FMEA-BASED METHODOLOGY FOR DELAY ANALYSIS OF CONSTRUCTION PROJECTS

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ABSTRACT

FMEA-BASED METHODOLOGY FOR DELAY ANALYSIS OF CONSTRUCTION PROJECTS

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Delay is prevalent in construction projects. Projects can hardly be completed on estimated targets due to emergent risk factors. Decision-makers need a delay analysis method to estimate construction duration accurately, considering the occurrence of several risk events. Due to the non-existence of historical databases about previous projects and the one-off nature of construction projects; the expertise of project managers is a valuable source of knowledge for delay analysis. In this study, the objective is to develop a delay analysis method that depends on the utilization of subjective judgment to estimate the main causes of delay and assess their impacts on project duration using failure mode and effects analysis (FMEA). Twenty – nine (29) different delay risk factors were determined through the literature survey, and they were classified into ten (10) distinctive levels. The risk priority number of schedule delay factors was quantified by the FMEA method and the ranking of the factors was demonstrated considering their importance on schedule delay. Three alternative methods were proposed to estimate corresponding durations of delay risk factors and to cross-check the effects of the proposed methodology. Then, the proposed methodology was applied to a demonstrative case study by using

Primavera P6 Software. The estimated duration of schedule delay was calculated after the specified inputs were inserted into the software. In the light of the demonstrative case study results, the critical delay risk factors were discussed. There were three different results from three different alternative methods in methodology, and it was observed that results were approximate to each other. Although the proposed methodology was developed based on subjective judgment, the outputs were found to be conceivably satisfactory for the aim of the thesis.

Keywords: Construction Projects, Delay Analysis, Delay Risks, Failure Mode and Effect Analysis, FMEA, Risk Factors

ÖZ

İNŞAAT PROJELERİNDE GECİKME ANALİZİ İÇİN HTEA-TABANLI BİR YÖNTEM

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Gecikme, inşaat projelerinde çok yaygın karşılaşılan bir durumdur. Projeler, ortaya çıkan risk faktörleri nedeniyle tahmini hedeflerinde nadiren gerçekleştirilebilir. Karar vericiler, çeşitli risk faktörlerinin gerçekleşmesini göz önünde bulundurarak inşaat süresini doğru bir şekilde tahmin etmek için bir gecikme analizi yöntemine ihtiyaç duyarlar. Önceki projeler hakkında tarihi verinin bulunmaması ve inşaat projelerinin kendine özgü özelliklerinin olması nedeniyle, proje yöneticilerinin deneyimi gecikme analizi için değerli bir bilgi kaynağıdır. Bu çalışmada amaç, hata türü ve etkileri analizini (HTEA) kullanarak, gecikme kaynaklarını tahmin etmek ve öznel yargı kullanımına dayalı bir gecikme analizi yöntemi geliştirmektir. Literatür taramasında belirlenen yirmi dokuz (29) gecikme risk faktörü, on (10) farklı seviyede sınıflandırılmıştır. Gecikme faktörlerinin risk öncelik sayısı, HTEA yöntemi ile hesaplanmış ve bu faktörler göreceli önem düzeyleri dikkate alınarak sıralanmıştır. Gecikme risk faktörlerine karşılık gelen süreleri tahmin etmek ve önerilen metodolojinin etkilerini çapraz kontrol etmek için üç alternatif senaryo önerilmiştir. Daha sonra, önerilen metot, Primavera P6 programı kullanılarak örnek vaka çalışmasında uygulanmıştır. Girdiler programa entegre edilerek projenin tahmini

gecikme süresi hesaplanmıştır. Örnek vaka incelemesi sonuçlarına göre, süresel gecikmelere neden olan en kritik faktörler tartışılmıştır. Metodolojide yer alan üç farklı senaryonun, üç farklı sonucu bulunmakta olup; sonuçların birbirine yakın olduğu gözlemlenmiştir. Önerilen metodoloji öznel yargılara dayanarak geliştirilmiş olmasına rağmen, sonuçlar tezin amacına göre makul seviyede yeterli bulunmuştur.

Anahtar Kelimeler: İnşaat Projeleri, Gecikme Analizi, Gecikme Riskleri, Hata Türü ve Etkileri Analizi, HTEA, Risk Faktörleri

To my beloved and open-hearted family..

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LIST OF ABBREVIATIONS

ABBREVIATIONS	
AHP	Analytical Hierarchical Process
ANP	Analytic Network Process
COPRAS	Complex Proportional Assessment
D	Detection
DEMATEL	Decision Making Trial and Evaluation Laboratory
EOT	Extension of Time
ER	Evidence Reasoning
FMEA	Failure Mode and Effect Analysis
LPS	Last Planner System
MCDM	Multi-Criteria Decision Making Methods
MOORA	Multi-Objective Optimization Method by Ratio Analysis
PMBOK	Project Management Body of Knowledge
PMI	Project Management Institute
RBS	Risk Breakdown Structure
RII	Relative Importance Index
RM	Risk Management
RPN	Risk Priority Number
S	Severity
SVRP	Surface Vehicle Recommended Practice

O	Occurrence
TOPSIS	Technique for Order Preference by Similarity to Ideal Solutions
VAR	Value at Risk
WBS	Work Breakdown Structure

CHAPTER 1

INTRODUCTION

This chapter is related to the general idea about *delays in construction projects* and the definition of the problem statement, aim and objective, scope of the thesis subject including methodology, and organization of the thesis.

1.1 Introduction to Delays in Construction Projects

Delay in construction projects is seen as one of the most common problems that have adverse effects on construction projects and different parties of projects. Bramble and Callahan (1987) have defined delay as "the time during which some part of the construction project has been extended or not performed due to an unanticipated circumstance."

Assaf and Al-Hejji (2006) stated that delays in construction projects have effects on different parties. For the owner, it means loss of revenue due to a lack of facilities. Also, it means high overhead costs for the contractor due to an increase in labor and material costs and a longer working period.

Completion of projects within the specified time is an indicator of efficiency. However, as Assaf and Al-Hejji (2006) stated that there are unpredictable factors such as the performance of different parties, availability of resources, contract-related factors, environmental factors, the inclusion of different parties, and others. Due to these factors, construction projects are seldom completed within the specified time.

Alnuaimi and Al Mohsin (2013) stated that the effect of delay as a phenomenon could be a negative factor for all construction plans if it is not appropriately tackled. Thus, there should be additional thoughts to develop solutions to minimize/ remove possible problems.

As stated above, delay analysis becomes one of the important milestones not to rush up problems in construction projects. Therefore, the analysis of delays is the most proper way to minimize/solve related issues in construction projects.

1.2 Problem Statement

A construction project is usually accepted as successful if it is completed on time, within budget, and in compliance with the specifications (Frimpong et al. 2003). Nevertheless, the construction industry does not fully succeed at overcoming delays. Delays generally are ignored or thought of as a contingency by simple calculations. As a result, most of the projects fail due to significant delays in deadlines.

The delay means that projects cannot be completed within a specified time agreed upon in project contracts. Projects have different stakeholders, and delays have knock-on-effect on different parties. Because of the challenging structure of the construction sector, proper delay analysis is one of the essential issues for projects. Once the stability of the ongoing project is destroyed, the delay becomes hardly controllable.

Therefore, there must be a comprehensive approach to analyze delays to meet all needs and problems resulting from the delay. The identification, quantification, and analysis of delays are essential for executing projects properly. Moreover, if there is enough knowledge to cope with delays in projects, it provides users to prevent such cases before they happen.

As a result, there is a requirement to develop a method to analyze delays as a support point for decision-makers. FMEA method is preferred because it is a simple method that identifies risk factors, and it is applicable to construction projects in practice.

1.3 Aim and Scope of the Study

This research's main objective is to develop an effective delay analysis method that can be used to predict delays and mitigate risk factors to prevent the delay. For this purpose, the following steps are taken:

- Identify the critical delay risk factors in the construction sector
- Form a taxonomy of risk factors on different levels
- Quantify the risk priority numbers (RPN) of each delay factors and levels
- Select critical delay factors to analyze the effects on the project schedule
- Propose a delay analysis method to insert risk factors into the project schedule
- Insert risk factors into the schedule by using the related software
- Apply the proposed methodology in a demonstrative case study
- Make recommendations to minimize the possibility of delay risk factors in projects

No approach reflects the direct impacts of risk factors at the exact point on the project schedule in the existing literature. This study focuses on implementing one of the hazard risk assessment methods, FMEA, to a new area, which is delay analysis. It is hypothesized that FMEA can provide a useful and practical method to understand, analyze, and manage delays.

1.4 Organization of the Thesis

This thesis comprises six (6) chapters.

- A literature review will be presented in Chapter 2, considering the general idea of risk management, history, and detailed explanation of FMEA and the causes of delay risk factors in construction projects.
- The proposed methodology will be presented in Chapter 3.
- The proposed methodology will be applied to a demonstrative case study in Chapter 4.
- The findings of the demonstrative case study and overview of the thesis will be presented in Chapter 5.
- Conclusions of the study, limitations of the method, and recommendations for future studies will be mentioned in Chapter 6.

CHAPTER 2

LITERATURE REVIEW

The literature review process is carried out in three stages. The first stage is a literature review on risk, risk management, and construction risk management to describe the concept of "risk." The second stage is a construction delay analysis to examine delays that are more critical and frequent in construction projects. The third stage is a literature review on failure mode and effect analysis (FMEA), which is one of the risk identification methods.

2.1 A General View on Risk and Its Management

2.1.1 Risk Definition

There are several definitions in the literature. Jaafari (2001) stated that the term "risk" equals "the exposure to loss/gain." Also, Kartam and Kartam (2001) defined the risk as "the construction process whose variation culminates in the uncertainty of duration, cost, and quality in the project."

Risk is complex as much as the complexity of the project itself. The majority of the construction projects involve risk, which makes the projects worth pursuing (Chapman, C. and Ward, S. 2003). Darnall and Preston (2010) stated that risk means the possibility of losses in projects. However, the risk may become treat/ opportunity according to situations in projects. Webb (2003) also specified that risk could affect the projects either positively or negatively. The risk could be managed effectively if the organization has enough knowledge about its actual risk.

Winch (2002) defined the risk as a stage where there is not enough information. However, if knowledge from past experiences is used, the "risk" becomes more

predictable. Cooper et al. (2005) pointed out that risk is one of the outcomes of uncertainty. Also, Smith et al. (2006) stated that this situation equals the risk if there is some information. Otherwise, a lack of information means uncertainty. Similarly, Cleden (2009) remarked that the risk as a state in which problems may arise due to a lack of knowledge.

2.1.2 Risk Management

Before covering the proposed methodology and its implementation process, it is useful to clarify what "risk management" is in terminology.

If there are risks, it is expected to be managed adequately with taking necessary actions systematically, or intuitionally—risk derives from uncertainty, which is the situation that limits knowledge about the future.

At the earliest time of the companies, risk management is not considered worthy. Baker et al. (1999) stated that the first place that the risk management explored was related to people who are called Asipu that lived in the Tigris River and Euphrates River throughout 3200 BC. These people were known as consultants. They applied a procedure that is highly parallel to the ones proposed in recent risk management guidelines. This procedure started with identifying critical points of problems, advising alternative actions, and collecting data that reflects the possible results. Then, the most suitable actions were chosen to report to the client.

The risk resembles daily life. It is directly related to personal conditions, society, and business. As Hillson (2006) stated, the concept of "risk management" is used to identify, understand, and control risk in all attempts almost in every segment of the business. Therefore, humanity abidingly tries to find a way to cope with risk and manage appropriately. It means that not only is the risk encountered everywhere is significant, but also the risk management concept is.

Kenett and Raanan (2010) stated that risk is always available, and since the civilizations began, it has been thought and controlled. Baker et al. (1999) explained

that with proper risk management, the estimated project cost would be minimized, and profit would be maximized.

In the flow of this chapter, the suggested risk management practices will be investigated in detail to clarify the steps of risk management processes.

Risk management processes are planning, identification, analysis, responses, monitoring, and controlling. There will be more chances to increase the probability of positive events on projects applying proper risk management to projects, rather than negative ones.

In PMI's the PMBOK (2000), processes of risk management in projects defined as:

- Risk Management Planning: It is deciding how to approach and plan the risk management activities for a project.
- Risk Identification: It is determining which risks might affect the project and documenting their characteristics.
- Qualitative Risk Analysis: It is prioritizing risks to see effects on projects.
- Quantitative Risk Analysis: It is analyzing the probability of risk and consequences, also predicting implementations for projects.
- Risk Response Planning: It is developing methods to create opportunities and mitigate possible threats available in projects.
- Risk Monitoring and Control: It is monitoring existing risks, identifying possible new risks, and applying risk mitigation plans, and evaluating the effectiveness of plans throughout the project cycle.

There are project management knowledge areas in Project Management Body of Knowledge (PMBOK). As stated in Table 2.1, according to the 6th Edition of the PMBOK (2017), ten project management areas (scope, integration, cost, quality, human resource, communications, risk, time, procurement, and stakeholders) are identified, and risk management is one of them.

Table 2.1 Knowledge Areas of Project Management Process (6th Edition of the PMBOK, 2017)

Knowledge Areas	Project Management Process Groups				
	Initiating Process Group	Planning Process Group	Executing Process Group	Monitoring and Controlling Process Group	Closing Process Group
4. Project Integration Management	4.1 Develop Project Charter	4.2 Develop Project Management Plan	4.3 Direct and Manage Project Work 4.4 Manage Project Knowledge	4.5 Monitor and Control Project Work 4.6 Perform Integrated Change Control	4.7 Close Project or Phase
5. Project Scope Management		5.1 Plan Scope Management 5.2 Collect Requirements 5.3 Define Scope 5.4 Create WBS		5.5 Validate Scope 5.6 Control Scope	
6. Project Schedule Management		6.1 Plan Schedule Management 6.2 Define Activities 6.3 Sequence Activities 6.4 Estimate Activity Durations 6.5 Develop Schedule		6.6 Control Schedule	
7. Project Cost Management		7.1 Plan Cost Management 7.2 Estimate Costs 7.3 Determine Budget		7.4 Control Costs	
8. Project Quality Management		8.1 Plan Quality Management	8.2 Manage Quality	8.3 Control Quality	
9. Project Resource Management		9.1 Plan Resource Management 9.2 Estimate Activity Resources	9.3 Acquire Resources 9.4 Develop Team 9.5 Manage Team	9.6 Control Resources	
10. Project Communications Management		10.1 Plan Communications Management	10.2 Manage Communications	10.3 Monitor Communications	
11. Project Risk Management		11.1 Plan Risk Management 11.2 Identify Risks 11.3 Perform Qualitative Risk Analysis 11.4 Perform Quantitative Risk Analysis 11.5 Plan Risk Responses	11.6 Implement Risk Responses	11.7 Monitor Risks	
12. Project Procurement Management		12.1 Plan Procurement Management	12.2 Conduct Procurements	12.3 Control Procurements	
13. Project Stakeholder Management	13.1 Identify Stakeholders	13.2 Plan Stakeholder Engagement	13.3 Manage Stakeholder Engagement	13.4 Monitor Stakeholder Engagement	

Similarly, Asadi (2015) worked on risk management processes and elaborated on the risk management process flow, as in Figure 2.1.

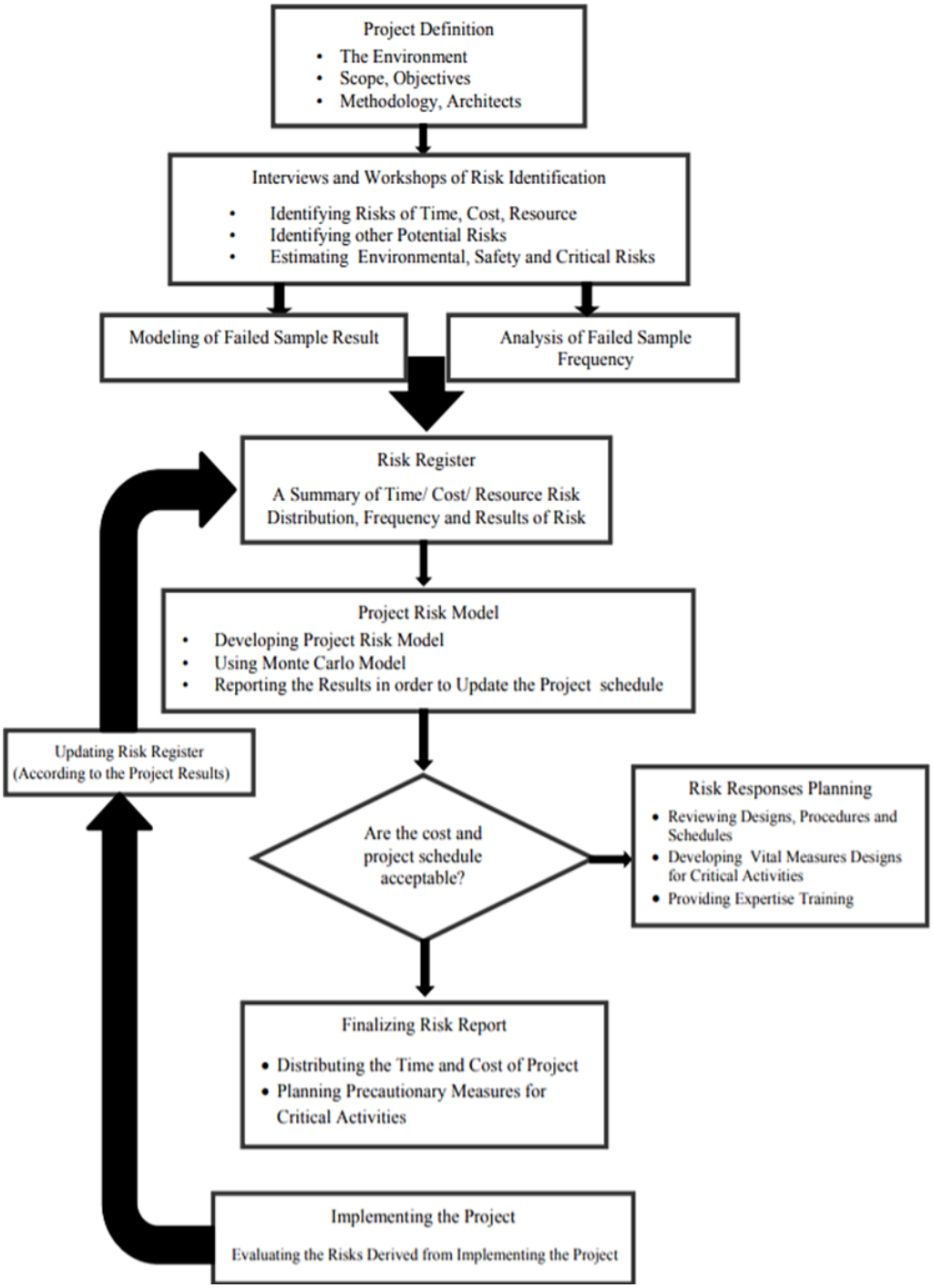

Figure 2.1 Example Risk Management Process (Asadi 2015)

2.1.2.1 Risk Identification

The prementioned steps of the risk management process are detailed in the following parts.

The methodology, roles, and responsibilities shall be established and agreed on at the start of the project. Steyn (2018) described the initiation output as the desired outcome of the risk management planning, which should, as a minimum, include management commitment, defined roles, clear risk statements, pre-determined risk categories, a custom risk matrix, and a risk register.

Once the risks have been identified, the focus shall move to their associated causes and effects. Potential sources of risk related to the project shall be identified by using various recommended techniques, the inclusion of brainstorming, expert consultation, assumptions analysis, and review of lessons learned from other previous projects. Ahmed et al. (2007) listed non-specific techniques for risk identification, such as:

- A checklist is a trivial risk identification technique based on experience,
- An influence diagram is a graphical flowchart of decisions and their consequences, and examples are cause-and-effect diagram (also known as fishbone diagram), fault trees and event trees, and
- Failure Mode and Effect Analysis (FMEA) is a procedure that enables the determination of causes, effects, and relationships through exploration of the failure mode.

Steyn (2018) indicated that the identification and documentation of project risks should take place throughout the project cycle. Once identified the risks, the author recommends documenting risks in a risk register, containing the preliminary lists of opportunities and risks. They should be improved in the risk assessment process—additionally, the risk owners and the risk responses must be added at later risk management stages.

2.1.2.2 Risk Analysis

According to PMI's PMBOK (2017), risk assessment through qualitatively and quantitatively risk analysis shall be conducted to assess the probability, impact, and severity of the relevant risks. The demonstration of the risk assessment matrix is presented in Table 2.2. It enables users to identify and focus on those risks that have the highest severity. Qualitative Risk Analysis evaluates the impact and the probabilities of the identified risks, assigning an index to the risk. On the other hand, Quantitative Risk Analysis is the process that is a numerical analysis of the combined effect of both individual project risks and other sources of risks on overall project objectives.

Table 2.2 Risk Assessment Matrix (taken from http://www.advanceddivingsystems.com/RiskAssessment.aspx)

RISK ASSESSMENT MATRIX				
SEVERITY / PROBABILITY	Catastrophic (1)	Critical (2)	Marginal (3)	Negligible (4)
Frequent (A)	High	High	Serious	Medium
Probable (B)	High	High	Serious	Medium
Occasional (C)	High	Serious	Medium	Low
Remote (D)	Serious	Medium	Medium	Low
Improbable (E)	Medium	Medium	Medium	Low
Eliminated (F)	Eliminated			

There are several techniques to assess risk factors. Ahmed et al. (2007) proposed the following techniques to determine the influence of risk factors on the project.

- Probability and impact grids represent risks on a grid that comprises the probability and impact axis to show the relative importance of risk events.

- Estimation of system reliability is the technique employed to assess the cumulative effects of combined risks.
- Fault tree analysis is used for a lower-level assessment of risks.
- Sensitivity analysis is a what-if type of analysis that enables the assessment of different scenarios.

Ahmed (2014) suggested the following risk assessment techniques: decision tree analysis, portfolio management, and multiple criteria decision-making (MCDM) methods. Ahmed et al. (2007) also stated that in risk evaluation, different aspects of the project, comprising strategy, budget, and schedule, may be considered in light of a risk event to determine the most suitable risk mitigation plan.

2.1.2.3 Risk Response

The risk response plan shall focus on maximizing the opportunities and minimizing the threats while ensuring a transparent and tailored communication of the responses, roles, and responsibilities of the implementation team. Asadi (2015) determined which risks need responses and their respective priorities, and secondly, ensure the stakeholders are aware and committed to their responsibilities on the risk response. The planning process shall determine the list of priority risks, establish a contingency plan with actionable responses to the priority risks, and assess the residual risks.

The risk responses, usually based on the risk being either a threat or an opportunity, are detailed below:

According to 5th Edition of PMBOK (2013), harmful risks/ threats can be managed by either:

- *Avoid* – is a risk response strategy that eliminates the impacts of the adverse risks from the project. This strategy usually contains changes in the project management plan to sift threats thoroughly. Also, risk impact can be eliminated by a project manager with an extending project schedule or changing the response strategy. The most extreme avoidance strategy is to

close down the project. On the other hand, some threats can be easily coped within the early stages of the project by clarifying deficiencies in the project, acquiring necessary information, obtaining expertise, and having good communication.

