
G01B12(	Shop Drawings submittal for Teleco...	21	30/09/2015	23/10/2015				
: Design	Defective Design	0	24/10/2015	23/10/2015	ZCRI[0]	9	10	12
SG01B1:	**Submittal for Panel Boards schedule**	**21**	**08/10/2015**	**31/10/2015**				
G01B13(	Submittal for Panel Boards schedule	21	08/10/2015	31/10/2015				
: Design	Defective Design	0	02/11/2015	31/10/2015	ZCRI[195,384]	185	216	247
SG01B1	**Submittal for composite drwgs for ...**	**21**	**08/10/2015**	**31/10/2015**				
G01B14(	Submittal for composite drwgs for M...	21	08/10/2015	31/10/2015				
: Design	Defective Design	0	02/11/2015	31/10/2015	ZCRI[19,775]	185	216	247
SG01B1	**Submittal for Pavement marking to ...**	**21**	**02/11/2015**	**25/11/2015**				
G01B15(	Submittal for Pavement marking to tr...	21	02/11/2015	25/11/2015				
: Design	Defective Design	0	26/11/2015	25/11/2015	ZCRI[0]	9	10	12
SG01B1(	**Submittal for Curbstones & sidewal...**	**21**	**26/11/2015**	**19/12/2015**				
G01B16(	Submittal for Curbstones & sidewalk...	21	26/11/2015	19/12/2015				
: Design	Defective Design	0	21/12/2015	19/12/2015	ZCRI[0]	3	3	4
AG01B1	**Material approval for Waterproofing**	**21**	**28/09/2015**	**21/10/2015**				
G01B14(	Material approval for Waterproofing	21	28/09/2015	21/10/2015				
: Design	Defective Design	0	22/10/2015	21/10/2015	ZCRI[0]	18	21	24
AG01B1	**Material approval for Strends of pos...**	**21**	**09/10/2015**	**02/11/2015**				
G01B15(	Material approval for Strends of post ...	21	09/10/2015	02/11/2015				
: Design	Defective Design	0	03/11/2015	02/11/2015	ZCRI[0]	12	14	16

Figure 74: Full Gantt Chart of the Optimized Case Study (18)



ID	Description	Remaining Duration	Start	Finish	Resources	Minimum Duration	Most Likely	Maximum Duration
AG01B1(	Material approval for Expansion Jo...	21	03/11/2015	26/11/2015				
G01B16(	Material approval for Expansion Joints	21	03/11/2015	26/11/2015				
: Design	Defective Design	0	27/11/2015	26/11/2015	ZCRI[0]	12	14	16
AG01B1	Material approval for Curbs & Pave...	21	27/11/2015	21/12/2015				
G01B17(	Material approval for Curbs & Pave...	21	27/11/2015	21/12/2015				
: Design	Defective Design	0	22/12/2015	21/12/2015	ZCRI[0]	9	10	12
AG01B1	Material approval for Alm Handrails	21	22/12/2015	16/01/2016				
G01B18(	Material approval for Alm Handrails	21	22/12/2015	16/01/2016				
: Design	Defective Design	0	18/01/2016	16/01/2016	ZCRI[0]	12	14	16
AG05B1	Material approval for Concrete mix ...	21	18/08/2015	10/09/2015				
G05B11(	Material approval for Concrete mix d...	21	18/08/2015	10/09/2015				
: Design	Defective Design	0	11/09/2015	10/09/2015	ZCRI[195,384]	185	216	247
AG05B1	Material approval-Bridge Bearings ...	30	13/08/2015	16/09/2015				
G05B13(	Material approval-Bridge Bearings & ...	30	13/08/2015	16/09/2015				
: Design	Defective Design	0	17/09/2015	16/09/2015	ZCRI[19,775]	185	216	247
AG06B1	Material approval- Highway signing	21	17/09/2015	14/10/2015				
G06B11(	Material approval- Highway signing	21	17/09/2015	14/10/2015				
: Design	Defective Design	0	15/10/2015	14/10/2015	ZCRI[0]	3	3	4
AG10B1	Material approval- Lighting Poles	21	17/09/2015	14/10/2015				
G10B12(	Material approval- Lighting Poles	21	17/09/2015	14/10/2015				
: Design	Defective Design	0	15/10/2015	14/10/2015	ZCRI[0]	6	7	8
AG10B1	Material approval- Traffic signals	21	17/09/2015	14/10/2015				
G10B13(	Material approval- Traffic signals	21	17/09/2015	14/10/2015				
: Design	Defective Design	0	15/10/2015	14/10/2015	ZCRI[0]	9	10	12
SG01B1	Material submittals for Waterproofing	21	31/08/2015	26/09/2015				
G01B14(	Material submittals for Waterproofing	21	31/08/2015	26/09/2015				
: Design	Defective Design	0	28/09/2015	26/09/2015	ZCRI[2,810.5]	15	17	20
SG01B1	Material submittals for Strends of p...	21	11/09/2015	08/10/2015				
G01B15(	Material submittals for Strends of po...	21	11/09/2015	08/10/2015				
: Design	Defective Design	0	09/10/2015	08/10/2015	ZCRI[16,376.829]	6	7	8
SG01B1(	Material submittals for Expansion J...	21	09/10/2015	02/11/2015				
G01B16(	Material submittals for Expansion Joi...	21	09/10/2015	02/11/2015				
: Design	Defective Design	0	03/11/2015	02/11/2015	ZCRI[13,734]	15	17	20
SG01B1	Material submittals for Curbs & Pav...	21	03/11/2015	26/11/2015				
G01B17(	Material submittals for Curbs & Pave...	21	03/11/2015	26/11/2015				
: Design	Defective Design	0	27/11/2015	26/11/2015	ZCRI[0]	15	17	20
SG01B1	Material submittals for Alm Handrail	21	27/11/2015	21/12/2015				
G01B18(	Material submittals for Alm Handrail	21	27/11/2015	21/12/2015				
: Design	Defective Design	0	22/12/2015	21/12/2015	ZCRI[10,231.2]	9	10	12
SG05B1	Material submittals for Concrete mi...	25	27/07/2015	24/08/2015				
G05B11(	Material submittals for Concrete mix...	25	27/07/2015	24/08/2015				
: Design	Defective Design	0	25/08/2015	24/08/2015	ZCRI[0]	9	10	12
SG05B1	Material submittals-Bridge Bearing...	30	27/07/2015	29/08/2015				