- *Transfer* – is a risk response strategy where the impact of threats is mitigated by shifting to a third party with ownership of the response. In this strategy, there is another party responsible for the management of threats. There is no elimination of adverse risks/ threats. Transferring does not stand for denying the risk by shifting it to other parties or next projects without any agreement. Risk transference usually contains payment of premium to another party. This strategy equals to transferring liabilities for adverse risks/ threats considering the exposure amount of risk. Tools for transferring can be varied and include insurance and guarantees. Sometimes, in contracts, transfer liabilities are assigned to designated risks. Generally, risks are transferred to the buyer in cost-plus contracts. On the other hand, risks are transferred to the seller in fixed-price contracts.
- *Mitigate* - is a response strategy where project teams take action to decrease occurrence probability or effects of risks. It is crucial to hold this probability/ effect of risk within the desirable threshold limits. Taking early actions to mitigate the probability of occurrence/ impacts of risk is usually more effective than repairing the available damages by decreasing the complexity of projects and conducting comprehensive tests.
- *Accept* - is a risk response strategy that risk is accepted, and if the risk does not occur, there is no action to prevent before the occurrence of the risk. In this strategy, a change in the project management plan is not preferred by project teams.

According to 5th Edition of the PMBOK (2013), positive risks/ opportunities can be managed by either:

- *Exploit* – If the company wants to ensure that positive risk is realized, this strategy could be selected. This strategy aims to discard the uncertainty of upside risk by assuring the positive risk happens.
- *Enhance* – This strategy is used to enhance the probability and effects of a positive risk/opportunity. By determining and maximizing key factors of positive risks, such as adding more resources to the projects, the probability of occurrence may be increased.
- *Share* – This strategy contains allocating parts/all of the ownership of the positive risk to share the benefit of the project with third parties. Examples of share strategy are or joint ventures or special-purpose companies.
- *Accept* – This is being eager to use the opportunity if it occurs, but not follow up actively.

2.1.2.4 Risk Review

Risk review contains implementing the risk responses, monitoring the residual risks, the correct execution of the contingency plan, updating the risk, and contingency plan as the project or circumstances change.

Asaid (2015) pointed out that one of the most critical problems projects face is a lack of communication, which is vital in risk management. An active and effective communication strategy should be implemented to ensure communication among project team members and stakeholders.

As mentioned throughout the Risk Management sections, the correct definition of risks, assessment, monitoring, and controlling the risk is vital for projects. The main objective of this study is to develop a methodology for delay risk assessment of construction projects through a detailed taxonomy and an analysis/ implementation of the proposed method. Spelling out of risk management is considered as an essential step for this study to clear understanding. Thus, in the next step, the history of risk management and its applications in the construction sectors will be explained.

2.1.3 Risk Management in the Construction Sector

Risk management in the construction industry has been characterized as weak, insufficient, nebulous, backward, and slow to react to changing conditions. Clough and Sears (1994) stated that the construction industry is at or near the top in the annual rate of business failures and resulting liabilities in the overall picture.

As Nigel et al. (2009) said that change is connatural for the construction sector. For many years, the sector has a poor reputation for overcoming adverse results of change. In many projects, these results lead to failure in meeting completion time, cost, and quality goals of projects. It is not an unexpected situation because there is no perfection in projects for design, workers, or any other things that inhere in construction projects. Due to changes that cannot be entirely shifted, additional implementations must be implemented to decrease the effects of changes. By applying the principle of proper risk management, the flow of construction projects (pre-construction phases, design, engineers, and other works) can be advanced to mitigate the adverse effects of changes.

Ropel (2011) stated that risk management becomes more critical due to the character of the construction sector. If a high level of uncertainty is available in projects, the risk management concept is widely used. The pre-mentioned steps of the risk management process characterize risks in these projects. The simplest way to identify risk is by analyzing and drawing outcomes of projects that failed in history.

If there is a proper risk management process for projects, it improves the productivity of projects. According to Chapman (1997) and Jayasudha BVidivelli and Gokul Surjith (2014), some of the advantages of risk management process in projects are:

- Economic efficiency
- Minimizing capital cost
- Gaining successful contracts rather than harmful contracts
- Ability to detect and mitigate risks/ uncertainties in projects
- Increasing profit of projects

- Improving design documentation and process
- Successful completion of the project, although there are risks
- The accomplishment of project objectives

As stated above, risk management is essential for construction projects. However, as is known, the construction sector continuously suffers from a weak project management system because of an insufficient risk management system lacking a sufficient understanding of risks in projects. There are lots of studies to propose a suitable method/ technique for construction project risk management. Some of these methods are summarized.

Smith (1999) stated that qualitative risk analysis is generally seen as the most practical risk management step in construction projects.

Tah and Carr (2001) recommended a comprehensive risk management methodology for construction projects.

Del Caño and De La Cruz (2002) recommended comprehensive project risk management processes for the construction sector. These processes could be arranged for the requirements of other project participants. Besides, they stated that project risk management processes should be adapted to the specific circumstances of the projects and organizations.

Wang et al. (2004) studied at Alien Eyes' Risk Model, and it categorizes risks in the project, their relationships, and proposed a risk mitigation framework qualitatively.

Kim et al. (2005) studied at risk management technique that quickly becomes one of the useful methods based on a VaR (Value at Risk) concept to realize project objectives and improve the performance of projects considering all uncertainties that gradually increase in the construction sector.

Schieg (2006) applied a risk management process considering personal area risks in construction projects.

Ling and Hoi (2006) studied the risks faced by construction companies in Singapore during working in India and analyzed the risk response systems applied by these companies.

De Brito and Branco (2006) carried out the study, which makes the efficient use of resources to give the proper decisions for reworks and maintenance processes, which leads to a loss in time, cost, and structural failures if processes fail.

Zou et al. (2007) determined risk management steps in construction project management as identifying, analyzing, and dealing with associated risks in projects.

Tang et al. (2007) carried out an empirical survey on the construction project risks, risk management applications, the status of available systems, and obstacles to risk management systems in the Chinese industry. Results show that almost all project risks are shared concerns of participants, and they are mitigated to reduce risks.

Moreover, Dikmen et al. (2008) proposed a learning-based approach to risk management. Risk-related information was stored in memory, and based on data of previous projects, decision-makers could make more confident decisions about risk events that may happen coming projects.

Zavadskas et al. (2010) proposed a risk assessment method by applying COPRAS – G and TOPSIS grey, which are types of MCDM methods.

Wen (2010) combined artificial neural networks and rough sets to apply FMEA during the risk evaluation process of construction projects.

Fouladgar et al. (2012) presented a risk evaluation method based on Fuzzy – TOPSIS methodology for construction projects throughout the tunneling processes.

Mohammadi and Tavakolan (2013) used two methods that are Fuzzy Logic, and AHP combined with traditional Failure Mode Effect Analysis (FMEA) at the risk assessment process of construction projects.

Taylan et al. (2014) presented a hybrid methodology based on Fuzzy TOPSIS and Fuzzy AHP according to the relative importance index (RII) method to rank project risks using historical data.

Serpella et al. (2014) carried out a knowledge-based approach, considering the function of risk management and the three-fold method to evaluate and address project risks in the construction sector adequately.

Ebrat and Ghodsi (2014) determined risks in construction projects considering the stepwise regression model and neuro-fuzzy inference system for a construction project's risk evaluation process.

Iqbal et al. (2015) studied two methods that are curative (after the risk occurs) and inhibitor techniques (before the risk happens) during the execution of risk management processes in construction projects.

Otobo et al. (2016) remarked that there are various quantitative risk analysis techniques, such as influence diagrams, probabilistic analysis, decision trees, sensitivity analysis, and Monte Carlo simulation. Also, Otobo et al. (2016) stated that they became more important in the implementation step of construction projects after identifying and analyzing project risks. As a result of the analysis, liabilities of the project's parties were determined, then plans and effective mitigation methods were applied to the projects before or during the occurrence of risks.

Vafadarnikjoo et al. (2016) proposed an intuitive Fuzzy DEMATEL to prioritize risks faced in construction projects.

Yousefi et al. (2016) suggested a method that anticipates emerging time and cost issues of construction projects in Iran by applying a neural network.

Santos and Jungles (2016) examined the completion time of construction projects considering the schedule performance index and delay correlation associated with any time overrun.

Shin et al. (2016) carried out a comparative analysis to evaluate risk factors of a nuclear power plant at a construction site by using AHP and Fuzzy AHP methods.

Kao et al. (2016) proposed a balanced scorecard system based on Fuzzy ANP to evaluate mutual risk factors of construction projects in Taiwan.

Ahmadi et al. (2017) studied at potential risk events to prioritize and quantify risks using Fuzzy FMEA and AHP methods.

As understood from the literature survey, several studies are into the risk management process in the construction industry. Although there are different approaches, there is no approach reflecting the direct impacts of risk factors on the project schedule during the risk management process. Existing studies were mainly focused on ranking the root causes of construction schedule delays. Therefore, this situation supports the source of the thesis study to develop a new approach during the estimation of the direct impacts of the schedule delay risks on construction projects' schedules.

According to Smith et al. (2006), cost, time, and quality are the three main targets of construction projects. Furthermore, these project parameters are supposed to be subject to risk/ uncertainty. In such a case, realistic estimation becomes important with enough knowledge and foresight. Project managers take action on and propose methods to mitigate risk/ uncertainties in projects before these cases occur. It is essential to determine and examine the leading causes of risks because they do not randomly happen. They can be mitigated if the leading causes can be determined correctly. After that, problems can be solved and manageable during the life cycle of the project. Project managers also make sure that the residuary risks are assigned to the project parties to optimize the performance of the project. In Figure 2.2, a risk management strategy for the construction project is represented.

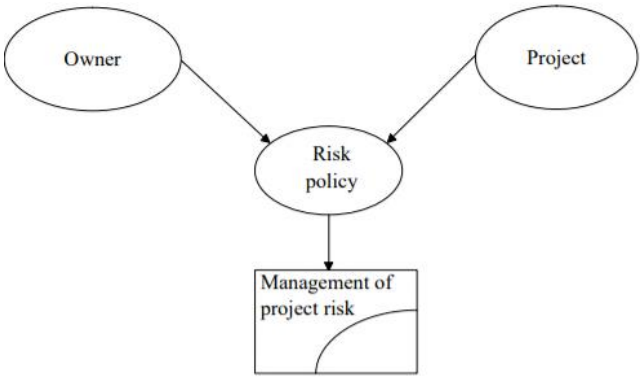

Figure 2.2 Risk Management Strategy for Construction Projects (Smith et al., 2006)

Smith et al. (2006) also stated that the client/ owner has a strategy and policy for the risk management process of the project. Primary concerns of the owner's strategy in the projects are risk ownership, financing of all risk, budget allowance, and contingency. The risk management policy of the owner contains procedures, liabilities, and reporting.

Moreover, Jia et al. (2013) represented six processes of the risk management (RM) construction projects process. In Figure 2.3, risk management processes are illustrated.

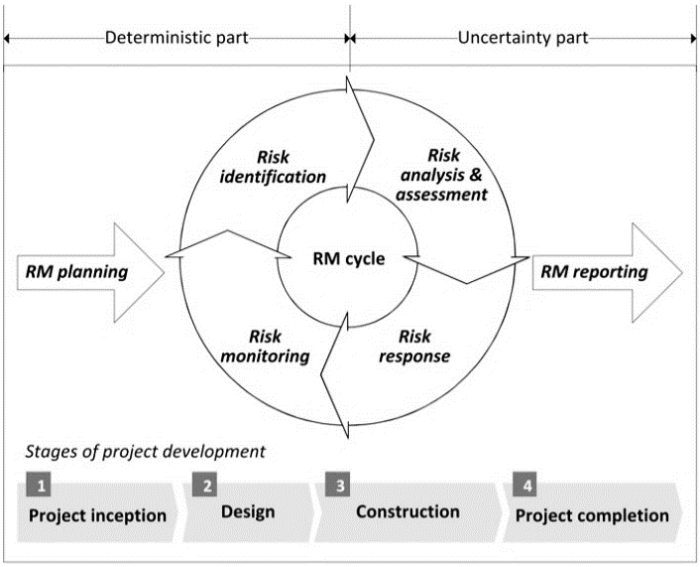

Figure 2.3 Risk Management Process (Jia et al., 2013)

Considering the RM cycle of construction projects, Sodhi and Tang (2012) clarified possible conclusions of using proper methods/ models during risk management in the construction sector:

- Comprehend the nature of adverse risks/threats to face with them better
- Promote measure of risks by informing different parties of projects (contractor, client, and consultant)
- Support management system on specific issues
- Allocate enough effort/budget to mitigate risks and to answer which party should invest in related risk

In the next section, delay analysis in the construction sector will be held.

2.2 Delays in the Construction Projects

In the construction sector, some milestones have to be achieved to complete projects successfully. Navarre and Schaan (1990) stated that the success level of the construction project is measured considering duration, cost, and performance of the project. Shenhar et al. (1997) explained that the success of construction projects depends on four primary time-dependent dimensions. The first one is the time throughout the project, which contains the time after the project completion. The second one is the time when the project is delivered to the client. The third dimension could be measured according to sales in 1 – 2 years. The final dimension could be evaluated after 3 – 5 years from the completion of projects. Lim and Mohamed (1999) mentioned that the success of projects should be discussed considering different perspectives of projects' owners, contractors, and customers both in the macro and micro views. Also, Chan and Chan (2004) proposed a framework for testing the success of construction projects, as stated in Figure 2.4.

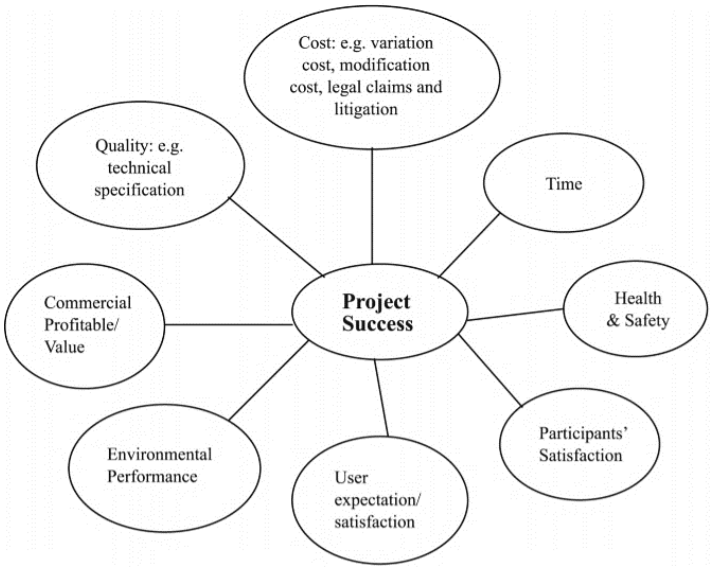

Figure 2.4 Framework for Evaluating Project Success (Chan and Chan 2004)

Also, Majid (2006) explained that a construction project is accepted as successful if it is completed within the specified time and budget, considering the satisfaction of stakeholders and compatibility of specifications.

In the concept of this study, the aim is minimizing risk factors that result from delays in a project to improve the success of construction projects.

2.2.1 Classification of the Construction Delays

Delays are originated from various factors. There are several studies to classify delays in construction projects.

Ahmed et al. (2003) classified the causes of delays as internal and external. Internal causes of delays result from contract parties such as contractors, consultants, and clients. Besides, external causes of delays occur because of the events that are beyond the control of construction parties, like the act of God.

Similarly, Tumi et al. (2009) reported two groups of delays used to detailed delay results, as shown in Figure 2.5.

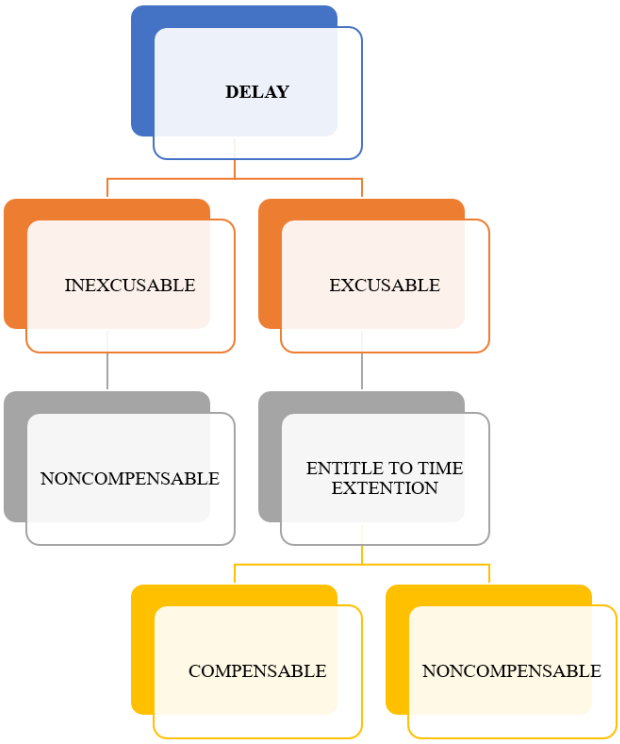

Figure 2.5 Classification of Delays (Tumi et al., 2009)

2.2.1.1 Excusable Delays

This type of delay consists of compensable delays and non-compensable delays.

- Compensable delays: Generally, owner/ owner related parties lead to these delays under different circumstances. Tumi et al. (2009) cited that the late release of design drawings is an example of compensable delays. In such cases, the contractor is exposed to additional indirect costs.
- Non-compensable delays: Beyond the owner's/contractor's control, this type of delay might happen by third parties because of unusual conditions. In these circumstances, the contractor is entitled to an extension of time (EOT) without any compensation.

2.2.1.2 Inexcusable (Non-Excusable) Delays

This type of delay occurs due to the actions/inactions of contractors. Underestimation of project complexity, improper planning/ scheduling of the project, poor management at the site, and improper construction methods are the main reasons. As a result, there is no entitlement to EOT for the contractor if there is no proof to show delay impact.

Considering these classifications, as illustrated in Figure 2.6, Ogunlana et al. (1996) stated that there are three leading causes of delays during the handling of construction projects from the contractor's point of view.

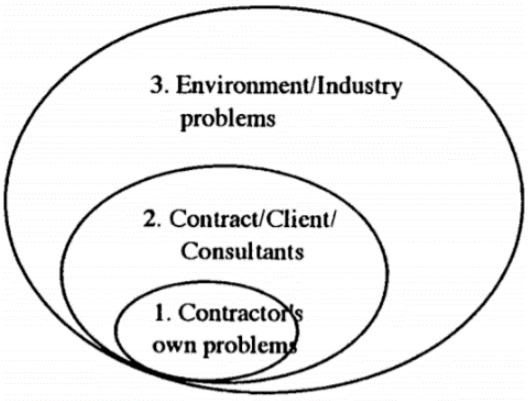

Figure 2.6 Causes of Delays (Ogunlana et al., 1996)

2.2.2 Causes of Construction Delays

First, the general framework of risks in construction projects according to the risk breakdown structure of the Fourth Edition of the PMBOK Guide is demonstrated in Figure 2.7.

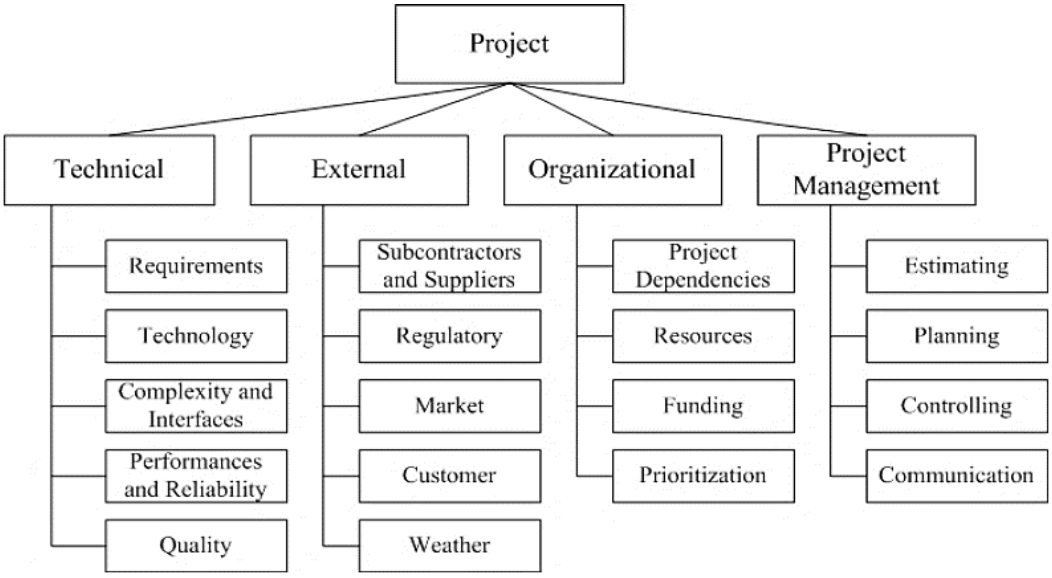

Figure 2.7 Risk Breakdown Structure (RBS)

In this study, to form taxonomy, the causes for schedule delays in construction projects are classified and adapted according to general categories in Figure 2.7.

2.2.2.1 Client – Owner Related Delay Factors

Several studies identified delay factors result from a client - owner actions in construction projects.

Ogunlana et al. (1996) identified the factors slow decision-making and changed orders by owner affected delays 41.7 % and 33.7 % of the total.

Long et al. (2004) and Shaikh et al. (2011) stated delay factors as lack of strategic management, confusing requirements, improper project feasibility study, lack of transparent bidding process, excessive change orders, unclear responsibility, lack of capable representatives, owner's financial difficulties, owner's poor contract management, slow decision making throughout the projects.

Koushki et al. (2005) studied at a sample project for analyzing delay factors in construction projects, the financial difficulties of owners were in second place (22%). Also, the lack of an owner's experience has a significant effect on delays.

Faridi and El-Sayegh (2006) and Alaghbari et al. (2007) clarified owner related delay factors as changes by the owner, inadequate project preparation and planning, slow decision-making process, lack of communication between the stakeholders of construction projects.

As a result, five (5) factors of client/ owner-related delay factors were selected as more critical using subjective judgment.

2.2.2.2 Contractor Related Delay Factors

Several studies identified delay factors result from contractor actions.

Chan and Kumaraswamy (1997) stated that lack of contractor experience in the projects, contractor's deficiencies in planning and scheduling phases of a project, lack of communication b/w contractor and other stakeholders, and delays in subcontractor's works results from contractor's actions.

Odeh and Battaineh (2002) identified the delay factors that are an inadequate experience of contractors/ subcontractors, improper planning/ techniques during the construction, improper construction methods, and site management strategies.

Long et al. (2004) identified the delay factors as improper planning/ scheduling, lack of experience, inaccurate time/cost estimation, poor project management, improper construction methods, underestimating the project complexity, financial difficulties of contractors, and inadequate experience of subcontractors or suppliers.

Assaf and Al-Hejji (2006) and Faridi and El-Sayegh (2006) classified delay risk factors as lots of reworks, financial difficulties of contractor in a project, disagreements between a contractor and other parties (sub-contractor, consultant, and owner), poor site management, poor communication and coordination with other parties, ineffective planning and scheduling of the project, implementation of improper construction method, delays in sub-contractors work and site mobilization.

Also, Alaghbari et al. (2007) determined the delay factors related to contractors as lack of contractor experience, using inappropriate methods, improper planning/ scheduling of the project, unreliable/ inadequate subcontractor, and low quality of the material.

As a result, nine (9) factors of contractor-related delay factors were selected as more critical using subjective judgment.

2.2.2.3 Consultant Related Delay Factors

Several studies have carried out consultant related factors to cause schedule delays.

Odeh and Battaineh (2002) stated that consultant related delays ranked higher than contractor related factors contrary to anticipated. One of these delay factors is poor contract management and quality controls. The other one is ineffective preparation and approval of design documents.

Long et al. (2004) determined that inadequate experience of the consultant, lack of standardization in design, abstract design drawings, lack of liabilities of consultants, improper and inadequate project management, slow response are consultant-related.

Similarly, Faridi and El-Sayegh (2006) explained that inadequate inspection, late approval of significant changes in the process, consultant's rigidity, and lack of experience stemmed from the consultant's actions.

Aziz (2013) classified the delays factors of poor management during the design process, slow response to problems and poor control/ inspection, and incomplete design drawings.

As a result, two (2) factors of consultant-related delay factors were selected as more critical using subjective judgment.

2.2.2.4 Government Related Delay Factors

Faridi and El-Sayegh (2006) identified that government-related delay factor is a delay in obtaining permits from the municipality.

2.2.2.5 Labor Related Delay Factors

Some studies designated delay factors result from labor actions in construction projects.

Odeh and Battaineh (2002) stated that as expected, labor productivity is one of the critical causes leading to projects' failure.

Faridi and El-Sayegh (2006) studied factors that lead to a delay in the construction sector. According to their study, skill, and the productivity of laborers affect every stage of construction projects.

According to Assaf and Al-Hejji (2006), personal conflicts among laborers, shortage of laborers, unskilled workforce, low productivity of laborers, and their nationalities impact the project schedule.

Furthermore, Sweis et al. (2008) specified that a shortage of workforce and the presence of unskilled labor are the main labor-related delay factors.

Similarly, Aziz (2013) emphasized that the shortage of labor and low labor productivity are causes of delay.

As a result, three (3) factors of labor-related delay factors were selected as more critical using subjective judgment.

2.2.2.6 Material Related Delay Factors

These causes of delays are crucial for construction projects. Several studies identified these delay factors in construction projects.

Abd. Majid and McCaffer (1998) and Assaf and Al-Hejji (2006) determined that the late delivery of material, insufficient planning/ controlling and communication, damages of materials, untrusty suppliers, and poor quality of materials. In addition to this, Assaf and Al-Hejji (2006) specified that the shortage of materials in the market, damages of stored material, late procurement of materials, changes in specifications, and availability of various materials in the market are critical for directing the flow of projects.

In a like manner, Aziz (2013) stated that a shortage and late delivery of construction materials at a construction site, price escalation of materials, ineffective/ low quality of materials have a significant impact on the construction projects schedule.

As a result, one (1) factor of material-related delay factors was selected as more critical using subjective judgment.

2.2.2.7 Equipment Related Delay Factors

Equipment related factor is also one of the most important causes of delays in the construction project schedule. Several studies identified such delay factors in construction projects.

Chan and Kumaraswamy (1997) expressed that incapable of equipment affects the delay in project scheduling.

Additionally, Long et al. (2004) also stated that using obsolete equipment during the project's life cycle contributes to schedule delays in projects.

Aziz (2013) designated equipment-related factors as shortages of equipment, low efficiency of equipment, inappropriate selection/ breakdown of equipment that impact schedule delays.

As a result, one (1) factor of equipment-related delay factors was selected as more critical using subjective judgment.

2.2.2.8 Design Related Delay Factors

There are several studies on identifying design - related delay factors. Chan and Kumaraswamy (1997) grouped delay risk factors in the Hong Kong construction industry. According to them, a lack of experience of design team experience, the complexity of design documents, errors, and late preparation/ approval of documents are the main reasons for the delay.

Aziz (2013) studied the causes of delays in large building projects. According to the study, stakeholders of projects agreed on the importance of delay factors that arise from the design process. As a result, design errors and design changes were seen as the most crucial delay factors.

As a result, two (2) factors of design-related delay factors were selected as more critical using subjective judgment.

2.2.2.9 Contract Related Delay Factors

There are several studies on contract-related delay factors. Assaf and Al-Hejji (2006) pointed out that the duration in the contract was not estimated correctly. Also, there can be legal disputes and a lack of communication between parties to the contract, and inadequate determination of the scope of contract type, like in turnkey contracts.

Also, Bu-Qammaz et al. (2009) determined that the vagueness of contract clauses has a remarkable effect on the project schedule.

As a result, two (2) factors of contract-related delay factors were selected as more critical using subjective judgment.

2.2.2.10 External Related Delay Factors

There are several studies on identifying delay factors that are beyond the control of project participants.

Odeh and Battaineh (2002) studied a survey on the determination of the causes of delays. External factors are classified as unforeseen weather conditions, regulatory changes, and adverse ground conditions like other studies. As a result of this survey, they remarked that external factors had the lowest ranking by stakeholders of projects than other delay factors.

Besides, Long et al. (2004) stated that unexpected ground conditions, cold weather conditions, and price fluctuations arise from external conditions.

Finally, Aziz (2013) specified the delay risk factors are unpredictable subsurface/ ground conditions, hot/cold/ rainy weather conditions, delay in obtaining permits from a municipality, deficiencies of utilities at the construction site such as electricity, accidents during the projects, changes in law/ regulations, social and cultural events.

As a result, three (3) factors of external-related delay factors were selected as more critical using subjective judgment.

2.2.2.11 Summary

After a literature review on construction delay analysis, delay factors are summarized according to subjective judgments. Delay risk factors and their references are in Table 2.3.

Table 2.3 Final Risk Factors with their References

Risk Factors	References
Changes by the owner	[6], [31]
Owner/ client lack of experience in construction projects	[52]
Slow decisions by the owner	[56]
Lack of communication and coordination	[6], [31]
Financial difficulties	[56]
Construction mistakes	[18], [65]
Improper construction methods	[12], [31]
Contractor's poor site management and supervision skills	[12], [31]
Inadequate contractor experience	[6], [56], [65]
Poor sub-contractor works	[56], [65]
Inadequate planning and scheduling	[12], [56]
Inaccurate cost estimation	[56]
Low material quality	[6]
Underestimation of project complexity	[56]
Slow response and poor inspection	[13], [56]
Deficient tender documentation	[13], [65]
Obtaining permits from municipality	[31]
Inadequate skills for manpower	[12], [31]
Poor/low labour productivity	[13], [65]
Shortage of skilled/unskilled labour	[85]
Shortage of material at site	[1], [12], [13]
Inavailability/ shortage of equipment at site	[13], [13], [56]
Delay in preparation/ approving design documents	[19]
Design changes during the project	[13]
Vagueness of contract clauses	[16]
Lack of communication between parties	[12]
Unforeseen weather, ground, and environmental condition at site	[56], [65]
Price inflation/ fluctuations	[56]
Other risks (conflict, war, country risks, force majeure vb.)	[13]

A total of twenty - nine (29) factors in ten (10) sub-levels and three (3) primary levels of schedule delay factors in construction projects were categorized. Considering final classification, taxonomy was formed to analyze delays using the FMEA method, as shown in Table 2.4.

Table 2.4 Delay Risk Taxonomy for Construction Projects (adapted from (Derakhshanfar et al. 2019)

Level 3	Level 4 (Failure)
Owner	Changes by the owner
	Owner/ client lack of experience in construction projects
	Slow decisions by the owner
	Lack of communication and coordination
	Financial difficulties
Contractor	Construction mistakes
	Improper construction methods
	Contractor's poor site management and supervision skills.
	Inadequate contractor experience
	Poor sub-contractor works
	Inadequate planning and scheduling
	Inaccurate cost estimation
	Low material quality
	Underestimation of project complexity
Consultant	Slow response and poor inspection
	Deficient tender documentation (design, bills of quantities and specification).
Government	Obtaining permits from municipality
Labour	Inadequate skills for manpower
	Poor/low labour productivity
	Shortage of skilled/unskilled labour
Material	Shortage of material at site
Equipment	Inavailability/ shortage of equipment at site
Design	Delay in preparation/ approving design documents
	Design changes during the project
Contract Related	Vagueness of contract clauses
	Lack of communication between parties
External	Unforeseen weather, ground, and environmental condition at site
	Price inflation/ fluctuations
	Other risks (conflict, war, country risks, force majeure vb.)

After the delay concept in construction projects is clarified and taxonomy is formed, failure mode and effect analysis (FMEA) and its utilization in projects will be presented in the following section.

2.3 FMEA

FMEA is a qualitatively bottom-up risk analysis technique used in quality management and risk management to identify, prioritize, and eliminate potential failures/ risks from the system, design, or process with continuous improvement.

There are different areas that FMEA was used. Arnzen (1966) stated that failure mode and effect analysis was used at Grumman in the early 1950s by the reliability sector. SVRP (1997) had researched the FMEA methodology, which first was improved and implemented in 1949 by the United States Army.

Ford Motor Company (1988) used this method for regulatory and safety issues. On the other hand, Ziegel and Tague (1995) mentioned that FMEA was performed on an ATM system of a bank to prioritize risks "machine jams" and "heavy computer network traffic," which have the highest risks.

Scipioni et al. (2002) conducted a study of the production of a wafer in a food company using FMEA methods. It was utilized as a tool to guarantee the quality of the product. Also, it was used to improve the performance of the production process. They studied at calculating the risk using the FMEA method, where risk has three components. These components were multiplied to produce a risk priority number (RPN), which is a way to prioritize failure modes.

Puente et al. (2002) stated that the FMEA technique aims to determine and prioritize deficiencies in the production process.

Furthermore, Arvanitoyannis and Varzakas (2008) conducted FMEA techniques on salmon processing risks such as receiving fish, cooling, distribution of fishes, and other risks. After the determination of risks that has high-risk priority number (RPN), necessary actions were taken.

Zammori and Gabbrielli (2012) demonstrated a risk assessment procedure using the integration of FMEA and ANP. According to the study, parameters of FMEA (S, O,

and D) were divided into sub-criteria, and an adjusted hybrid decision system was used to calculate the risk priority number (RPN).

According to Charan and Krishnamoorthi (2019), FMEA was developed as a military method in 1949, and it was entitled as Procedures for Performing a Failure Mode, Effects and Criticality Analysis. Then, the technique has gained in complexity as different industries adopted it in their planning.

As summarized above, different sectors have used FMEA during the risk analysis process for a long time because it is a simple method that identifies risk factors.

2.3.1 Utilization of FMEA for Risk Management

In this section, the utilization of FMEA for the risk management process will be elaborated.

According to Kara-Zaitri et al. (1991), FMEA answers the following questions:

- What might go wrong?
- What might be reasons?
- What impacts would it have?

Wang (2011) explained failure modes and effects analysis (FMEA) as an approach to determine, prioritize, and mitigate possible failures in the process systematically.

In this perspective, Charan and Krishnamoorthi (2019) mentioned FMEA and its three parameters: severity (S), occurrence (O), and detection (D).

- Severity (S): This parameter measures the intensity of the failure mode. Severity is on a 10-point scale.
- Occurrence (O): This parameter predicts the frequency of the failure mode. Occurrence is on a 10-point scale.

- Detection (D): This parameter considers the likelihood of failure mode. Detection is on a 10-point scale. Moreover, considering priority, 10 is the highest value for each parameter.

The equation of risk priority number is indicated below. As in stated research, RPN can take the minimum value 1, while the maximum value of RPN equals 1000.

$$\mathrm{RPN} = \mathrm{S} * \mathrm{O} * \mathrm{D}$$

(eq. 2.3.1)

Ford Motor Company (1988) described the criteria and ranking system of these three parameters. Table 2.5, Table 2.6, and Table 2.7 show severity, occurrence, and detection parameters' scale, respectively.

This process is known as traditional FMEA, and Nuchpho et al. (2014) stated that this method is seen as one of the most important methods to prevent failure modes/ errors during the occurrence.

Table 2.5 Ranking System for the Severity Parameters (Ford Motor Company, 1988)

Effect	Criteria: severity of effect	Rank
Hazardous	Failure is hazardous, and occurs without warning. It suspends operation of the system and/or involves noncompliance with government regulations	10
Serious	Failure involves hazardous outcomes and/or noncompliance with government regulations or standards	9
Extreme	Product is inoperable with loss of primary function. The system is inoperable	8
Major	Product performance is severely affected but functions. The system may not operate	7
Significant	Product performance is degraded. Comfort or convince functions may not operate	6
Moderate	Moderate effect on product performance. The product requires repair	5
Low	Small effect on product performance. The product does not require repair	4
Minor	Minor effect on product or system performance	3
Very minor	Very minor effect on product or system performance	2
None	No effect	1

Table 2.6 Ranking System for the Occurrence Parameters (Ford Motor Company, 1988)

Probability of failure	Possible failure rates	Rank
Extremely high: Failure almost inevitable	≥1 in 2	10
Very high	1 in 3	9
Repeated failures	1 in 8	8
High	1 in 20	7
Moderately high	1 in 80	6
Moderate	1 in 400	5
Relatively low	1 in 2,000	4
Low	1 in 15,000	3
Remote	1 in 150,000	2
Nearly impossible	≤1 in 1,500,000	1

Table 2.7 Ranking System for the Detection Parameters (Ford Motor Company, 1988)

Detection	Criteria: likelihood of detection by design control	Rank
Absolute uncertainty	Design control does not detect a potential cause of failure or subsequent failure mode; or there is no design control	10
Very remote	Very remote chance the design control will detect a potential cause of failure or subsequent failure mode	9
Remote	Remote chance the design control will detect a potential cause of failure or subsequent failure mode	8
Very low	Very low chance the design control will detect a potential cause of failure or subsequent failure mode	7
Low	Low chance the design control will detect a potential cause of failure or subsequent failure mode	6
Moderate	Moderate chance the design control will detect a potential cause of failure or subsequent failure mode	5
Moderately high	Moderately high chance the design control will detect a potential cause of failure or subsequent failure mode	4
High	High chance the design control will detect a potential cause of failure or subsequent failure mode	3
Very high	Very high chance the design control will detect a potential cause of failure or subsequent failure mode	2
Almost certain	Design control will almost certainly detect a potential cause of failure or subsequent failure mode	1

Moreover, Sankar and Prabhu (2001) determined the essential steps of successful FMEA process and its stages as follows:

- ✓ Identifying potential failure modes
- ✓ Estimation of severity parameter
- ✓ Listing the potential causes of failure

- ✓ Estimation of occurrence parameter
- ✓ Identifying failure detection method
- ✓ Estimation of detection parameter
- ✓ Calculation of the RPN which indicates the importance between a given failure mode and its cause
- ✓ Taking corrective action to mitigate risks considering their high RPN values

Similarly, Liu (2016) determined the general framework for conducting an FMEA, as shown in Figure 2.8.

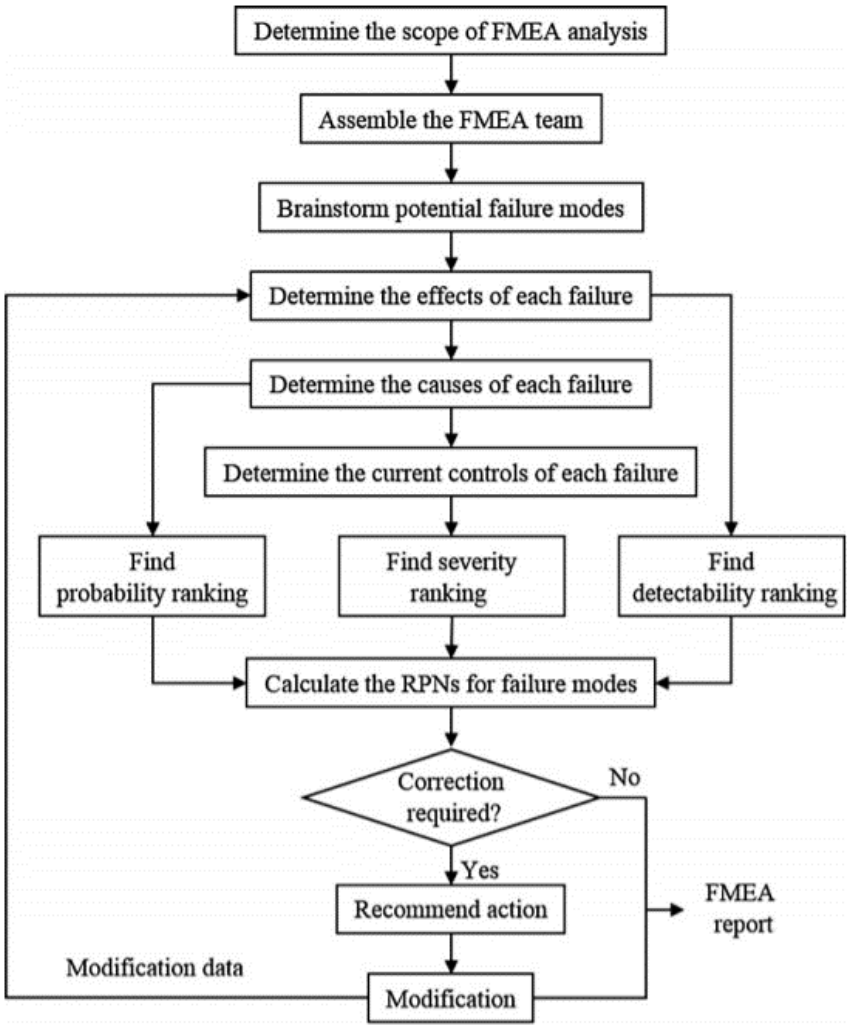

Figure 2.8 Main Steps of FMEA (Liu, 2016)

In the following section, sample applications of FMEA in the construction sector will be summarized.

2.3.2 FMEA in the Construction Risk Management

Construction risks are more likely to occur during construction and post-construction stage, where there is a lack of proper planning in the pre-construction and design stages of the project. This situation makes FMEA a potent tool as the construction industry can apply during planning and construction as well as any other stage.

Several studies show the different usage of FMEA in construction projects.

Mecca and Masera (1999) used FMEA to support quality management with appropriate measures and obtain high efficiency in the construction management process.

Also, Song et al. (2007) proposed a methodology that applies the FMEA technique to analyze the erection of structural steel works and clarify the safety of each activity. In the study, the quantitative analysis results of FMEA were compared to historical data of accidents to verify the results of the proposed methods.

Carmignani (2009) identified the FMEA technique, which is a priority-cost-based. Considering the results of RPN values, the AHP method used a new variable of profitability to determine the weights of different risk factors.

Abdelgawad and Fayek (2010) applied a combination of fuzzy logic and fuzzy analytical hierarchy process (AHP) to the FMEA technique to extend the application of FMEA in the construction industry. They mapped the relationship between impact (I), probability of occurrence (P), and detection/control (D) and the level of criticality of risk events. The results obtained confirm the capability of fuzzy FMEA and fuzzy AHP to address the limitations of traditional FMEA.

Yu and Lee (2012) developed Fuzzy-Failure Mode and Effect Analysis (Fuzzy-FMEA) to assess conflict-risk between stakeholders on highly complex urban

regeneration projects adequately, examining possible conflict risks more precisely compared with previous risk assessment models, including the traditional FMEA method.

Wehbe and Hamzeh (2013) researched reducing the workflow variability and increasing the FMEA's reliability in the construction planning stage by using it in conjunction with the Last Planner System (LPS). The use of FMEA in LPS provided an additional means of filtering critical activities and managing their associated risks.

Hsu et al. (2013) used the FMEA approach to develop a materiality analysis model to identify material-related problems. In sustainability reports, this process used ANP to determine the risk weights of each factor and RPN during ranking problems according to the needs of stakeholders.

Ahmed (2014) studied at conventional FMEA for the risk assessment process of construction projects using the integration of Markov Chain and Pairwise Comparison methods.

Also, Purwanggono and Margarette (2017) stated that FMEA a self-diagnostic technique that enabled companies to analyze and identify the key factors contributing to their problems, to minimize the risk of selecting an inappropriate course of corrective action. Notwithstanding, they were one of the first to apply FMEA through the construction of Ishikawa, also known as the fishbone diagram, to classify the leading causes of non-excusable delays and identify contributing factors.

Ahmadi et al. (2017) presented a comprehensive framework to control significant risk factors of highway projects considering three stages: determination of possible risk events, assessment/prioritization of determining risks using Fuzzy – FMEA approach, then a determination of proper response for these risks.

Mete (2019) carried out an integrated FMEA-based AHP-MOORA approach under Pythagorean Fuzzy sets to assess occupational risks and reduce the adverse effects of these risks in a natural gas pipeline construction project.

FMEA analysis has not been combined with delay analysis, so that is the missing part of the literature. During the thesis study, the traditional FMEA was used to enhance delay risk analysis in the construction projects by determining critical risk factors in the taxonomy. The process of prioritizing failure modes in the new method is more realistic, flexible, and practical than the traditional RPN calculation and different methods of its kind in the literature.

In this approach, the analysis is based on S, O, and D, the frequency of occurrence, occurrence, and detection parameters of RPN. In contrast to existing methods and their applications, especially in this method, the detection parameter gives users a chance to make a proper risk assessment. Therefore, even if some of the users' evaluations of these parameters are not the same, failure modes can be distinguished and ranked very well from each other.

2.3.3 Limitations and Benefits of FMEA

Although FMEA is a widely used method. There are some limitations. Xie (2013) stated that these limitations:

- There can be different combinations of parameters (S, O, and D), and the meaning of each risk factor is different, but they can produce the same value of RPN.
- Risks are classified as high risk, low risk, or medium risk according to an interval of RPN values, but there can be a difference in RPN values at the same interval. In other words, the 800 – 1000 RPN interval is stated as high risk, but risk factors that one of them has 800 RPN and the other one is 1000 RPN values do not have the same importance.
- Three parameters of FMEA (S, O, and D) are seen to be equally essential, but it may not be the same for users of this method during the evaluation of each parameter.

- Due to the calculation process of RPN, small changes in one of the parameters can lead to significant differences in RPN results.
- Each parameter is a linguistic variable. Thus, it can be hard to determine and quantify parameters precisely.

On the other hand, the benefits of FMEA can be summarized as follows:

- Mohr (2002) stated that FMEA helps to discover potential single-point failures.
- Mohr (2002) also remarked that it assesses risk for potential failure modes considering each identified target.
- Additionally, Mohr (2002) expressed that it is a guide for the evaluation and improvement of processes.
- Besides, Teoh and Case (2004) stated that FMEA helps to monitor failure modes of products, their causes, and effects. They remarked that it provides precious knowledge for future product and process design.
- Finally, Arunajadai et al. (2004) stated that FMEA provides the designer with an indication of the predominant failure modes that should receive considerable attention while the product is being designed.