Figure 75: Full Gantt Chart of the Optimized Case Study (19)



ID	Description	Remaining Duration	Start	Finish	Resources	Minimum Duration	Most Likely	Maximum Duration
G05B13(	Material submittals-Bridge Bearings ...	30	27/07/2015	29/08/2015				
Design	Defective Design	0	31/08/2015	29/08/2015	ZCRI[0]	6	7	8
SG06B1	Material submittals- Highway signing	21	31/08/2015	26/09/2015				
G06B11(	Material submittals- Highway signing	21	31/08/2015	26/09/2015				
Design	Defective Design	0	28/09/2015	26/09/2015	ZCRI[0]	1	1	1
SG10B1	Material submittals- Lighting Poles	21	31/08/2015	26/09/2015				
G10B12(	Material submittals- Lighting Poles	21	31/08/2015	26/09/2015				
Design	Defective Design	0	28/09/2015	26/09/2015	ZCRI[0]	6	7	8
SG10B1	Material submittals- Traffic signals	21	31/08/2015	26/09/2015				
G10B13(	Material submittals- Traffic signals	21	31/08/2015	26/09/2015				
Design	Defective Design	0	28/09/2015	26/09/2015	ZCRI[1,354.5]	6	7	8
GENERAL	Mobilization & General Requirements	366	27/07/2015	26/07/2016				
OFF010	Official start date of the project	0	27/07/2015					
OFF020	Mobilization & Site installation	15	27/07/2015	12/08/2015				
FF020: I	Mobilization & Site installation	15	27/07/2015	12/08/2015				
Design - I	Defective Design	0	13/08/2015	12/08/2015	ZCRI[0]	12	14	16
nditions	Unforeseen Site Conditions	0	13/08/2015	12/08/2015	ZCRI[0]	0	1	1
OFF025	Mobilization and temporary works run...	309	27/07/2015	26/07/2016	B01A[1]			
OFF035	Provisional sum for day works	309	27/07/2015	26/07/2016	B01B[1]			
OFF050	Handing Over and close out includi...	15	04/07/2016	20/07/2016				
FF050: I	Handing Over and close out includin...	15	04/07/2016	20/07/2016				
Design - I	Defective Design	0	21/07/2016	20/07/2016	ZCRI[0]	12	14	16
nditions	Unforeseen Site Conditions	0	21/07/2016	20/07/2016	ZCRI[2,810.5]	0	1	1
OFF060	Demobilization	5	21/07/2016	26/07/2016				
municat	Communication Barriers	0	27/07/2016	26/07/2016	ZCRI[2,272,110]	146	183	220
FF060: I	Demobilization	5	21/07/2016	26/07/2016				
Design - I	Defective Design	0	27/07/2016	26/07/2016	ZCRI[0]	12	14	16
nditions	Unforeseen Site Conditions	0	27/07/2016	26/07/2016	ZCRI[13,734]	0	1	1
OFF090	The Project Overall Completion Date	0		26/07/2016				
T OF LON	Procurement of Long Lead items	215	17/09/2015	18/04/2016				
R01B10	All Material Procurements	171	17/09/2015	08/04/2016				
R05B13	Procurement Of Bridge Bearings & E...	120	17/09/2015	09/02/2016				
R06B11	Procurement of Highway signing	120	15/10/2015	04/03/2016				
R10B12	Procurement of Lighting fixtures	140	07/11/2015	18/04/2016				
R10B13	Procurement of Traffic signals	150	15/10/2015	08/04/2016				
ARY DUR	Summary Durations	342	27/07/2015	02/07/2016				
G02B10(	Summary Duration for Earthworks	190	21/08/2015	04/04/2016	B02-1[0]			
G03B10(	Summary Duration for Base Courses	84	12/02/2016	19/05/2016	B03-1[0]			
G04B10(	Summary Duration for Bituminous Co...	78	22/03/2016	20/06/2016	B04-1[0]			
G05B10(	Summary Duration for R. Concrete St...	94	28/01/2016	16/05/2016	;B05.18[0];B05.19[0];B(			
G06B10(	Summary Duration for Incidental Con...	107	01/03/2016	02/07/2016	B06.11[0];B06.12[0];B0(			
G07B10(	Summary Duration for Street Lighting ...	39	19/04/2016	02/06/2016	07.28-12(2)[6];B07.17[1			
G10B10(	Summary Duration for Environmental ...	47	26/10/2015	18/12/2015	.01[0];B10.05[0];B10.05			

Figure 76: Full Gantt Chart of the Optimized Case Study (20)

ID	Description	Remaining Duration	Start	Finish	Resources	Minimum Duration	Most Likely	Maximum Duration
ESTING	Phase of Final Testing & Commissi...	41	10/06/2016	20/07/2016				
FG10B0(	Testing and Commissioning For Ele...	25	20/06/2016	18/07/2016				

Figure 77: Full Gantt Chart of the Optimized Case Study (21)