In the following chapter, the proposed methodology will be explained in detail. Within the scope of this study, the traditional FMEA is combined with the construction project scheduling process using Primavera software to analyze the impact of risk factors, as identified in the delay risk taxonomy.

CHAPTER 3

DEVELOPMENT OF THE PROPOSED METHODOLOGY

In the previous chapter, a comprehensive literature survey on FMEA and delay analysis was carried. Then, the framework of the proposed methodology was determined.

During the development process of the proposed methodology, the main steps of risk management were identified as risk identification, risk assessment, risk mitigation, and risk monitoring. The proposed methodology covers the first three stages of the delay risk management process: identification of delay risk factors, assessment of risk impacts on the duration, and finally, development of delay risk mitigation strategies. Brief information about the development steps are as follows:

Step 1: Delay risk taxonomy of risk factors generally encountered in construction projects was determined as a result of the literature survey.

Step 2: Severity, occurrence, and detection parameters of RPN were rated with subjective judgment to figure out RPN values of each risk factor.

Step 3: Critical risk factors were selected according to RPN values using subjective judgment.

Step 4: The duration of these factors was calculated with three alternative methods.

Step 5: Critical risk factors were considered at the activity level to integrate these factors into the project schedule.

If a decision-maker wants to apply the proposed methodology, the following steps that are indicated in Figure 3.1 should be carried out:

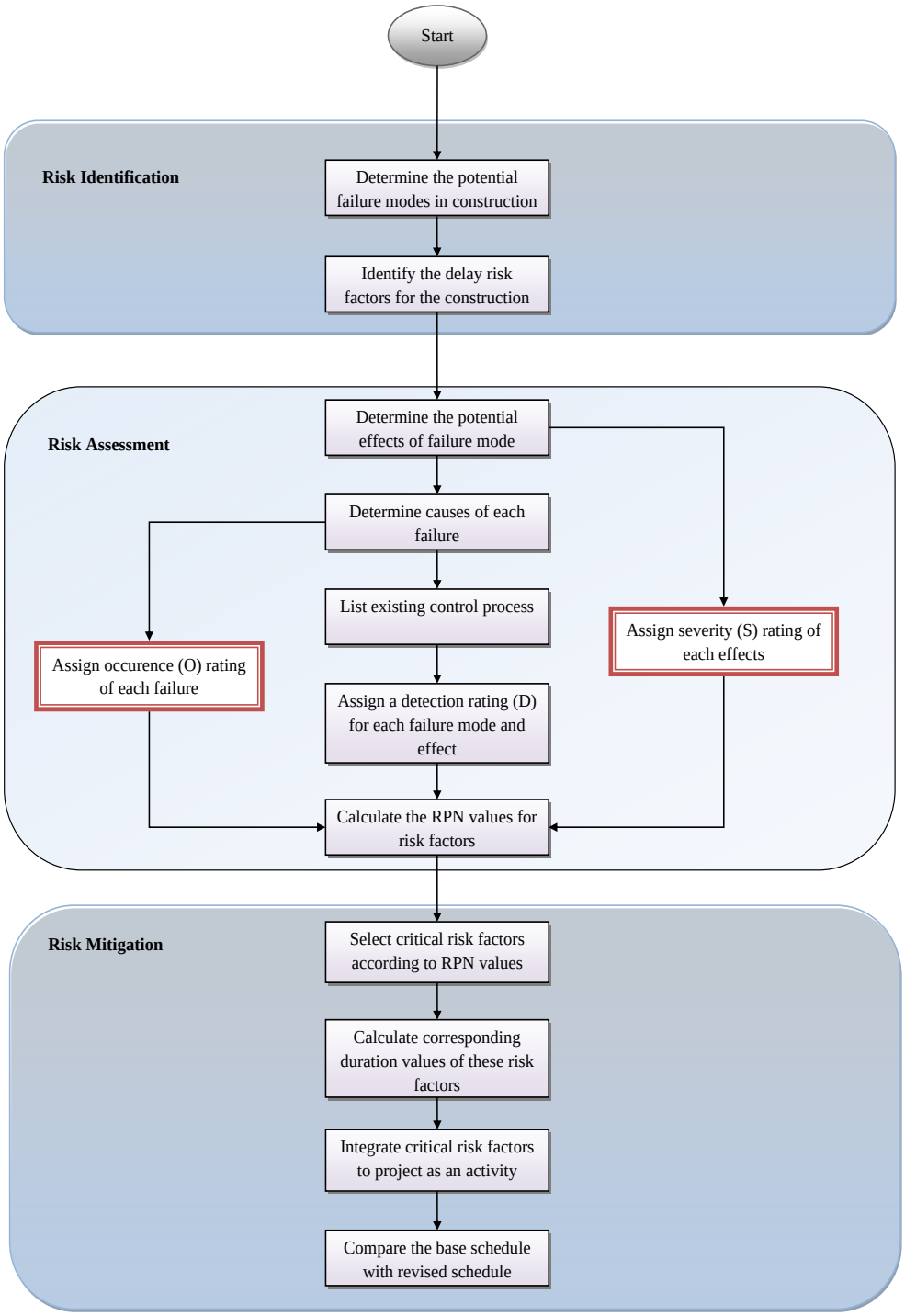

Figure 3.1 Roadmap of the Methodology

As indicated in Figure 3.1, the steps during the application of methodology by decision-makers are summarized as:

Step 1. Determination of potential failure modes in construction projects using the taxonomy.

Step 2: Potential effects, causes, and existing controls of risk factors should be determined to integrate the taxonomy with FMEA. Then, for each risk factor, the risk priority number (RPN) should be calculated. In this step, expert judgments, interviews, and other techniques could be used to calculate RPN parameters.

Step 3: The most critical risk factors should be selected, according to pre-calculated RPN values, to mitigate risk factors/activities.

Step 4: Effects of each critical risk factor should be calculated as a duration.

Step 4: Corresponding activities affected by high risk (critical) factors should be integrated into the project schedule.

Step 5: Results should be compared with the baseline schedule to take necessary actions.

The proposed methodology will be explained in detail in the forthcoming sections.

3.1 Implementation of Proposed Methodology

The implementation of the proposed methodology is demonstrated in the roadmap given above in Figure 3.1.

Delay Risk Identification has two steps:

- Determination of potential failure modes
- Identification of the delay risk factors

Delay Risk Assessment comprises of determination of effects and causes of failure modes. Then, the RPN calculation is applied for risk factors.

Delay Risk Mitigation is related to results of RPN values, corresponding effects, and reflections on the project. This process also contains a comparison of alternative methods.

3.1.1 Risk Identification

As a result of the literature review, schedule delay factors in construction projects were designated and listed in Table 3.1. Risk factors are detailed in different levels, as stated in Derakhshanfar et al. (2019). In the most outer level (level 1), risk factors are gathered under the broadest title of “project risks.” In level 2, risk factors are categorized to shape risk breakdown structure (RBS). In level 3, there are ten risk categories considering different components of construction projects. In level 4, risk factors that constitute failure modes in FMEA methodology are listed in taxonomy.

Table 3.1 Hierarchical Representation of Project Delay Risks

Level 1	Level 2	Level 3	Level 4 (Failure)
Project risks	Stakeholder	Owner	Changes by the owner
			Owner/ client lack of experience in construction projects
			Slow decisions by the owner
			Lack of communication and coordination
			Financial difficulties
		Contractor	Construction mistakes
			Improper construction methods
			Contractor's poor site management and supervision skills.
			Inadequate contractor experience
			Poor sub-contractor works
			Inadequate planning and scheduling
			Inaccurate cost estimation
			Low material quality
			Underestimation of project complexity
		Consultant	Slow response and poor inspection
			Deficient tender documentation (design, bills of quantities and specification).
		Government	Obtaining permits from municipality
	Resources	Labour	Inadequate skills for manpower
			Poor/low labour productivity
			Shortage of skilled/unskilled labour
		Material	Shortage of material at site
		Equipment	Inavailability/ shortage of equipment at site
	Process	Design	Delay in preparation/ approving design documents
			Design changes during the project
		Contract Related	Vagueness of contract clauses
			Lack of communication between parties
		External	Unforeseen weather, ground, and environmental condition at site
			Price inflation/ fluctuations
			Other risks (conflict, war, country risks, force majeure vb.)

3.1.2 Risk Assessment

After the determination of risk factors according to failure mode in projects, risk assessment is the step in which probability and impact of each risk factor are determined by using expert judgment and risk repositories that contain risk-related information about previous projects if the risk exists (Dikmen et al. 2008). For this reason, effective risk assessment of risk factors gives the direction to the methodology by using expert judgment and repositories.

The process of risk assessment contains the following steps:

- ✓ Determination of the potential failure which can take place because of risk factors to assign a severity (S) rating
- ✓ Determination of the causes of each failure to assign an occurrence (O) rating

- ✓ Listing of existing control processes in the project to assign a detection (D) rating
- ✓ The calculation of risk priority number (RPN) based on S, O, and D

3.1.2.1 Determination of Occurrence Ratings

Occurrence is rated considering the failure probability, which represents the relative number of anticipated failures. According to Sankar and Prabhu (2001), occurrence (O) ratings could be based on knowledge of the probability of the failure cause.

The criteria which are used to rate the occurrence of failure mode are shown in Table 3.2.

Table 3.2 Rating System for the Occurrence Parameters

Occurrence Ratings	Description	Definition
10	Dangerously high	≥1/2
9	Extremely high	1/3
8	Very high	1/8
7	High	1/20
6	Moderate	1/80
5	Low	1/400
4	Very low	1/2000
3	Minor	1/15000
2	Very Minor	1/150,000
1	None	1/1,500,000

Here in Table 3.3, critical risk factors are represented in red color. There might be risk factors that are rated in less/more critical interval than other parameters of RPN in the table. For example, underestimation of project complexity is rated as critical for the severity parameter, but for the occurrence, it may not be considered as critical.

Table 3.3 Representation of Occurrence Ratings

Level 4 (Failure)	Potential Effects of Failure	Occurrence (O)
Changes by the owner	Delays in project commencement and completion	1-10
Owner/ client lack of experience in construction projects	Make wrong decisions or use improper methods in projects	1-10
Slow decisions by the owner	Delays in activities and total projects	1-10
Lack of communication and coordination	Poor completion of activities	1-10
Financial difficulties	Delays and interruptions of activities	1-10
Construction mistakes	Reworks, delays in project	1-10
Improper construction methods	Weak structures/project completion delays	1-10
Contractor's poor site management and supervision skills.	Injuries,loss of materials/material damage	1-10
Inadequate contractor experience	Poor project completion/delays and material wastage	1-10
Poor sub-contractor works	Poor project completion/delays and material wastage	1-10
Inadequate planning and scheduling	Make wrong decisions and misconnection between activities	1-10
Inaccurate cost estimation	Pricing problems & claims	1-10
Low material quality	Weak structures/increased costs	1-10
Underestimation of project complexity	Failure to meet deadlines	1-10
Slow response and poor inspection	Wastage and delays	1-10
Deficient tender documentation (design, bills of quantities and specification)	Project suspension	1-10
Obtaining permits from municipality	Project suspension	1-10
Inadequate skills for manpower	Poor completion of tasks	1-10
Poor/low labour productivity	Delays in activity/ project completion	1-10
Shortage of skilled/unskilled labour	Delays in activity/ project completion	1-10
Shortage of material at site	Delays in activity/ project completion	1-10
Inavailability/ shortage of equipment at site	Delays in activity/ project completion	1-10
Delay in preparation/ approving design documents	Delays in project commencement	1-10
Design changes during the project	Delays in completion of tasks	1-10
Vagueness of contract clauses	Poor project completion	1-10
Lack of communication between parties	Major inconveniences	1-10
Unforeseen weather, ground and environmental condition at site	Project suspension	1-10
Price inflation/ fluctuations	Major inconveniences	1-10
Other risks (conflict, war, country risks, force majeure vb.)	Project suspension	1-10

3.1.2.2 Determination of Potential Effects of Failure Mode

Sankar and Prabhu (2001) studied that the effect of failure mode is ranking in conformity with the severity (S) of failure mode. Severity rating should designate the worst situations and scenarios which can be differed from the occurrence ratings.

The criteria which are used to rate the severity of failure effects are shown in Table 3.4.

Table 3.4 Rating System for the Severity Parameters

Severity Ratings	Description	Definition
10	Dangerously high	Failure could result in material damage, project suspension and serious financial loses
9	Extremely high	Failure could result in errors and noncompliance with government regulations
8	Very high	Failure could seriously affect laid out timeframes
7	High	Failure could result in major inconveniences with financial losses
6	Moderate	Failure could result in stakeholder dissatisfaction
5	Low	Failure leads to minor inconveniences without significant financial implications
4	Very low	Failure results in negligible inconveniences
3	Minor	Failure does not have any significant impact on the project
2	Very Minor	Failure does not have any significant impact on the project
1	None	Failure may not even be felt

According to risk factors used in the methodology, parameters of FMEA, which are severity, occurrence, and detection, will be rated in the demonstrative case study. Then, factors that have high risk were selected.

As shown in Table 3.5, critical risk factors are rated as high risk using subjective judgment, according to the severity rating of the related project.

Table 3.5 Representation of Severity Ratings

Level 4 (Failure)	Potential Effects of Failure	Severity (S)
Changes by the owner	Delays in project commencement and completion	1-10
Owner/ client lack of experience in construction projects	Make wrong decisions or use improper methods in projects	1-10
Slow decisions by the owner	Delays in activities and total projects	1-10
Lack of communication and coordination	Poor completion of activities	1-10
Financial difficulties	Delays and interruptions of activities	1-10
Construction mistakes	Reworks, delays in project	1-10
Improper construction methods	Weak structures/project completion delays	1-10
Contractor's poor site management and supervision skills.	Injuries,loss of materials/material damage	1-10
Inadequate contractor experience	Poor project completion/delays and material wastage	1-10
Poor sub-contractor works	Poor project completion/delays and material wastage	1-10
Inadequate planning and scheduling	Make wrong decisions and misconnection between activities	1-10
Inaccurate cost estimation	Pricing problems & claims	1-10
Low material quality	Weak structures/increased costs	1-10
Underestimation of project complexity	Failure to meet deadlines	1-10
Slow response and poor inspection	Wastage and delays	1-10
Deficient tender documentation (design, bills of quantities and specification)	Project suspension	1-10
Obtaining permits from municipality	Project suspension	1-10
Inadequate skills for manpower	Poor completion of tasks	1-10
Poor/low labour productivity	Delays in activity/ project completion	1-10
Shortage of skilled/unskilled labour	Delays in activity/ project completion	1-10
Shortage of material at site	Delays in activity/ project completion	1-10
Inavailability/ shortage of equipment at site	Delays in activity/ project completion	1-10
Delay in preparation/ approving design documents	Delays in project commencement	1-10
Design changes during the project	Delays in completion of tasks	1-10
Vagueness of contract clauses	Poor project completion	1-10
Lack of communication between parties	Major inconveniences	1-10
Unforeseen weather, ground and environmental condition at site	Project suspension	1-10
Price inflation/ fluctuations	Major inconveniences	1-10
Other risks (conflict, war, country risks, force majeure vb.)	Project suspension	1-10

3.1.2.3 Listing Existing Control of Each Failure Mode

Sankar and Prabhu (2001) remarked that detection is an evaluation of the competence of a recommended design verification project to expose possible weaknesses to prevent before the part/assembly is released to production.

Here, the aim is to control the failure mode to minimize delays in the project. For different risk factors, there must be different detection ratings. The criteria which are used to rate the detection of failure modes are shown in Table 3.6.

Table 3.6 Rating System for Detection Parameter

Detection Ratings	Description	Definition
10	Absolutely impossible	There is no process control
9	Very remote	Project controls will not/cannot detect a potential cause or subsequent failure mode
8	Remote	Remote chance that the process controls will detect a potential cause and subsequent failure mode
7	Very low	Very low chance that the process controls will detect a potential cause and subsequent failure mode
6	Low	Low chance that the process controls will detect a potential cause and subsequent failure mode
5	Moderate	Moderate chance that the process controls will detect a potential cause and subsequent failure mode
4	Moderately high	Moderately high chance that the process controls will detect a potential cause and subsequent failure mode
3	High	High chance that the process controls will detect a potential cause and subsequent failure mode
2	Very high	Very high chance that the process controls will detect a potential cause and subsequent failure mode
1	Almost certain	Almost certain chance that the process controls will detect a potential cause and subsequent failure mode

Risk factors are rated considering the definition of detection ratings. Factors are shown in red color in Table 3.7 indicates higher ratings, and it can differ from ratings in other parameters (severity and occurrence).

Table 3.7 Representation of Detection Ratings

Level 4 (Failure)	Potential Effects of Failure	Detection (D)
Changes by the owner	Delays in project commencement and completion	1-10
Owner/ client lack of experience in construction projects	Make wrong decisions or use improper methods in projects	1-10
Slow decisions by the owner	Delays in activities and total projects	1-10
Lack of communication and coordination	Poor completion of activities	1-10
Financial difficulties	Delays and interruptions of activities	1-10
Construction mistakes	Reworks, delays in project	1-10
Improper construction methods	Weak structures/project completion delays	1-10
Contractor's poor site management and supervision skills.	Injuries,loss of materials/material damage	1-10
Inadequate contractor experience	Poor project completion/delays and material wastage	1-10
Poor sub-contractor works	Poor project completion/delays and material wastage	1-10
Inadequate planning and scheduling	Make wrong decisions and misconnection between activities	1-10
Inaccurate cost estimation	Pricing problems & claims	1-10
Low material quality	Weak structures/increased costs	1-10
Underestimation of project complexity	Failure to meet deadlines	1-10
Slow response and poor inspection	Wastage and delays	1-10
Deficient tender documentation (design, bills of quantities and specification)	Project suspension	1-10
Obtaining permits from municipality	Project suspension	1-10
Inadequate skills for manpower	Poor completion of tasks	1-10
Poor/low labour productivity	Delays in activity/ project completion	1-10
Shortage of skilled/unskilled labour	Delays in activity/ project completion	1-10
Shortage of material at site	Delays in activity/ project completion	1-10
Inavailability/ shortage of equipment at site	Delays in activity/ project completion	1-10
Delay in preparation/ approving design documents	Delays in project commencement	1-10
Design changes during the project	Delays in completion of tasks	1-10
Vagueness of contract clauses	Poor project completion	1-10
Lack of communication between parties	Major inconveniences	1-10
Unforeseen weather, ground and environmental condition at site	Project suspension	1-10
Price inflation/ fluctuations	Major inconveniences	1-10
Other risks (conflict, war, country risks, force majeure vb.)	Project suspension	1-10

The next step is integrating all three parameters to calculate the risk priority number (RPN) for each risk factor that is failure modes of projects.

3.1.2.4 Calculate RPN Values for Each Risk Factors

The RPN is calculated by multiplying three parameters. Using RPN values, it is possible to rank risk factors from the risk that has the highest score to the smallest score.

The risk assessment matrix used is given in Table 3.8.

Table 3.8 Risk Assessment Matrix

		RISK MATRIX									
		Detection (D)									
		1	2	3	4	5	6	7	8	9	10
Occurrence (O)	1	1	4	9	16	25	36	49	64	81	100
	2	2	8	18	32	50	72	98	128	162	200
	3	3	12	27	48	75	108	147	192	243	300
	4	4	16	36	64	100	144	196	256	324	400
	5	5	20	45	80	125	180	245	320	405	500
	6	6	24	54	96	150	216	294	384	486	600
	7	7	28	63	112	175	252	343	448	567	700
	8	8	32	72	128	200	288	392	512	648	800
	9	9	36	81	144	225	324	441	576	729	900
	10	10	40	90	160	250	360	490	640	810	1000
		1	2	3	4	5	6	7	8	9	10
		Severity (S)									

In the matrix, critical risk factors are shown with red color, which has an RPN value higher than 400. Determination of the threshold value can differ according to the users. The threshold value was determined as 400, referring to the subjective judgment. Other RPN values are also demonstrated in different color scales (green – low, orange – moderate).

As shown in Table 3.9, the RPN values of each risk factor are determined according to the ratings of three parameters. Then, according to the threshold value, critical risk factors are selected.

Table 3.9 Representation of RPN Values

Level 4 (Failure)	Risk Prioritization Number (RPN)
R1	S*O*D
R2	S*O*D
R3	S*O*D
R4	S*O*D
R5	S*O*D
R6	S*O*D
R7	S*O*D
R8	S*O*D
R9	S*O*D
R10	S*O*D
R11	S*O*D
R12	S*O*D
R13	S*O*D
R14	S*O*D
R15	S*O*D
R16	S*O*D
R17	S*O*D
R18	S*O*D
R19	S*O*D
R20	S*O*D
R21	S*O*D
R22	S*O*D
R23	S*O*D
R24	S*O*D
R25	S*O*D
R26	S*O*D
R27	S*O*D
R28	S*O*D
R29	S*O*D

3.1.3 Risk Mitigation

After the calculation of the RPN value, the risk mitigation step proceeded. Within the scope of the thesis, to mitigate risk, risk factors are assigned to activities to practice strategies.

In previous steps, parameters of RPN values (S, O, and D) are rated to determine critical risk factors. After RPN values are calculated using different alternative methods, corresponding durations of critical risk factors are designated based on subjective judgment. Critical Risk Factors and their RPN values in taxonomy are presented in Table 3.10.

Table 3.10 Critical Risk Factors and RPN Values

Critical Risk Factors	**RPN Values**
R_1	RPN_1
R_4	RPN_4
R_5	RPN_5
R_{17}	RPN_{17}
R_{23}	RPN_{23}
R_{24}	RPN_{24}

3.1.3.1 Calculation of the Corresponding Duration of Activities for Critical Risk Factors

As part of this study, three alternative methods are proposed to calculate the corresponding duration of RPN values before mapping risk factors with actual activities.

Here, three different alternative methods are explained.

<u>Alternative Method 1: Based on Severity Parameter</u>

In this alternative, the duration is estimated as a function of the severity parameter. Here, the severity parameter is the base point to convert risk factors to activity. As shown in Table 3.11, using subjective judgments, corresponding durations of severity ratings are classified as in interval.

Table 3.11 Duration considering Severity Ratings

Severity Ratings	**Description**	**Duration**
10	Dangerously high	26-30 days
9	Extremely high	21-25 days
8	Very high	18-20 days
7	High	16-18 days
6	Moderate	13-15 days
5	Low	11-13 days
4	Very low	8-10 days
3	Minor	6-8 days
2	Very Minor	3-5 days
1	None	0-2 days

Values in the mid-point of each interval are taken using Table 3.11. Then, sample critical risk factors and resulting durations will be obtained, as in Table 3.12.

Table 3.12 Risk Factors and Durations in Alternative 1

Critical Risk Factors	**Duration (Days)**
R_1	D_1
R_4	D_4
R_5	D_5
R_{17}	D_{17}
R_{23}	D_{23}
R_{24}	D_{24}

<u>Alternative Method 2: Based on Total RPN Values of FMEA Taxonomy</u>

For the second alternative, RPN values of critical risk factors are divided into total RPN values of all risk factors available in taxonomy. After getting the ratio for each critical risk factors, these rates are multiplied with total project duration.

$$Ratio = \frac{RPN\ Values\ of\ Each\ Critical\ Risk\ Factors}{Total\ RPN\ Values\ of\ Taxonomy}$$

(eq. 3.1.3.1)

$$Duration\ of\ Critical\ Risk\ Factors = Ratio * Total\ Project\ Duration$$

(eq. 3.1.3.2)

The total duration of the project changes according to projects. Then, corresponding durations will be calculated in a demonstrative case study considering project duration. The representation of this process is shown in Table 3.13.

Table 3.13 Risk Factors and Durations in Alternative 2

Critical Risk Factors	**Duration (Days)**
R_1	$Ratio_1$*Total Project Duration
R_4	$Ratio_4$*Total Project Duration
R_5	$Ratio_5$*Total Project Duration
R_{17}	$Ratio_{17}$*Total Project Duration
R_{23}	$Ratio_{23}$*Total Project Duration
R_{24}	$Ratio_{24}$*Total Project Duration

<u>Alternative Method 3: Based on Total Project Duration</u>

The final alternative method is also according to subjective judgment considering different RPN intervals. In each interval, corresponding durations are equals to different ratios of total project duration. Impacts considering % of total project duration is shown in Table 3.14.

Table 3.14 RPN Values and Impacts

RPN Value	Impact (% of project duration)
901 - 1000	15.0%
751 - 900	12.5%
601 - 750	10.0%
451 - 600	8.0%
301 - 450	5.0%
151 - 300	3.0%
0 - 150	Insignificant delay

For example, a risk factor with 901- 1000 RPN values has a %15 impact on the total project duration. As in alternative method 2, the final alternative also depends on the total project duration. Durations, according to method two, are in Table 3.15.

Table 3.15 Risk Factors and Durations in Alternative 3

Critical Risk Factors	Duration (Days)
R_1	$Ratio_1$*Total Project Duration
R_4	$Ratio_4$*Total Project Duration
R_5	$Ratio_5$*Total Project Duration
R_{17}	$Ratio_{17}$*Total Project Duration
R_{23}	$Ratio_{23}$*Total Project Duration
R_{24}	$Ratio_{24}$*Total Project Duration

According to these three alternatives, durations are assigned to new activities. Then, the schedule of the project is revised after inserting new activities into the schedule. Which are the projects:

1) Compare the baseline schedule and revised schedule of the project to mitigate delays that may occur in the project.

2) See the effects of critical risk factors by adding new activities to schedule to develop a risk response plan of the project before considering failures happen.

In the next step, inputs and outputs of the proposed methodology will be clarified.

3.2 Overview of Proposed Methodology

In this step, an overview of the proposed methodology is provided for users. Figure 3.2 shows the interconnected components of the proposed methodology. Inputs of the methodology were delay risk factors that were identified in taxonomy. Then, three parameters of FMEA were rated by a subjective judgment to calculate RPN values of each risk factor. According to RPN value, critical risk factors were selected.

The primary process of this study was reflecting the corresponding effects of critical risk factors to the existing project schedule. The impact of critical risk factors was calculated as the duration using three alternative methods. Three alternative methods were used to compare and validate the effect of risk factors to project schedule.

Another crucial process of the study was converting critical risk factors into the activities. After the duration of the critical risk factors was calculated, they were considered as new activities to detect the risk factors at the exact point that they occur and to relate to available activities properly.

In most of the projects, the completion time of the project is calculated by adding a simple lag to the project life cycle, considering all project risks with a general overview. However, the baseline schedule of projects generally does not actualize. Therefore, in this study, using Primavera P6 software, new activities were inserted

into the existing project schedule. Then, a revised schedule of the project was obtained, considering the most critical risk factors.

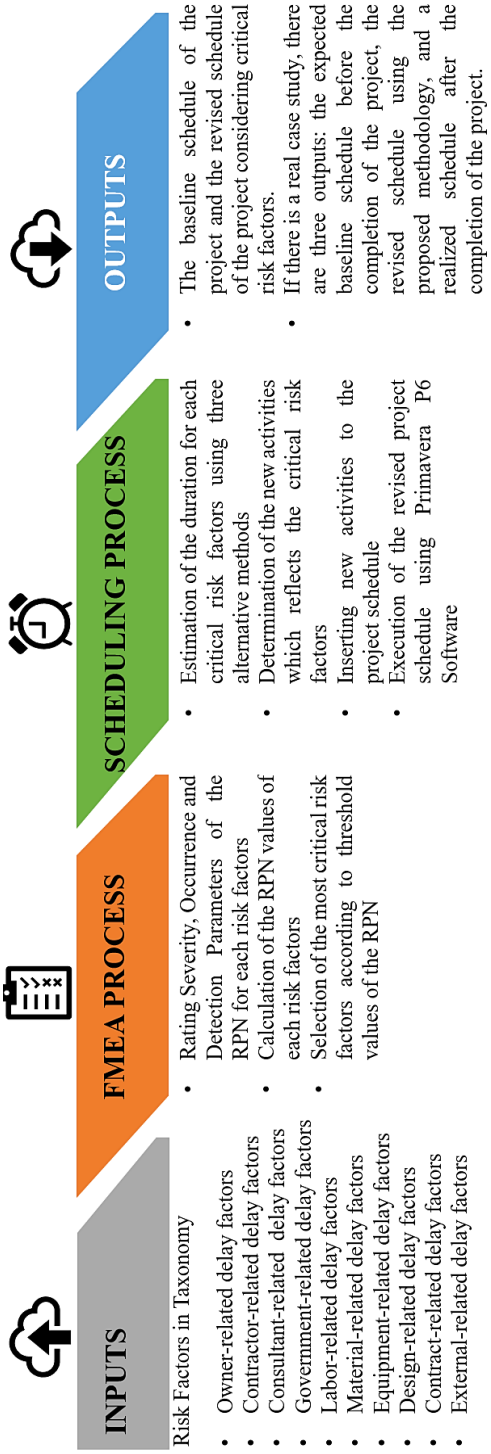

Figure 3.2 Components of the Proposed Methodology

The revised schedule of the projects shows the impact of critical risk factors, and it is a warning for users to take corrective action before the suspension or failure of the project. Schedule risk analysis of the project gives three critical results to the users:

- The completion time of the projects could deviate from the specified time, although decision-makers take into account some general risk factors during the project. In this study, it is supposed to get the completion time of the revised project schedule must be later than expected.
- Critical delay risk factors could be detected and linked to the project's activities more systematically.
- Corrective actions could be taken at the right place that risk occurs rather than determine lag by chance.

Due to applying a demonstrative case study, this thesis was proceeded considering only two different schedules of the project: the baseline schedule and the revised schedule of the project. However, if a real case study is used to implement the proposed methodology, the results could be more significant and efficient for decision-makers. In that case, there will be three (3) different schedule:

- Expected baseline project schedule before the completion of the project
- Revised project schedule using the proposed methodology
- A realized project schedule after the completion of the project

According to the results of the three different project schedules, the users could validate the methodology and see the impacts of significant delay risk factors.

Consequently, using taxonomy with FMEA, delay risk analysis of construction projects could be improved. First, taxonomy enables users to analyze delay risk factors logically. Then, FMEA provides to prioritize these delay factors by the knowledge of users.

In the following chapter, a demonstrative case study will be elaborated.

CHAPTER 4

DEMONSTRATIVE CASE STUDY

In the demonstrative case study, the above process was applied to a hypothetical project. The hypothetical project is a housing project which has only finished construction works.

A case study is conducted, modifying the term project used in the CE434-Construction Planning course in the Civil Engineering Department of METU. In addition to the project, a full list of the project's details is presented in Appendix A.

In the case study, there are two different schedules of projects:

1. Baseline project
2. Baseline project with delays according to RPN values (for critical risk factors)

4.1 Baseline Project without Risk Factors

In the case study, a housing complex will be constructed on a parcel with two different blocks (Block 1 & 2) is shown in Table 4.1. The structural works of the project have been finished. Some of the remaining works, related activities, durations, corresponding resources, and budgeted units are given in Table 4.2. According to these works, a revised schedule with the help of FMEA was obtained. The case study aims to explain how delays can be reflected in the schedule of projects as activities. Then, results show that risks on the projects can be controllable.

Table 4.1 Blocks and Floors in House Complex (continued in Appendix A)

Block Number	# of the floor in blocks
1	7 Floors
2	6 Floors

It is required to prepare the term project by solving the network on Primavera P6 software, using the given information.

Table 4.2 Related Information about Activities in Project (continued in Appendix A)

Activity Name	Duration (days)	Resource	Budgeted Units
Masonry Works	5	Bricks	662.25 m^2
Mechanical Installations Under Screed	7	-	-
Screed Works	4	Screed Concrete	471.13 m^2
Installation of PVC Windows	2	-	-
Gypsum Plastering	10	Plaster	1348.49 m^2
Installation of Electrical Conduits	5	-	-
Installation of Unit Doors	1	-	-
Ceramic Tiling	4	Ceramic Tiles	94.47 m^2
First Coat Painting	5	Paint	958.67 m^2
Landscaping	3 days per building	-	-

There are some assumptions for the scheduling of the project:

1) The project start date was 01/06/2020.
2) There were six working days in a week except for Sundays.
3) Daily working hours were assumed as 8 hours/day.
4) It was assumed that works at different blocks are sequential. The works at block-2 began only after the works at the block-1 finish.
5) There are official holidays in Turkey:
    - New Year's Day
    - National Sovereignty and Children's Day
    - Democracy and National Solidarity Day
    - Labor and Solidarity Day
    - Commemoration of Atatürk-Youth and Sports Day

- Ramadan Feast
- Sacrifice Feast
- Victory Day
- Republic Day

6) Per unit cost for each resource was 7.00 $.
7) For activities that have delays, per unit cost for each resource was assumed as 0.00 $ because the aim of the project is not about the cost over-run.
8) All activities had Finish to Start (FS) relation. The flow of the activities is shown in Figure 4.1.

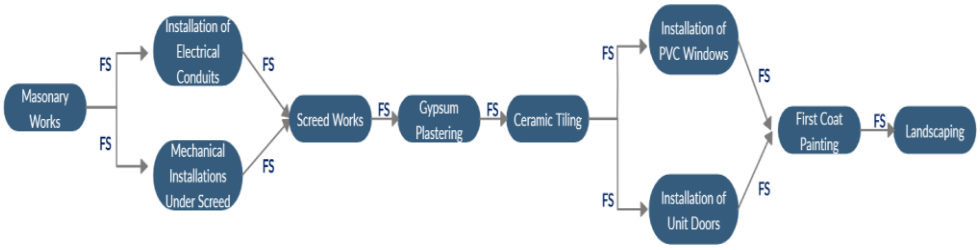

Figure 4.1 Relationship between Activities

Until 2022, the holidays were arranged according to the given official holidays, as in Figure 4.2.

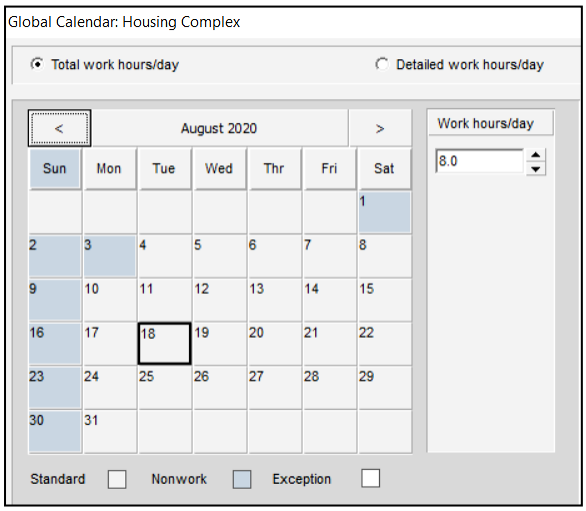

Figure 4.2 A Sample of the Calendar Showing Working and Non-working Days (Taken from the Primavera P6)

Bricks, screed concrete, plaster, ceramic tiles, paint were added manually. Also, the square meters were again manually added from the units of measure menu. The resources have their calendars as default. It was changed manually with the edited previously mentioned calendar to every resource one by one, as in Figure 4.3. and Figure 4.4. Additionally, other details of the project and results of software are available in Appendix B.

Resources

Activities | Resources

Display: Current Project's Resources

Resource ID	Resource Name	Resource Type	Unit of Measure	Primary Role	Default Units / Time
Paint-	Paint	Material	meter square		8/d
Ceramic Tiles	Ceramic Tiles	Material	meter square		8/d
Plaster	Plaster	Material	meter square		8/d
Screed Concrete	Screed Concrete	Material	meter square		8/d
Bricks	Bricks	Material	meter square		8/d

Figure 4.3 Resource Assignment (taken from the Primavera P6)

General | Status | Resources | Predecessors | Successors | Relationships | Expenses

Activity P1K1F11000 Masonry Works

Resource ID Name	Actual Cost	Budgeted Cost	ıary Resou	Remaining Units / Time	Original Lag	Start	Finish	Budgeted Units
Bricks.Bricks	$0.00	$4,647.23		133/d	0	01-Jun-20	05-Jun-20	664

Figure 4.4 Resource Details (taken from the Primavera P6)

After activities, their durations and all other information were inserted into Primavera P6, and total project duration was found as **160 days** for the baseline project schedule, as indicated in Figure 4.5.

Layout: Classic Schedule Layout | Filter: All Activities

Activity ID	Activity Name	Original Duration
Housing Complex-2	Case Study	160

Figure 4.5 Duration of the Baseline Project (taken from the Primavera P6)

4.2 Baseline Project with Delays according to RPN Values

In this step of the study, transactions concluded based on pre-defined methodology are as follows:

- ✓ The severity, occurrence, and detection parameters of RPN were rated according to the project.
- ✓ RPN values of each risk factor in taxonomy were calculated for the case study project.
- ✓ Critical risk factors were selected.
- ✓ Corresponding durations of selected risk factors were calculated according to alternatives that were defined in section 3.1.3.1.
- ✓ Additional activities were determined according to critical risk factors.
- ✓ The duration of the activities was calculated.
- ✓ Activities were inserted into the project schedule.
- ✓ Results of the new schedule and baseline project schedule were compared.

4.2.1 Severity Rating

The potential effects of failure mode for schedule delay were estimated by using subjective judgment considering construction projects. For the process, assumptions are as follows:

1) The user/decision-maker has sufficient knowledge of delay factors in construction projects.
2) There is no time limitation.

For the severity parameter, the following tasks were done:

1) Control the linguistic scale of severity
2) Rate the severity of the parameter
3) Identify the potential effects of failure modes on construction projects
4) Check and make changes if any need is available

As a result, the effects and ratings of each risk factor were constructed in Table 4.3.

Table 4.3 Severity Ratings based on Subjective Judgement

Level 4 (Failure)	Potential effect of the failure	Severity (S)
Changes by the owner	Delays in project commencement and completion	8
Owner/ client lack of experience in construction projects	Make wrong decisions or use improper methods in projects	5
Slow decisions by the owner	Delays in activities and total projects	8
Lack of communication and coordination	Poor completion of activities	9
Financial difficulties	Delays and interruptions of activities	10
Construction mistakes	Reworks, delays in project	9
Improper construction methods	Weak structures/project completion delays	8
Contractor's poor site management and supervision skills.	Injuries,loss of materials/material damage	10
Inadequate contractor experience	Poor project completion/delays and material wastage	10
Poor sub-contractor works	Poor project completion/delays and material wastage	9
Inadequate planning and scheduling	Make wrong decisions and misconnection between activities	10
Inaccurate cost estimation	Pricing problems & claims	8
Low material quality	Weak structures/increased costs	9
Underestimation of project complexity	Failure to meet deadlines	5
Slow response and poor inspection	Wastage and delays	10
Deficient tender documentation (design, bills of quantities and specification)	Project suspension	8
Obtaining permits from municipality	Project suspension	10
Inadequate skills for manpower	Poor completion of tasks	8
Poor/low labour productivity	Delays in activity/ project completion	7
Shortage of skilled/unskilled labour	Delays in activity/ project completion	7
Shortage of material at site	Delays in activity/ project completion	8
Inavailability/ shortage of equipment at site	Delays in activity/ project completion	8
Delay in preparation/ approving design documents	Delays in project commencement	8
Design changes during the project	Delays in completion of tasks	6
Vagueness of contract clauses	Poor project completion	8
Lack of communication between parties	Major inconveniences	7
Unforeseen weather, ground and environmental condition at site	Project suspension	10
Price inflation/ fluctuations	Major inconveniences	7
Other risks (conflict, war, country risks, force majeure vb.)	Project suspension	2

Most of the risk factors were rated as high risk. Nevertheless, the effects on the calculation of RPN can be different. It means that risk factors that have a high severity rating can have a slight effect on RPN value because of other parameters.

4.2.2 Occurrence Rating

As mentioned above, there were some assumptions for rating parameters. For the occurrence parameter, the same assumptions are valid.

For the occurrence parameter, the following tasks were done:

1) Rate the occurrence parameter
2) Determine the potential causes of failure modes on construction projects
3) Check and make changes if any need is available

After subjective judgments, results are shown in Table 4.4.

Table 4.4 Occurrence Ratings based on Subjective Judgement

Level 4 (Failure)	Potential cause of the failure	Occurrence (O)
Changes by the owner	Different preferences	7
Owner/ client lack of experience in construction projects	First project	7
Slow decisions by the owner	Lack of adequate information	10
Lack of communication and coordination	Hastened project completion	6
Financial difficulties	Poor financial planning	8
Construction mistakes	Lack of experience/human error	10
Improper construction methods	Incompetent personnel	9
Contractor's poor site management and supervision skills.	Incompetent personnel	4
Inadequate contractor experience	Poor selection process	6
Poor sub-contractor works	Poor outsourcing	7
Inadequate planning and scheduling	Lack of sufficient information	9
Inaccurate cost estimation	Miscalculations	8
Low material quality	Poor material selection	7
Underestimation of project complexity	Lack of adequate information	9
Slow response and poor inspection	Negligence/ giving lack of importance	3
Deficient tender documentation (design, bills of quantities and specification)	Poor management capacity to control project	9
Obtaining permits from municipality	Incompetent personnel	7
Inadequate skills for manpower	Lack of training/poor recruitment	6
Poor/low labour productivity	Poor work environment/poor remuneration	9
Shortage of skilled/unskilled labour	Lack of training/poor recruitment	9
Shortage of material at site	Poor quantity estimations	8
Inavailability/ shortage of equipment at site	Poor outsourcing	8
Delay in preparation/ approving design documents	Project complexity	6
Design changes during the project	Poor contract management	9
Vagueness of contract clauses	Incompetent personnel	7
Lack of communication between parties	Lack of communication channels	6
Unforeseen weather, ground and environmental condition at site	Climate changes	5
Price inflation/ fluctuations	Economic changes	5
Other risks (conflict, war, country risks, force majeure vb.)	Epidemics etc.	3

There are risk factors that some of them have high risk as in severity rating, but some of them are different. So, it does not have to be the same ratings for different parameters.

4.2.3 Detection Rating

In this step, tasks were done as follows:

1) Rate the detection parameter
2) List existing control for each failure mode on construction projects

The results are shown in Table 4.5.

Table 4.5 Detection Ratings based on Subjective Judgement

Level 4 (Failure)	Existing controls	Detection (D)
Changes by the owner	Change control plan	3
Owner/ client lack of experience in construction projects	None	9
Slow decisions by the owner	Simplification of cases	3
Lack of communication and coordination	Project management plan	3
Financial difficulties	Project management plan	3
Construction mistakes	Supervision	7
Improper construction methods	Project management plan	7
Contractor's poor site management and supervision skills.	Project management plan	3
Inadequate contractor experience	Project management plan	2
Poor sub-contractor works	Project management plan	2
Inadequate planning and scheduling	Project management plan	9
Inaccurate cost estimation	Project management plan	2
Low material quality	Material specification	2
Underestimation of project complexity	Project management plan	9
Slow response and poor inspection	Project management plan	3
Deficient tender documentation (design, bills of quantities and specification)	Project management plan	4
Obtaining permits from municipality	Project management plan	3
Inadequate skills for manpower	HR management	3
Poor/low labour productivity	HR management	4
Shortage of skilled/unskilled labour	HR management	9
Shortage of material at site	Material specification	4
Inavailability/ shortage of equipment at site	Project management plan	1
Delay in preparation/ approving design documents	Project management plan	1
Design changes during the project	Project management plan	8
Vagueness of contract clauses	Project management plan	2
Lack of communication between parties	Project management plan	1
Unforeseen weather, ground and environmental condition at site	Project management plan	3
Price inflation/ fluctuations	Project management plan	3
Other risks (conflict, war, country risks, force majeure vb.)	Project mitigation plan according to process	7

As indicated above, factors that have high detection values are in red. Moreover, there are fewer failure modes that are designated more critical than in other parameters.

4.2.4 Calculation of RPN Values

After previous steps for estimating S, O, and D parameters, RPN values were calculated for each risk factor. Eventually, there were six critical risk factors. Results with failure modes are shown in Table 4.6.

Table 4.6 RPN of Each Failure Mode

Level 4 (Failure)	Risk Prioritization Number (RPN)
Changes by the owner	168
Owner/ client lack of experience in construction projects	315
Slow decisions by the owner	240
Lack of communication and coordination	162
Financial difficulties	240
Construction mistakes	630
Improper construction methods	504
Contractor's poor site management and supervision skills.	120
Inadequate contractor experience	120
Poor sub-contractor works	126
Inadequate planning and scheduling	810
Inaccurate cost estimation	128
Low material quality	126
Underestimation of project complexity	405
Slow response and poor inspection	90
Deficient tender documentation (design, bills of quantities and specification)	288
Obtaining permits from municipality	210
Inadequate skills for manpower	144
Poor/low labour productivity	252
Shortage of skilled/unskilled labour	567
Shortage of material at site	256
Inavailability/ shortage of equipment at site	64
Delay in preparation/ approving design documents	48
Design changes during the project	432
Vagueness of contract clauses	112
Lack of communication between parties	42
Unforeseen weather, ground and environmental condition at site	150
Price inflation/ fluctuations	105
Other risks (conflict, war, country risks, force majeure vb.)	42

In Table 4.7, critical risk factors in the project are available.

Table 4.7 Critical Risk Factors

Critical Risk Factors	**RPN Values**
Construction mistakes	**630**
Improper construction methods	**504**
Inadequate planning and scheduling	**810**
Underestimation of project complexity	**405**
Shortage of skilled/unskilled labor	**567**
Design changes during the project	**432**

4.2.5 Calculation of Duration of Critical Risk Factors

As mentioned in Chapter 3, three alternative methods can be used to calculate corresponding durations of risk factors.

Alternative Method 1: Results

As mentioned before (in detail of alternative method 1), durations were determined according to the severity parameters of critical risk factors. The outcomes are shown in Table 4.8.

Table 4.8 Results of Alternative Method 1

Critical Risk Factors	**Severity Ratings**	**Duration (Days)**
Construction mistakes	9	23.00
Improper construction methods	8	19.00
Inadequate planning and scheduling	10	28.00
Underestimation of project complexity	5	12.00
Shortage of skilled/unskilled labor	7	17.00
Design changes during the project	6	14.00

Alternative Method 2: Results

There are two steps for estimating durations of risk factors.

- Calculation of ratio, according to equation 3.1.3.1
  RPN values of critical risk factors were divided to total RPN values in taxonomy.
- Calculation of duration, according to equation 3.1.3.2
  The ratio of each risk factor was multiplied with the total baseline project duration, which is 160 days.

There were four different levels in taxonomy, and total RPN values were gathered under Level 1, as in Table 4.9. The duration for critical risk factors is in Table 4.10.

Table 4.9 Total RPN Values of Taxonomy

Level 1	**Category RPN (for Level 1)**
Project Risks	4682
	1283
	931
TOTAL RPN	**6896**

Table 4.10 Results of Alternative Method 2

Critical Risk Factors	**RPN Values**	**RPN Ratio in Total**	**Duration (Days)**
Construction mistakes	630	0.09	14.62
Improper construction methods	504	0.07	11.69
Inadequate planning and scheduling	810	0.12	18.79
Underestimation of project complexity	405	0.06	9.40
Shortage of skilled/unskilled labor	567	0.08	13.16
Design changes during the project	432	0.06	10.02

Alternative Method 3: Results

Durations were calculated considering impacts that are % of total project duration, as indicated in Table 4.11.

Table 4.11 Results of Alternative Method 3

Critical Risk Factors	**RPN Values**	**Impacts**	**Duration (Days)**
Construction mistakes	630	10.0%	16.00
Improper construction methods	504	8.0%	12.80
Inadequate planning and scheduling	810	12.5%	20.00
Underestimation of project complexity	405	5.0%	8.00
Shortage of skilled/unskilled labour	567	8.0%	12.80
Design changes during the project	432	5.0%	8.00

4.2.6 Determination of Activities and Durations

Activities were determined in the project according to critical risk factors. Based on subjective judgment, risk factors were matched with activities. If critical risk factors affect different activities/phases of the project, the duration of each activity was calculated by taking the average of the total duration of related risk factors according to three alternative methods.

In Table 4.12, risk factors and related activities that existed in the project are shown.

Table 4.12 Critical Risk Factors and Activities

Most Critical Risk Factors	Demonstrative Activities of Risk Factors
Construction mistakes	Breakdown of Mechanical Testing Procedure - First Floor of 1st Block
	Breakdown of Mechanical Testing Procedure - Third Floor of 1st Block
	Breakdown of Mechanical Testing Procedure - Seventh Floor of 1st Block
Improper construction methods	Missing Weep Screeds in 2nd Block
Inadequate planning and scheduling	Misarrangement of Mechanical Installation Team Right After Masonary Works in 1st Block - 1st Floor
	Misarrangement of Mechanical Installation Team Right After Masonary Works in 1st Block - Fourth Floor
	Misarrangement of Mechanical Installation Team Right After Masonary Works in 2nd Block - Second Floor
	Misarrangement of Mechanical Installation Team Right After Masonary Works in 2nd Block - Fifth Floor
Underestimation of project complexity	Miscalculation of Completion Time for 2nd Block
Shortage of skilled/unskilled labour	Shortage of Team Work on Electrical Installation - Third Floor of 1st Block
	Shortage of Team Work on Electrical Installation - Fifth Floor of 1st Block
	Shortage of Team Work on Electrical Installation - First Floor of 2nd Block
Design changes during the project	Changes in Landscaping Project of 1st & 2nd Block

These activities were arranged into the project schedule based on three alternatives.

- For the first alternative method, durations of risk factors were calculated previously. Corresponding values for activities are given in Table 4.13.

Table 4.13 Activity Durations in the First Alternative

Critical Risk Factors	Delay (in Days)	Demonstrative Activities of Risk Factors	Corresponding Values According to Place that Delays Happen
Construction mistakes	23.00	Breakdown of Mechanical Testing Procedure - First Floor of 1st Block	7.67
		Breakdown of Mechanical Testing Procedure - Third Floor of 1st Block	
		Breakdown of Mechanical Testing Procedure - Seventh Floor of 1st Block	
Improper construction methods	19.00	Missing Weep Screeds in 2nd Block	3.17
Inadequate planning and scheduling	28.00	Misarrangement of Mechanical Installation Team Right After Masonary Works in 1st Block - 1st Floor	7.00
		Misarrangement of Mechanical Installation Team Right After Masonary Works in 1st Block - Fourth Floor	
		Misarrangement of Mechanical Installation Team Right After Masonary Works in 2nd Block - Second Floor	
		Misarrangement of Mechanical Installation Team Right After Masonary Works in 2nd Block - Fifth Floor	
Underestimation of project complexity	12.00	Miscalculation of Completion Time for 2nd Block	12.00
Shortage of skilled/unskilled labour	17.00	Shortage of Team Work on Electrical Installation - Third Floor of 1st Block	5.67
		Shortage of Team Work on Electrical Installation - Fifth Floor of 1st Block	
		Shortage of Team Work on Electrical Installation - First Floor of 2nd Block	
Design changes during the project	14.00	Changes in Landscaping Project of 1st & 2nd Block	7.00

- For the second alternative, the duration of risk factors was calculated. Corresponding values for activities are in Table 4.14.

Table 4.14 Activity Durations in the Second Alternative

Critical Risk Factors	Delay (in Days)	Demonstrative Activities of Risk Factors	Corresponding Values According to Place that Delays Happen
Construction mistakes	14.62	Breakdown of Mechanical Testing Procedure - First Floor of 1st Block	4.87
		Breakdown of Mechanical Testing Procedure - Third Floor of 1st Block	
		Breakdown of Mechanical Testing Procedure - Seventh Floor of 1st Block	
Improper construction methods	11.69	Missing Weep Screeds in 2nd Block	1.95
Inadequate planning and scheduling	18.79	Misarrangement of Mechanical Installation Team Right After Masonary Works in 1st Block - 1st Floor	4.70
		Misarrangement of Mechanical Installation Team Right After Masonary Works in 1st Block - Fourth Floor	
		Misarrangement of Mechanical Installation Team Right After Masonary Works in 2nd Block - Second Floor	
		Misarrangement of Mechanical Installation Team Right After Masonary Works in 2nd Block - Fifth Floor	
Underestimation of project complexity	9.40	Miscalculation of Completion Time for 2nd Block	9.40
Shortage of skilled/unskilled labour	13.16	Shortage of Team Work on Electrical Installation - Third Floor of 1st Block	4.39
		Shortage of Team Work on Electrical Installation - Fifth Floor of 1st Block	
		Shortage of Team Work on Electrical Installation - First Floor of 2nd Block	
Design changes during the project	10.02	Changes in Landscaping Project of 1st & 2nd Block	5.01

- For the third alternative, the duration of risk factors was calculated. The corresponding values for activities are in Table 4.15.

Table 4.15 Activity Durations in the Third Alternative

Critical Risk Factors	Delay (in Days)	Demonstrative Activities of Risk Factors	Corresponding Values According to Place that Delays Happen
Construction mistakes	16.00	Breakdown of Mechanical Testing Procedure - First Floor of 1st Block	5.33
		Breakdown of Mechanical Testing Procedure - Third Floor of 1st Block	
		Breakdown of Mechanical Testing Procedure - Seventh Floor of 1st Block	
Improper construction methods	12.80	Missing Weep Screeds in 2nd Block	2.13
Inadequate planning and scheduling	20.00	Misarrangement of Mechanical Installation Team Right After Masonary Works in 1st Block - 1st Floor	5.00
		Misarrangement of Mechanical Installation Team Right After Masonary Works in 1st Block - Fourth Floor	
		Misarrangement of Mechanical Installation Team Right After Masonary Works in 2nd Block - Second Floor	
		Misarrangement of Mechanical Installation Team Right After Masonary Works in 2nd Block - Fifth Floor	
Underestimation of project complexity	8.00	Miscalculation of Completion Time for 2nd Block	8.00
Shortage of skilled/unskilled labour	12.80	Shortage of Team Work on Electrical Installation - Third Floor of 1st Block	4.27
		Shortage of Team Work on Electrical Installation - Fifth Floor of 1st Block	
		Shortage of Team Work on Electrical Installation - First Floor of 2nd Block	
Design changes during the project	8.00	Changes in Landscaping Project of 1st & 2nd Block	4.00

After the determination of the duration of activities, activities were inserted into the project schedule. Critical points of this process are:

- While adding new activities to the project, duration values were rounded to the closest integer.
- New relations were constructed between activities.

Primavera Results of the first alternative method is available in Appendix C, the second alternative is given in Appendix D, and the last alternative method is available in Appendix E.

CHAPTER 5

DISCUSSION OF FINDINGS

5.1 Findings of Demonstrative Case Study

In this section, the significant consequences of the demonstrative case study are presented based on two steps.

- Evaluation of the results of the FMEA process
- Evaluation of the results of the scheduling process

1) First of all, based on the rating process of each risk factors, the top five (5) most critical groups of risk factors causing schedule delays in the demonstrative case study were shown in Table 5.1:

Table 5.1 List of Top Five (5) Most Important Factors Causing Schedule Delays

Level 1	Level 2	Level 3 (Construction Parties)	Level 4 (Failure)	RPN (for Level 3)
Project risks	Stakeholder	Owner	Changes by the owner	1125
			Owner/ client lack of experience in construction projects	
			Slow decisions by the owner	
			Lack of communication and coordination	
			Financial difficulties	
		Contractor	Construction mistakes	2969
			Improper construction methods	
			Contractor's poor site management and supervision skills.	
			Inadequate contractor experience	
			Poor sub-contractor works	
			Inadequate planning and scheduling	
			Inaccurate cost estimation	
			Low material quality	
			Underestimation of project complexity	
		Consultant	Slow response and poor inspection	378
			Deficient tender documentation (design, bills of quantities and specification)	
		Government	Obtaining permits from municipality	210
	Resources	Labor	Inadequate skills for manpower	963
			Poor/low labor productivity	
			Shortage of skilled/unskilled labor	
		Material	Shortage of material at site	256
		Equipment	Inavailability/ shortage of equipment at site	64
	General Process	Design	Delay in preparation/ approving design documents	480
			Design changes during the project	
		Contract Related	Vagueness of contract clauses	154
			Lack of communication between parties	
		External	Unforeseen weather, ground, and environmental condition at site	297
			Price inflation/ fluctuations	
			Other risks (conflict, war, country risks, force majeure vb.)	

Initially, each group of delay factors is summarized, then the most critical delay risk factors in the case study will be evaluated to compare the effects of Level 3 and Level 4.

1. Contractor- related delay factors: As shown in Table 5.1, this group was the most determinative one to cause the schedule delay. It was mostly due to the delay risk factors "inadequate planning and scheduling (RPN=810), construction mistakes (RPN=630), improper construction methods (RPN=504), and underestimation of project complexity (RPN=405)."
2. Owner- related delay factors: These types of delay risk factors were seen as critical at Level 3. However, as seen in Table 5.1, when each failure mode in Level 3 was evaluated, they did not have critical RPN values (in yellow color).
3. Labor-related delay factors: This group of schedule delay factors was also seen as critical. It was mainly due to the factor "shortage of skilled/ unskilled labor (RPN=567)."
4. Design-related delay factors: This group of schedule delay factors affected the project schedule. It is because of the factor "design changes during the project (RPN= 432)."
5. Consultant-related delay factors: This group of schedule delay factors was seen as critical, yet there was no individual critical failure mode in this group.

Similarly, as indicated in Figure 5.1, the effects of each part in the taxonomy could be interpreted for Level 2 and Level 3.

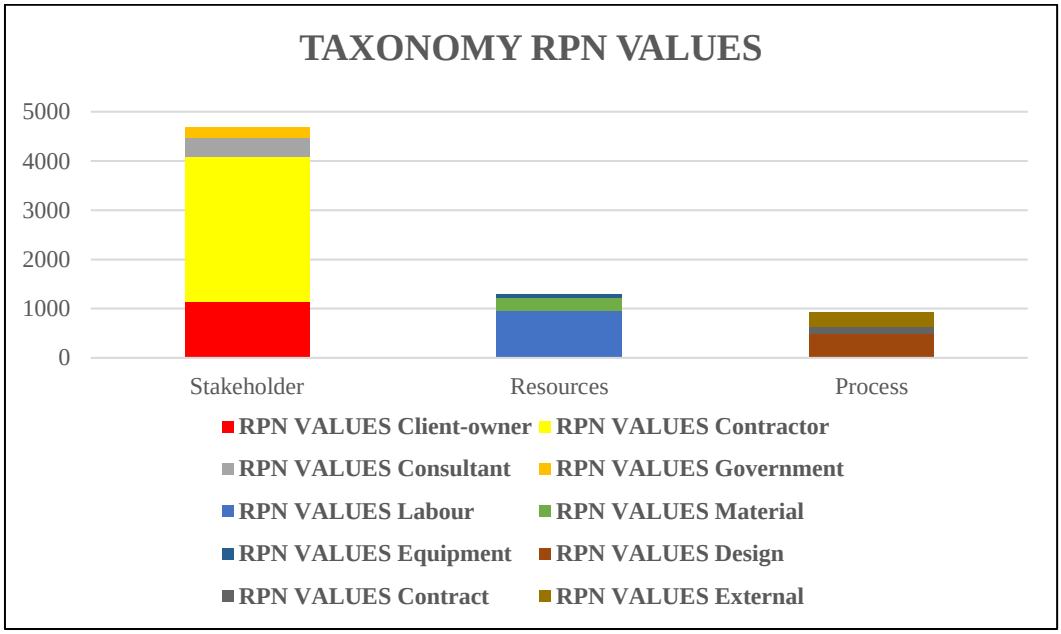

Figure 5.1 Graphical Representation of RPN Values of Taxonomy

1. Stakeholder – related delay factors: This level of delay factors was identified as the most critical. It includes owner-related, contractor-related, and consultant-related delay factors groups. However, the contractor -related delay factors had the main effect.
2. Resource – related delay factors: This level (Level 2) of delay factors was not seen as critical, but labor-related delay factors had a significant effect on the project schedule.
3. Process – related delay factors: This level of delay factors was not critical, as each failure mode in this level.

Briefly, looking at the risk factors from the outer levels might give the users clues about the place where critical risks arise. However, as understood from the results, a group of delay risk factors (Level 2 and Level 3) could be seen as critical, but it may not reflect the actual case. Therefore, delay risk factors should be evaluated individually (Level 4) to proper risk assessment.

2) After determining critical risk factors, the duration of these factors was calculated using three alternative methods. Then, they were converted to the activities and

inserted into the project schedule. As a result, there was a revised schedule of the housing complex project.

Primavera's results for the three alternatives are summarized as the figures below.

Activity ID	Activity Name	Original Duration
Housing Complex-3 Case Study		194
Housing Complex-3.Blocks Blocks		194
Housing Complex-3.Blocks.1. - Floor Block 1		122
P1K11235	Changes in Landscaping Project of First Block	7
P1K11225	Landscaping	3
Housing Complex-3.Blocks.1. - Floor.1. (New WBS)		52
P1K1F11200	First Coat Painting	5
P1K1F11175	Installation of Unit Doors	1
P1K1F11150	Installation of PVC Windows	2
P1K1F11125	Ceramic Tiling	4
P1K1F11100	Gypsum Plastering	10
P1K1F11075	Screed Works	4
P1K1F11050	Installation of Electrical Conduits	5
P1K1F11035	Breakdown of Mechanical Testing Procedure - First Floor	8
P1K1F11025	Mechanical Installations Under Screed	7
P1K1F11010	Misarrangement of Mechanical Installation Team Right After Masonary Works	7
P1K1F11000	Masonry Works	5

Figure 5.2 Result of the First Alternative

Activity ID	Activity Name	Original Duration
Housing Complex-1 Case Study		184
Housing Complex-1.Blocks Blocks		184
Housing Complex-1.Blocks.1. - Floor Block 1		115
P1K11235	Changes in Landscaping Project of First Block	5
P1K11225	Landscaping	3
Housing Complex-1.Blocks.1. - Floor.1. (New WBS)		47
P1K1F11200	First Coat Painting	5
P1K1F11175	Installation of Unit Doors	1
P1K1F11150	Installation of PVC Windows	2
P1K1F11125	Ceramic Tiling	4
P1K1F11100	Gypsum Plastering	10
P1K1F11075	Screed Works	4
P1K1F11050	Installation of Electrical Conduits	5
P1K1F11035	Breakdown of Mechanical Testing Procedure - First Floor	5
P1K1F11025	Mechanical Installations Under Screed	7
P1K1F11010	Misarrangement of Mechanical Installation Team Right After Masonary Works	5
P1K1F11000	Masonry Works	5

Figure 5.3 Result of the Second Alternative

Activity ID	Activity Name	Original Duration
Housing Complex-4 Case Study		182
Housing Complex-4.Blocks Blocks		182
Housing Complex-4.Blocks.1. - Floor Block 1		114
P1K11225	Landscaping	3
P1K11235	Changes in Landscaping Project of First Block	4
Housing Complex-4.Blocks.1. - Floor.1. (New WBS)		47
P1K1F11000	Masonry Works	5
P1K1F11010	Misarrangement of Mechanical Installation Team	5
P1K1F11025	Mechanical Installations Under Screed	7
P1K1F11035	Breakdown of Mechanical Testing Procedure - F	5
P1K1F11050	Installation of Electrical Conduits	5
P1K1F11075	Screed Works	4
P1K1F11100	Gypsum Plastering	10
P1K1F11125	Ceramic Tiling	4
P1K1F11150	Installation of PVC Windows	2
P1K1F11175	Installation of Unit Doors	1
P1K1F11200	First Coat Painting	5
Housing Complex-4.Blocks.1. - Floor.2. (New WBS)-1		52
P1K1F21000	Masonry Works	5

Figure 5.4 Result of the Third Alternative

Results of three alternative methods to Primavera P6 are:

- The duration of the first alternative is **194 days**.
- The duration of the second alternative is **184 days**.
- The duration of the third alternative is **182 days**.

Here, the aim is to compare and validate the effects of critical risk factors on the project durations. The new results of the demonstrative case project have also been compared with the baseline project results. The original project duration is 160 days, and in each method, there is a delay of 20 – 30 days based on the additional activities. The three alternative methods were evaluated, and it was observed that the application of each method and calculation of their effects on the project schedule gave similar results around 190 days. One of the alternative methods could be used, or new methods could be developed to analyze the duration of critical risk factors. As expected, the completion time of the revised project schedule is later than the completion time of the baseline project schedule. The point is that delay risk factors expand project schedule, and they should be considered in construction projects. The implementation of the proposed methodology in the construction projects examines the anticipated delay risk factors and supports the decision-making procedures during risk assessment practices.

In summary, FMEA-based methodology for delay analysis of construction projects was satisfying and useful for the risk assessment process in construction projects. It was emphasized that the methodology makes it possible to insert the delay risk factor into the project schedule as an activity. It provides a practical way to use the FMEA in construction projects and helps potential users in obtaining alternative methods to mitigate the risk of delay. It should also be emphasized that the duration of risk factors could be estimated using different methods. Moreover proposed methodology could further be developed considering different risk factors, preferences of users, and strategies of companies by following the process in this thesis.

5.2 General Overview of the Thesis

Delay is the most critical, complex, hazardous, and expensive problem met in the construction industry. Ahmed et al. (2003) stated that it is required to determine the causes of delay to mitigate/ prevent the delays in projects.

During the literature review, there were two main subjects. The first one was the define delay risk factors in the construction projects. As stated, there are many causes of delay risk factors. Therefore, lots of delay risks are available in projects. However, because the construction projects are multidisciplinary, it is challenging to direct all the risks properly. Several studies have been conducted to assess the delay risk factors in construction projects. Although there are different approaches, there is no approach reflecting the direct impacts of risk factors on the project schedule.

The second main subject was detailing the FMEA process and its application. Similarly, there were many studies on FMEA. Generally, the traditional FMEA approach was used to analyze risk factors in projects. For example, FMEA was simply applied the quantitative risk analysis using historical data of accidents in construction projects. However, advanced methods were also combined with FMEA, such as Fuzzy - FMEA. There is no application of FMEA in the literature to mitigate delay risk factors in construction projects in the grand scheme of things.

In this study, the traditional FMEA approach was modified and advanced using delay risk taxonomy to control project delay risk factors. FMEA is a simple procedure that enables analysis of potential failure modes, causes, and effects on the projects. Taxonomy was formed to have a more systematic process to assess risk factors in projects. By this means, it was aimed to apply the FMEA method more successfully and appropriately. Then, the proposed methodology and demonstrative case study were presented.

The proposed methodology was developed for users to quantify and detect delay risk factors in construction projects and to assign them into the project schedule by using risk priority number (RPN) of failure mode and effect analysis (FMEA) and Primavera P6.

There are some challenges to the proposed methodology:

- Construction projects have a dynamic character. Therefore, specified delay risk factors could always change. Different delay risk factors may occur depending on the type of construction projects. It means that taxonomy might be changed, and users must control the changing circumstances of projects.
- Second, because the FMEA methodology was straightforward, it has been criticized. When carrying out the FMEA, even if there are expert opinions rather than subjective judgments for calculating RPN, precise values for RPN parameters (S, O, and D) might not be possible.
- The most critical challenge is, there is no sufficient time to take action about the risk factors in the construction projects. Decision-makers sometimes have to make a decision immediately in case of urgent risk factors. Therefore, in such cases, it may not be possible to apply the proposed methodology in the flow of the project.

Although there are challenges related to the application of the proposed methodology, its benefits are verified in the following aspects:

- First, the methodology employs delay risk taxonomy based on risk factors that are mostly encountered in projects. The implementation of taxonomy and FMEA takes many possible impacts that available in construction projects into consideration, considering a cause-effect relation of risk factors. Therefore, the consequences of the risk assessment process are more credible and accurate.
- Although subjective judgments were used to implement the proposed methodology, RPN is not the only means of evaluating delay risk factors in the proposed methodology. RPN is an important step to determine delay risk factors in the project. Then, the software is used to insert the delay risk factors into a project schedule. This gives a chance for users to evaluate and monitor risk factors and their effects on projects. In this way, the subjectivity of the methodology could be reduced.
- Moreover, the proposed methodology smooths the way for the decision-makers because the application of the proposed methodology to the software is straightforward.
- Especially for more critical projects regarding time and cost issues, it becomes more important to apply such a methodology to manage risk factors in projects by users. Considering the practical use and benefits of the FMEA (simple, easy application, having widespread acceptance), this proposed methodology can be easily adapted to different types of construction projects by different project stakeholders (owner, contractor, consultant etc.).
- Consequently, using the proposed methodology in the construction projects, users may take corrective actions about the delay risk events, accurately detect where the causes of delays occur in projects and determine a reasonable time contingency to mitigate risk rather than adding a simple lag.

In the following section, this study will be concluded. Limitations of the proposed method and future works will be covered.

CHAPTER 6

CONCLUSIONS AND RECOMMENDATIONS

This chapter presents the summary and conclusions of the study. First of all, a summary of the study is presented. Secondly, the contribution of the study is explained. Then, the limitations of the study are addressed. Finally, this chapter includes recommendations for future work.

6.1 Summary

As stated throughout the study, time equals money in construction projects. Therefore, the prediction of delays and taking corrective actions are milestones of completion of a project successfully.

This research aimed to propose a methodology for users to quantify and detect delay risk factors in construction projects and to assign them into the project schedule by using risk priority number (RPN) of failure mode and effect analysis (FMEA) and Primavera P6.

There were eight main steps of this study.

1. The first one was to identify the delay factors in construction projects. Schedule delay factors were grouped considering different categories (owner related, contractor related etc.).
2. Whereby comprehensive literature review and subjective judgment, taxonomy was obtained, which contains twenty-nine (29) delay factors.

3. To apply FMEA, each parameter of method (severity, occurrence, and detection) was rated, and RPN values were calculated through subjective judgment.
4. Critical risk factors were selected according to RPN values to analyze their effects on the project schedule.
5. The baseline schedule of the demonstrative case study was executed in Primavera P6.
6. After determining critical risk factors, three alternative methods were applied to obtain corresponding effects as a duration.
7. Each delay factor was designated as an activity in the demonstrative case study, and their durations were reflected in the project schedule in Primavera P6.
8. The results of three alternative methods were obtained in the program.

In this research, delay risk taxonomy was utilized to demonstrate and categorize the schedule delay factors to analyze delay both individually and in the corresponding group.

6.2 Contributions of the Study

As stated in the literature review, there are several applications FMEA in the construction sector to analyze risks. The findings from this research make several contributions to the current literature. These contributions include the following:

- In this study, critical risk factors were considered as an activity and inserted into the project schedule to see their impacts and to deal with not being completed on time. The proposed methodology can be used to measure any potential losses/ damages that may occur due to the schedule impact at the activity level.

- In this methodology, users could identify critical risk factors considering three parameters: probability and impact. The strength of the FMEA is the easiness of understanding the risk factors with the detectability of FMEA.
- Another contribution is that Primavera P6 could take into account change in the critical path. Therefore, this proposed methodology could be used to tackle change in the critical path.
- The research has contributed to enhancing the delay analysis in the construction sector by identifying critical risk factors in a taxonomy using FMEA that have not been addressed up to now.

As stated above, by taking account of probable outputs, users may take corrective actions or determine a reasonable time contingency for the projects to mitigate delay risks. According to the risk response plan, decision-makers could also re-execute the rating process of risk parameters to monitor the impact of critical risk factors.

Considering the advantages of the FMEA (simple, easy application, having linguistic but addressable parameters during the determination of critical risk factors, having widespread acceptance), this proposed methodology can be easily applied to all kinds of construction projects by the users/ project's participants. It can be more practical and easily adapted to current projects through enough experience and knowledge.

6.3 Limitations of the Study

The proposed methodology has some constraints:

- Although the taxonomy framework was built based on the most critical delay factors, the method is limited to the twenty-nine delay factors. Different delay risk factors may occur depending on the type of construction projects. It means that taxonomy might be supposed to change.
- During the schedule in Primavera P6, unlimited resources were assumed. However, in real construction projects, this is not the actual case. Therefore,

there might be other factors that have an impact delay risk analysis of construction projects.

- The most critical limitation is that during the application of the FMEA method, demonstrative case study and subjective judgments were used to rate parameters of RPN rather than real experts and real case study. Therefore, the rating process might not be completely trustworthy. Additionally, as stated in Chapter 3, if the proposed methodology is tested on the real project, there will also be an occasion to compare results with the final project schedule. Subjectivity is a major problem, but it is not the most important problem. There are subjective judgments in the thesis, but if real experts want to use it, they will also use their subjective judgments during the application of the methodology.
- Because of the real conditions, real project data is not present. Therefore, there is no opinion/ advice from real experts about the hypothetical project. It means that there is no chance to validate the methodology using the realized results of the study. If there is an opportunity to validate the real case study project, there should be a comparison between the conventional schedule risk assessment methods and the proposed methodology.

6.4 Recommendations for Future Works

It is suggested that future studies are to undertake in the following areas:

- The taxonomy framework could be updated in future works to reflect any changes in construction projects (existing risk factors can be eliminated, or new ones can be added).
- In the concept of this study, Primavera P6 was used, which is straightforward software. For future studies, more powerful and user-friendly programs could analyze delay factors more reliably and make problematic assumptions.

- As stated in the literature review, time and cost are the essential items of construction projects. Therefore, this proposed methodology could be improved to analyze cost overruns in construction projects.
- Finally, and most importantly, the methodology should be tested with a real expert view in a real case study. In this study, a demonstrative case study was applied as a house complex building project. Above all, the proposed methodology should be implemented in real construction projects. Future studies could also be applied to specific types of construction projects like dam construction and bridge projects.

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APPENDICES

A. Original Case Study Project in METU - CE434 Lecture

CE 434

CONSTRUCTION PLANNING

TERM PROJECT

SPRING 2019

A housing complex will be constructed on two different parcels. The structural works of the project have been finished. Students are awarded for some of the architectural works. Related activities, their durations, corresponding resources, and budgeted units are given on the following pages.

Using the given information, it was required to prepare the term project by solving the network on Primavera P6 software.

Project Data:

1. Each group's project data will be based on the team member's student IDs.
2. Block Types will be the initial of either name or surname of the member. Please make sure that there will be no duplicate in Block Types.
3. # of floors per block will be equal to the last character (7th) in the student ID of the relevant group member. If the 7th character is 0, assume it as 4.
4. # of blocks in Parcel 1 and Parcel 2 will be equal to the 2nd and the 3rd characters of the student ID, respectively.

Project Data Sample:

Table A. 1 Project Data Sample

Student ID	Surname	Name	Block Type	# of floor in blocks	# of blocks in Parcel 1	# of blocks in Parcel 2
1492859	ALTAN	EMRE	A	9 Floors	4	9→0
1384403	BİLGİN	GÖZDE	B	3 Floors	3	8
1635490	EROL	ERDEM	E	0→4 Floors	6	3
1514819	AKÇAY	CANER	C	9 Floors	5	1

Total # of Floors = 9x4 + 3x3 + 3x8 + 4x6 + 4x3 + 9x5 + 9x1 = 159

Assumptions:

1. Project start date is 01/06/2019.
2. There are six working days in a week except for Sundays.
3. Per unit, the cost for each resource is 9.00$.
4. There are official holidays in Turkey:
    - New Year's Day
    - National Sovereignty and Children's Day
    - Democracy and National Solidarity Day
    - Labor and Solidarity Day
    - Commemoration of Atatürk-Youth and Sports Day
    - Ramadan Feast
    - Sacrifice Feast
    - Victory Day
    - Republic Day

Activity & Resource Data:

Table A. 2 Activity and Resources of Lecture Project

Activity ID	Activity Name	Duration (days)	Resource	Budgeted Units
PPB#F#1000	Masonry Works	5	Bricks	662.25 m^2
PPB#F#1025	Mechanical Installations Under Screed	7	-	-
PPB#F#1050	Screed Works	4	Screed Concrete	471.13 m^2
PPB#F#1075	Installation of PVC Windows	2	-	-
PPB#F#1100	Gypsum Plastering	10	Plaster	1348.49 m^2
PPB#F#1125	Installation of Electrical Conduits	5	-	-
PPB#F#1150	Installation of Unit Doors	1	-	-
PPB#F#1175	Ceramic Tiling	4	Ceramic Tiles	94.47 m^2
PPB#F#1200	First Coat Painting	5	Paint	958.67 m^2
PPB#1225	Landscaping	3 days per building	-	-

B. Primavera P6 Results of the Baseline Schedule

Case Study | Classic Schedule Layout | 14-Jul-20 22:42

Activity ID	Activity Name	Origina Duration	Start	Finish	Total Float	Predecessors	Calendar	Budgeted Total Cost
Housing Complex-2 Case Study		160	01-Jun-20	08-Dec-20	0		Housing Complex	323,883.56
Housing Complex-2.Blocks Blocks		160	01-Jun-20	08-Dec-20	0		Housing Complex	323,883.54
Housing Complex-2.Blocks.1.-Floor Block 1		100	01-Jun-20	28-Sep-20	57		Housing Complex	174,398.6
PIK1225	Landscaping	3	25-Sep-20	28-Sep-20	57	PIK1F71200	Housing Complex	$0.00
Housing Complex-2.Blocks.1.-Floor.1. (New WBS)		37	01-Jun-20	13-Jul-20	60		Housing Complex	$24,914.12
PIK1F11000	Masonry Works	5	01-Jun-20	05-Jun-20	0		Housing Complex	$4,647.23
PIK1F11025	Mechanical Installations Under Screed	7	06-Jun-20	13-Jun-20	0	PIK1F11000	Housing Complex	$0.00
PIK1F11050	Installation of Electrical Conduits	5	06-Jun-20	11-Jun-20	2	PIK1F11000	Housing Complex	$3,217.76
PIK1F11075	Screed Works	4	15-Jun-20	18-Jun-20	0	PIK1F11050, PIK	Housing Complex	$0.00
PIK1F11100	Gypsum Plastering	10	19-Jun-20	30-Jun-20	0	PIK1F11075	Housing Complex	$9,467.57
PIK1F11125	Ceramic Tiling	4	01-Jul-20	04-Jul-20	60	PIK1F11100	Housing Complex	$0.00
PIK1F11150	Installation of PVC Windows	2	06-Jul-20	07-Jul-20	60	PIK1F11125	Housing Complex	$0.00
PIK1F11175	Installation of Unit Doors	1	06-Jul-20	06-Jul-20	61	PIK1F11125	Housing Complex	$653.45
PIK1F11200	First Coat Painting	5	08-Jul-20	13-Jul-20	60	PIK1F11175, PIK	Housing Complex	$6,928.11
Housing Complex-2.Blocks.1.-Floor.2. (New WBS)-1		42	06-Jun-20	25-Jul-20	55		Housing Complex	$24,914.12
PIK1F21000	Masonry Works	5	06-Jun-20	11-Jun-20	5	PIK1F11000	Housing Complex	$4,647.23
PIK1F21025	Mechanical Installations Under Screed	7	15-Jun-20	22-Jun-20	3	PIK1F21000, PIK	Housing Complex	$0.00
PIK1F21050	Installation of Electrical Conduits	5	12-Jun-20	17-Jun-20	7	PIK1F11050, PIK	Housing Complex	$3,217.76
PIK1F21075	Screed Works	4	23-Jun-20	26-Jun-20	3	PIK1F21050, PIK	Housing Complex	$0.00
PIK1F21100	Gypsum Plastering	10	01-Jul-20	11-Jul-20	0	PIK1F21075, PIK	Housing Complex	$9,467.57
PIK1F21125	Ceramic Tiling	4	13-Jul-20	17-Jul-20	55	PIK1F21100, PIK	Housing Complex	$0.00
PIK1F21150	Installation of PVC Windows	2	18-Jul-20	20-Jul-20	55	PIK1F21125, PIK	Housing Complex	$0.00
PIK1F21175	Installation of Unit Doors	1	18-Jul-20	18-Jul-20	56	PIK1F11175, PIK	Housing Complex	$653.45
PIK1F21200	First Coat Painting	5	21-Jul-20	25-Jul-20	55	PIK1F21175, PIK	Housing Complex	$6,928.11
Housing Complex-2.Blocks.1.-Floor.3. (New WBS)-2		47	12-Jun-20	03-Aug-20	50		Housing Complex	$24,914.12
PIK1F31000	Masonry Works	5	12-Jun-20	17-Jun-20	10	PIK1F21000	Housing Complex	$4,647.23
PIK1F31025	Mechanical Installations Under Screed	7	23-Jun-20	30-Jun-20	6	PIK1F31000, PIK	Housing Complex	$0.00
PIK1F31050	Installation of Electrical Conduits	5	18-Jun-20	23-Jun-20	12	PIK1F21050, PIK	Housing Complex	$3,217.76
PIK1F31075	Screed Works	4	01-Jul-20	04-Jul-20	6	PIK1F31050, PIK	Housing Complex	$0.00
PIK1F31100	Gypsum Plastering	10	13-Jul-20	24-Jul-20	0	PIK1F31075, PIK	Housing Complex	$9,467.57
PIK1F31125	Ceramic Tiling	4	25-Jul-20	29-Jul-20	50	PIK1F31100, PIK	Housing Complex	$0.00
PIK1F31150	Installation of PVC Windows	2	30-Jul-20	01-Aug-20	50	PIK1F31125, PIK	Housing Complex	$0.00

Figure B. 1 Activity Tables of the Baseline Schedule

Case Study	Classic Schedule Layout	14-Jul-20 22:44

Activity ID	Activity Name	Origina Duration	Start	Finish	Total Float	Predecessors	Calendar	Budgeted Total Cost
P1K1F31175	Installation of Unit Doors	1	30-Jul-20	30-Jul-20	51	P1K1F21175, P1K	Housing Complex	$653.45
P1K1F31200	First Coat Painting	5	04-Aug-20	08-Aug-20	50	P1K1F31175, P1K	Housing Complex	$6,928.11
Housing Complex-2.Blocks.1. - Floor.4. (New WBS)-3		52	18-Jun-20	20-Aug-20	45		Housing Complex	$24,914.12
P1K1F41000	Masonry Works	5	18-Jun-20	23-Jun-20	15	P1K1F31000	Housing Complex	$4,647.23
P1K1F41025	Mechanical Installations Under Screed	7	01-Jul-20	08-Jul-20	9	P1K1F41000, P1K	Housing Complex	$0.00
P1K1F41050	Installation of Electrical Conduits	5	24-Jun-20	29-Jun-20	17	P1K1F31050, P1K	Housing Complex	$3,217.76
P1K1F41075	Screed Works	4	09-Jul-20	13-Jul-20	9	P1K1F41050, P1K	Housing Complex	$0.00
P1K1F41100	Gypsum Plastering	10	25-Jul-20	07-Aug-20	0	P1K1F41075, P1K	Housing Complex	$9,467.57
P1K1F41125	Ceramic Tiling	4	08-Aug-20	12-Aug-20	45	P1K1F41100, P1K	Housing Complex	$0.00
P1K1F41150	Installation of PVC Windows	2	13-Aug-20	14-Aug-20	45	P1K1F41125, P1K	Housing Complex	$0.00
P1K1F41175	Installation of Unit Doors	1	13-Aug-20	13-Aug-20	46	P1K1F31175, P1K	Housing Complex	$653.45
P1K1F41200	First Coat Painting	5	15-Aug-20	20-Aug-20	45	P1K1F41175, P1K	Housing Complex	$6,928.11
Housing Complex-2.Blocks.1. - Floor.5. (New WBS)-4		57	24-Jun-20	01-Sep-20	40		Housing Complex	$24,914.12
P1K1F51000	Masonry Works	5	24-Jun-20	29-Jun-20	20	P1K1F41000	Housing Complex	$4,647.23
P1K1F51025	Mechanical Installations Under Screed	7	09-Jul-20	17-Jul-20	12	P1K1F51000, P1K	Housing Complex	$0.00
P1K1F51050	Installation of Electrical Conduits	5	30-Jun-20	04-Jul-20	22	P1K1F41050, P1K	Housing Complex	$3,217.76
P1K1F51075	Screed Works	4	18-Jul-20	22-Jul-20	12	P1K1F51050, P1K	Housing Complex	$0.00
P1K1F51100	Gypsum Plastering	10	08-Aug-20	19-Aug-20	0	P1K1F51075, P1K	Housing Complex	$9,467.57
P1K1F51125	Ceramic Tiling	4	20-Aug-20	24-Aug-20	40	P1K1F51100, P1K	Housing Complex	$0.00
P1K1F51150	Installation of PVC Windows	2	25-Aug-20	26-Aug-20	40	P1K1F51125, P1K	Housing Complex	$0.00
P1K1F51175	Installation of Unit Doors	1	25-Aug-20	25-Aug-20	41	P1K1F41175, P1K	Housing Complex	$653.45
P1K1F51200	First Coat Painting	5	27-Aug-20	01-Sep-20	40	P1K1F51175, P1K	Housing Complex	$6,928.11
Housing Complex-2.Blocks.1. - Floor.6. (New WBS)-5		62	30-Jun-20	12-Sep-20	35		Housing Complex	$24,914.12
P1K1F61000	Masonry Works	5	30-Jun-20	04-Jul-20	25	P1K1F51000	Housing Complex	$4,647.23
P1K1F61025	Mechanical Installations Under Screed	7	18-Jul-20	25-Jul-20	15	P1K1F61000, P1K	Housing Complex	$0.00
P1K1F61050	Installation of Electrical Conduits	5	06-Jul-20	10-Jul-20	27	P1K1F51050, P1K	Housing Complex	$3,217.76
P1K1F61075	Screed Works	4	27-Jul-20	30-Jul-20	15	P1K1F61050, P1K	Housing Complex	$0.00
P1K1F61100	Gypsum Plastering	10	20-Aug-20	31-Aug-20	0	P1K1F61075, P1K	Housing Complex	$9,467.57
P1K1F61125	Ceramic Tiling	4	01-Sep-20	04-Sep-20	35	P1K1F61100, P1K	Housing Complex	$0.00
P1K1F61150	Installation of PVC Windows	2	05-Sep-20	07-Sep-20	35	P1K1F61125, P1K	Housing Complex	$0.00
P1K1F61175	Installation of Unit Doors	1	05-Sep-20	05-Sep-20	36	P1K1F51175, P1K	Housing Complex	$653.45
P1K1F61200	First Coat Painting	5	08-Sep-20	12-Sep-20	35	P1K1F61175, P1K	Housing Complex	$6,928.11
Housing Complex-2.Blocks.1. - Floor.7. (New WBS)-6		67	06-Jul-20	24-Sep-20	30		Housing Complex	$24,914.12

Figure B. 2 Activity Tables of the Baseline Schedule (cont'd)

Case Study | Classic Schedule Layout | 14-Jul-20 22:45

Activity ID	Activity Name	Origina Duration	Start	Finish	Total Float	Predecessors	Calendar	Budgeted Total Cost
PIKIF71000	Masonry Works	5	06-Jul-20	10-Jul-20	30	PIKIF61000	Housing Complex	$4,647.23
PIKIF71025	Mechanical Installations Under Screed	7	27-Jul-20	05-Aug-20	18	PIKIF71000, PIK	Housing Complex	$0.00
PIKIF71050	Installation of Electrical Conduits	5	11-Jul-20	17-Jul-20	32	PIKIF61050, PIK	Housing Complex	$3,217.76
PIKIF71075	Screed works	4	06-Aug-20	10-Aug-20	18	PIKIF71050, PIK	Housing Complex	$0.00
PIKIF71100	Gypsum Plastering	10	01-Sep-20	11-Sep-20	0	PIKIF71075, PIK	Housing Complex	$9,467.57
PIKIF71125	Ceramic Tiling	4	12-Sep-20	16-Sep-20	30	PIKIF71100, PIK	Housing Complex	$0.00
PIKIF71150	Installation of PVC Windows	2	17-Sep-20	18-Sep-20	30	PIKIF71125, PIK	Housing Complex	$0.00
PIKIF71175	Installation of Unit Doors	1	17-Sep-20	17-Sep-20	31	PIKIF61175, PIK	Housing Complex	$653.45
PIKIF71200	First Coat Painting	5	19-Sep-20	24-Sep-20	30	PIKIF71175, PIK	Housing Complex	$6,928.11
Housing Complex-2 Blocks-2 - Floor Block 2		125	11-Jul-20	08-Dec-20	0		Housing Complex	149,484.7
PIKI1225	Landscaping	3	05-Dec-20	08-Dec-20	0	PIKIF61200, PIK	Housing Complex	$0.00
Housing Complex-2 Blocks-2 - Floor 1 (New WBS)		72	11-Jul-20	03-Oct-20	25		Housing Complex	$24,914.12
PIKIF11000	Masonry Works	5	11-Jul-20	17-Jul-20	35	PIKIF71000	Housing Complex	$4,647.23
PIKIF11025	Mechanical Installations Under Screed	7	06-Aug-20	13-Aug-20	21	PIKIF11000, PIK	Housing Complex	$0.00
PIKIF11050	Installation of Electrical Conduits	5	18-Jul-20	23-Jul-20	37	PIKIF71050, PIK	Housing Complex	$3,217.76
PIKIF11075	Screed works	4	14-Aug-20	18-Aug-20	21	PIKIF11050, PIK	Housing Complex	$0.00
PIKIF11100	Gypsum Plastering	10	12-Sep-20	23-Sep-20	0	PIKIF11075, PIK	Housing Complex	$9,467.57
PIKIF11125	Ceramic Tiling	4	24-Sep-20	28-Sep-20	25	PIKIF11100, PIK	Housing Complex	$0.00
PIKIF11150	Installation of PVC Windows	2	29-Sep-20	30-Sep-20	25	PIKIF11125, PIK	Housing Complex	$0.00
PIKIF11175	Installation of Unit Doors	1	29-Sep-20	29-Sep-20	26	PIKIF71175, PIK	Housing Complex	$653.45
PIKIF11200	First Coat Painting	5	01-Oct-20	06-Oct-20	25	PIKIF11175, PIK	Housing Complex	$6,928.11
Housing Complex-2 Blocks-2 - Floor 2 (New WBS)-1		77	18-Jul-20	17-Oct-20	20		Housing Complex	$24,914.12
PIKIF21000	Masonry Works	5	18-Jul-20	23-Jul-20	40	PIKIF11000	Housing Complex	$4,647.23
PIKIF21025	Mechanical Installations Under Screed	7	14-Aug-20	21-Aug-20	24	PIKIF21000, PIK	Housing Complex	$0.00
PIKIF21050	Installation of Electrical Conduits	5	24-Jul-20	29-Jul-20	42	PIKIF11050, PIK	Housing Complex	$3,217.76
PIKIF21075	Screed Works	4	22-Aug-20	26-Aug-20	24	PIKIF21050, PIK	Housing Complex	$0.00
PIKIF21100	Gypsum Plastering	10	24-Sep-20	05-Oct-20	0	PIKIF21075, PIK	Housing Complex	$9,467.57
PIKIF21125	Ceramic Tiling	4	06-Oct-20	09-Oct-20	20	PIKIF21100, PIK	Housing Complex	$0.00
PIKIF21150	Installation of PVC Windows	2	10-Oct-20	12-Oct-20	20	PIKIF21125, PIK	Housing Complex	$0.00
PIKIF21175	Installation of Unit Doors	1	10-Oct-20	10-Oct-20	21	PIKIF11175, PIK	Housing Complex	$653.45
PIKIF21200	First Coat Painting	5	13-Oct-20	17-Oct-20	20	PIKIF21175, PIK	Housing Complex	$6,928.11
Housing Complex-2 Blocks-2 - Floor 3 (New WBS)-2		82	24-Jul-20	30-Oct-20	15		Housing Complex	$24,914.12
PIKIF31000	Masonry Works	5	24-Jul-20	29-Jul-20	45	PIKIF21000	Housing Complex	$4,647.23

Figure B. 3 Activity Tables of the Baseline Schedule (cont'd)

Case Study	Classic Schedule Layout	14-Jul-20 22:45

Activity ID	Activity Name	Origina Duration	Start	Finish	Total Float	Predecessors	Calendar	Budgeted Total Cost
P1K2F31025	Mechanical Installations Under Screed	7	22-Aug-20	29-Aug-20	27	P1K2F31000, P1K	Housing Complex	$0.00
P1K2F31050	Installation of Electrical Conduits	5	30-Jul-20	06-Aug-20	47	P1K2F21050, P1K	Housing Complex	$3,217.76
P1K2F31075	Screed Works	4	31-Aug-20	03-Sep-20	27	P1K2F31050, P1K	Housing Complex	$0.00
P1K2F31100	Gypsum Plastering	10	06-Oct-20	16-Oct-20	0	P1K2F31075, P1K	Housing Complex	$9,467.57
P1K2F31125	Ceramic Tiling	4	17-Oct-20	21-Oct-20	15	P1K2F31100, P1K	Housing Complex	$0.00
P1K2F31150	Installation of PVC Windows	2	22-Oct-20	23-Oct-20	15	P1K2F31125, P1K	Housing Complex	$0.00
P1K2F31175	Installation of Unit Doors	1	22-Oct-20	22-Oct-20	16	P1K2F21175, P1K	Housing Complex	$653.45
P1K2F31200	First Coat Painting	5	24-Oct-20	30-Oct-20	15	P1K2F31175, P1K	Housing Complex	$6,928.11
Housing Complex-2.Blocks.2. - Floor.4. (New WBS)-3		87	30-Jul-20	11-Nov-20	10		Housing Complex	$24,914.12
P1K2F41000	Masonry Works	5	30-Jul-20	06-Aug-20	50	P1K2F31000	Housing Complex	$4,647.23
P1K2F41025	Mechanical Installations Under Screed	7	31-Aug-20	07-Sep-20	30	P1K2F41000, P1K	Housing Complex	$0.00
P1K2F41050	Installation of Electrical Conduits	5	07-Aug-20	12-Aug-20	52	P1K2F31050, P1K	Housing Complex	$3,217.76
P1K2F41075	Screed Works	4	08-Sep-20	11-Sep-20	30	P1K2F41050, P1K	Housing Complex	$0.00
P1K2F41100	Gypsum Plastering	10	17-Oct-20	28-Oct-20	0	P1K2F41075, P1K	Housing Complex	$9,467.57
P1K2F41125	Ceramic Tiling	4	30-Oct-20	03-Nov-20	10	P1K2F41100, P1K	Housing Complex	$0.00
P1K2F41150	Installation of PVC Windows	2	04-Nov-20	05-Nov-20	10	P1K2F41125, P1K	Housing Complex	$0.00
P1K2F41175	Installation of Unit Doors	1	04-Nov-20	04-Nov-20	11	P1K2F31175, P1K	Housing Complex	$653.45
P1K2F41200	First Coat Painting	5	06-Nov-20	11-Nov-20	10	P1K2F41175, P1K	Housing Complex	$6,928.11
Housing Complex-2.Blocks.2. - Floor.5. (New WBS)-4		92	07-Aug-20	23-Nov-20	5		Housing Complex	$24,914.12
P1K2F51000	Masonry Works	5	07-Aug-20	12-Aug-20	55	P1K2F41000	Housing Complex	$4,647.23
P1K2F51025	Mechanical Installations Under Screed	7	08-Sep-20	15-Sep-20	33	P1K2F51000, P1K	Housing Complex	$0.00
P1K2F51050	Installation of Electrical Conduits	5	13-Aug-20	18-Aug-20	57	P1K2F41050, P1K	Housing Complex	$3,217.76
P1K2F51075	Screed Works	4	16-Sep-20	19-Sep-20	33	P1K2F51050, P1K	Housing Complex	$0.00
P1K2F51100	Gypsum Plastering	10	30-Oct-20	10-Nov-20	0	P1K2F51075, P1K	Housing Complex	$9,467.57
P1K2F51125	Ceramic Tiling	4	11-Nov-20	14-Nov-20	5	P1K2F51100, P1K	Housing Complex	$0.00
P1K2F51150	Installation of PVC Windows	2	16-Nov-20	17-Nov-20	5	P1K2F51125, P1K	Housing Complex	$0.00
P1K2F51175	Installation of Unit Doors	1	16-Nov-20	16-Nov-20	6	P1K2F41175, P1K	Housing Complex	$653.45
P1K2F51200	First Coat Painting	5	18-Nov-20	23-Nov-20	5	P1K2F51175, P1K	Housing Complex	$6,928.11
Housing Complex-2.Blocks.2. - Floor.6. (New WBS)-5		97	13-Aug-20	04-Dec-20	0		Housing Complex	$24,914.12
P1K2F61000	Masonry Works	5	13-Aug-20	18-Aug-20	60	P1K2F51000	Housing Complex	$4,647.23
P1K2F61025	Mechanical Installations Under Screed	7	16-Sep-20	23-Sep-20	36	P1K2F61000, P1K	Housing Complex	$0.00
P1K2F61050	Installation of Electrical Conduits	5	19-Aug-20	24-Aug-20	62	P1K2F51050, P1K	Housing Complex	$3,217.76
P1K2F61075	Screed Works	4	24-Sep-20	28-Sep-20	36	P1K2F61050, P1K	Housing Complex	$0.00

Figure B. 4 Activity Tables of the Baseline Schedule (cont'd)

Case Study	Classic Schedule Layout	14-Jul-20 22:47

Activity ID	Activity Name	Origina Duration	Start	Finish	Total Float	Predecessors	Calendar	Budgeted Total Cost
P1K2F61100	Gypsum Plastering	10	11-Nov-20	21-Nov-20	0	P1K2F61075, P1K	Housing Complex	$9,467.57
P1K2F61125	Ceramic Tiling	4	23-Nov-20	26-Nov-20	0	P1K2F61100, P1K	Housing Complex	$0.00
P1K2F61150	Installation of PVC Windows	2	27-Nov-20	28-Nov-20	0	P1K2F61125, P1K	Housing Complex	$0.00
P1K2F61175	Installation of Unit Doors	1	27-Nov-20	27-Nov-20	1	P1K2F51175, P1K	Housing Complex	$653.45
P1K2F61200	First Coat Painting	5	30-Nov-20	04-Dec-20	0	P1K2F61175, P1K	Housing Complex	$6,928.11

Figure B. 5 Activity Tables of the Baseline Schedule (cont'd)

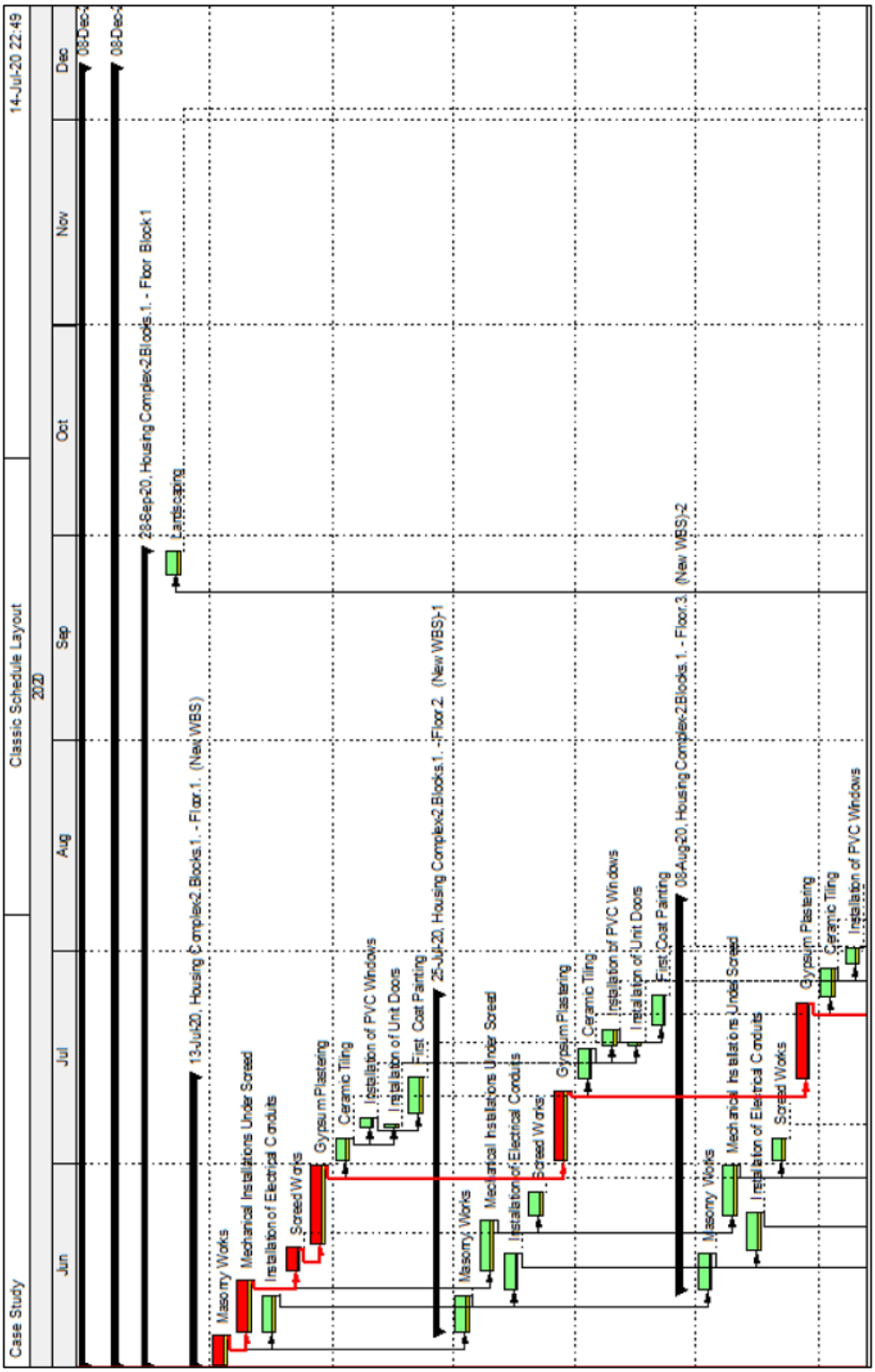

Figure B. 6 Gannt Chart of the Baseline Schedule

C. Primavera P6 Results According to the First Alternative Method

Case Study | Classic Schedule Layout | 14-Jul-20 23:19

Activity ID	Activity Name	Orgina Duration	Start	Finish	Total Float	Predecessors	Calendar	Budgetec Total Cos
Housing Complex-3 Case Study		194	01-Jun-20	18-Jan-21	0		Housing Complex	323,883.5
Housing Complex-3.Blocks Blocks		194	01-Jun-20	18-Jan-21	0		Housing Complex	323,883.5
Housing Complex-3.Blocks.1.-Floor Block 1		122	01-Jun-20	23-Oct-20	62		Housing Complex	174,398.8
PIK11225	Landscaping	3	13-Oct-20	15-Oct-20	62	PIK1F71200	Housing Complex	$0.00
PIK11235	Changes in Landscaping Project of First Block	7	16-Oct-20	23-Oct-20	62	PIK11225	Housing Complex	$0.00
Housing Complex-3.Blocks.1.- Floor1. (New WBS)		52	01-Jun-20	01-Aug-20	60		Housing Complex	$24,914.1
PIK1F11000	Masonry Works	5	01-Jun-20	05-Jun-20	0		Housing Complex	$4,647.23
PIK1F11010	Misarrangement of Mechanical Installation Team Right After I	7	06-Jun-20	13-Jun-20	0	PIK1F11000	Housing Complex	$0.00
PIK1F11025	Mechanical Installations Under Screed	7	15-Jun-20	22-Jun-20	0	PIK1F11010	Housing Complex	$0.00
PIK1F11035	Breakdown of Mechanical Testing Procedure - First Floor	8	23-Jun-20	01-Jul-20	0	PIK1F11025	Housing Complex	$0.00
PIK1F11050	Installation of Electrical Conduits	5	06-Jun-20	11-Jun-20	17	PIK1F11000	Housing Complex	$3,217.76
PIK1F11075	Screed Works	4	02-Jul-20	06-Jul-20	0	PIK1F11050, PIK	Housing Complex	$0.00
PIK1F11100	Gypsum Plastering	10	07-Jul-20	18-Jul-20	0	PIK1F11075	Housing Complex	$9,467.57
PIK1F11125	Ceramic Tiling	4	20-Jul-20	23-Jul-20	60	PIK1F11100	Housing Complex	$0.00
PIK1F11150	Installation of PVC Windows	2	24-Jul-20	25-Jul-20	60	PIK1F11125	Housing Complex	$0.00
PIK1F11175	Installation of Unit Doors	1	24-Jul-20	24-Jul-20	61	PIK1F11125	Housing Complex	$653.45
PIK1F11200	First Coat Painting	5	27-Jul-20	01-Aug-20	60	PIK1F11175, PIK	Housing Complex	$6,928.11
Housing Complex-3.Blocks.1.- Floor2. (New WBS)-1		57	06-Jun-20	14-Aug-20	55		Housing Complex	$24,914.1
PIK1F21000	Masonry Works	5	06-Jun-20	11-Jun-20	15	PIK1F11000	Housing Complex	$4,647.23
PIK1F21025	Mechanical Installations Under Screed	7	23-Jun-20	30-Jun-20	6	PIK1F21000, PIK	Housing Complex	$0.00
PIK1F21050	Installation of Electrical Conduits	5	12-Jun-20	17-Jun-20	21	PIK1F11050, PIK	Housing Complex	$3,217.76
PIK1F21075	Screed Works	4	07-Jul-20	10-Jul-20	6	PIK1F21050, PIK	Housing Complex	$0.00
PIK1F21100	Gypsum Plastering	10	20-Jul-20	30-Jul-20	0	PIK1F21075, PIK	Housing Complex	$9,467.57
PIK1F21125	Ceramic Tiling	4	01-Aug-20	06-Aug-20	55	PIK1F21100, PIK	Housing Complex	$0.00
PIK1F21150	Installation of PVC Windows	2	07-Aug-20	08-Aug-20	55	PIK1F21125, PIK	Housing Complex	$0.00
PIK1F21175	Installation of Unit Doors	1	07-Aug-20	07-Aug-20	56	PIK1F11175, PIK	Housing Complex	$653.45
PIK1F21200	First Coat Painting	5	10-Aug-20	14-Aug-20	55	PIK1F21175, PIK	Housing Complex	$6,928.11
Housing Complex-3.Blocks.1.- Floor3. (New WBS)-2		62	12-Jun-20	26-Aug-20	50		Housing Complex	$24,914.1
PIK1F31000	Masonry Works	5	12-Jun-20	17-Jun-20	17	PIK1F21000	Housing Complex	$4,647.23
PIK1F31025	Mechanical Installations Under Screed	7	01-Jul-20	08-Jul-20	6	PIK1F31000, PIK	Housing Complex	$0.00
PIK1F31035	Breakdown of Mechanical Testing Procedure - Third Floor	8	09-Jul-20	18-Jul-20	6	PIK1F31025	Housing Complex	$0.00
PIK1F31050	Installation of Electrical Conduits	5	18-Jun-20	23-Jun-20	21	PIK1F21050, PIK	Housing Complex	$3,217.76

Figure C. 1 Activity Tables of the First Alternative

Case Study	Classic Schedule Layout	14-Jul-20 23:20

Activity ID	Activity Name	Origina Duration	Start	Finish	Total Float	Predecessors	Calendar	Budgeted Total Cos
P1K1F31060	Shortage of Team Work on Electrical Installation - Third Floor	6	24-Jun-20	30-Jun-20	21	P1K1F31050	Housing Complex	$0.00
P1K1F31075	Screed Works	4	20-Jul-20	23-Jul-20	6	P1K1F21075, P1K	Housing Complex	$0.00
P1K1F31100	Gypsum Plastering	10	01-Aug-20	13-Aug-20	0	P1K1F31075, P1K	Housing Complex	$9,467.57
P1K1F31125	Ceramic Tiling	4	14-Aug-20	18-Aug-20	50	P1K1F31100, P1K	Housing Complex	$0.00
P1K1F31150	Instalation of PVC Windows	2	19-Aug-20	20-Aug-20	50	P1K1F31125, P1K	Housing Complex	$0.00
P1K1F31175	Instalation of Unit Doors	1	19-Aug-20	19-Aug-20	51	P1K1F21175, P1K	Housing Complex	$653.45
P1K1F31200	First Coat Painting	5	21-Aug-20	26-Aug-20	50	P1K1F31175, P1K	Housing Complex	$6,928.11
Housing Complex-3.Blocks.1. - Floor.4. (New WBS)-3		67	18-Jun-20	07-Sep-20	45		Housing Complex	$24,914.12
P1K1F41000	Masonry Works	5	18-Jun-20	23-Jun-20	23	P1K1F31000	Housing Complex	$4,647.23
P1K1F41010	Misarrangement of Mechanical Installation Team Right After I	7	24-Jun-20	01-Jul-20	23	P1K1F41000	Housing Complex	$0.00
P1K1F41025	Mechanical Instalations Under Screed	7	09-Jul-20	17-Jul-20	17	P1K1F41000, P1K	Housing Complex	$0.00
P1K1F41050	Instalation of Electrical Conduits	5	24-Jun-20	29-Jun-20	31	P1K1F31050, P1K	Housing Complex	$3,217.76
P1K1F41075	Screed Works	4	24-Jul-20	28-Jul-20	12	P1K1F41050, P1K	Housing Complex	$0.00
P1K1F41100	Gypsum Plastering	10	14-Aug-20	25-Aug-20	0	P1K1F41075, P1K	Housing Complex	$9,467.57
P1K1F41125	Ceramic Tiling	4	26-Aug-20	29-Aug-20	45	P1K1F41100, P1K	Housing Complex	$0.00
P1K1F41150	Instalation of PVC Windows	2	31-Aug-20	01-Sep-20	45	P1K1F41125, P1K	Housing Complex	$0.00
P1K1F41175	Instalation of Unit Doors	1	31-Aug-20	31-Aug-20	46	P1K1F31175, P1K	Housing Complex	$653.45
P1K1F41200	First Coat Painting	5	02-Sep-20	07-Sep-20	45	P1K1F41175, P1K	Housing Complex	$6,928.11
Housing Complex-3.Blocks.1. - Floor.5. (New WBS)-4		72	24-Jun-20	18-Sep-20	40		Housing Complex	$24,914.12
P1K1F51000	Masonry Works	5	24-Jun-20	29-Jun-20	31	P1K1F41000	Housing Complex	$4,647.23
P1K1F51025	Mechanical Instalations Under Screed	7	18-Jul-20	25-Jul-20	18	P1K1F51000, P1K	Housing Complex	$0.00
P1K1F51050	Instalation of Electrical Conduits	5	30-Jun-20	04-Jul-20	31	P1K1F41050, P1K	Housing Complex	$3,217.76
P1K1F51060	Shortage of Team Work on Electrical Installation - Fifth Floor	6	06-Jul-20	11-Jul-20	31	P1K1F51050	Housing Complex	$0.00
P1K1F51075	Screed Works	4	29-Jul-20	04-Aug-20	18	P1K1F41075, P1K	Housing Complex	$0.00
P1K1F51100	Gypsum Plastering	10	26-Aug-20	05-Sep-20	0	P1K1F51075, P1K	Housing Complex	$9,467.57
P1K1F51125	Ceramic Tiling	4	07-Sep-20	10-Sep-20	40	P1K1F51100, P1K	Housing Complex	$0.00
P1K1F51150	Instalation of PVC Windows	2	11-Sep-20	12-Sep-20	40	P1K1F51125, P1K	Housing Complex	$0.00
P1K1F51175	Instalation of Unit Doors	1	11-Sep-20	11-Sep-20	41	P1K1F41175, P1K	Housing Complex	$653.45
P1K1F51200	First Coat Painting	5	14-Sep-20	18-Sep-20	40	P1K1F51175, P1K	Housing Complex	$6,928.11
Housing Complex-3.Blocks.1. - Floor.6. (New WBS)-5		77	30-Jun-20	30-Sep-20	35		Housing Complex	$24,914.12
P1K1F61000	Masonry Works	5	30-Jun-20	04-Jul-20	35	P1K1F51000	Housing Complex	$4,647.23
P1K1F61025	Mechanical Instalations Under Screed	7	27-Jul-20	05-Aug-20	18	P1K1F61000, P1K	Housing Complex	$0.00
P1K1F61050	Instalation of Electrical Conduits	5	06-Jul-20	10-Jul-20	42	P1K1F51050, P1K	Housing Complex	$3,217.76

Figure C. 2 Activity Tables of the First Alternative (cont'd)

Case Study	Classic Schedule Layout	14-Jul-20 23:21

Activity ID	Activity Name	Origina Duration	Start	Finish	Total Float	Predecessors	Calendar	Budgeted Total Cost
P1K1F61075	Screed Works	4	06-Aug-20	10-Aug-20	23	P1K1F61050, P1K	Housing Complex	$0.00
P1K1F61100	Gypsum Plastering	10	07-Sep-20	17-Sep-20	0	P1K1F61075, P1K	Housing Complex	$9,467.57
P1K1F61125	Ceramic Tiling	4	18-Sep-20	22-Sep-20	35	P1K1F61100, P1K	Housing Complex	$0.00
P1K1F61150	Installation of PVC Windows	2	23-Sep-20	24-Sep-20	35	P1K1F61125, P1K	Housing Complex	$0.00
P1K1F61175	Installation of Unit Doors	1	23-Sep-20	23-Sep-20	36	P1K1F51175, P1K	Housing Complex	$653.45
P1K1F61200	First Coat Painting	5	25-Sep-20	30-Sep-20	35	P1K1F61175, P1K	Housing Complex	$6,928.11
Housing Complex-3.Blocks.1. - Floor.7. (New WBS)-6		82	06-Jul-20	12-Oct-20	30		Housing Complex	$24,914.12
P1K1F71000	Masonry Works	5	06-Jul-20	10-Jul-20	37	P1K1F61000	Housing Complex	$4,647.23
P1K1F71025	Mechanical Installations Under Screed	7	06-Aug-20	13-Aug-20	18	P1K1F71000, P1K	Housing Complex	$0.00
P1K1F71035	Breakdown of Mechanical Testing Procedure - Seventh Flo	8	14-Aug-20	22-Aug-20	18	P1K1F71025	Housing Complex	$0.00
P1K1F71050	Installation of Electrical Conduits	5	11-Jul-20	17-Jul-20	42	P1K1F61050, P1K	Housing Complex	$3,217.76
P1K1F71075	Screed works	4	24-Aug-20	27-Aug-20	18	P1K1F71050, P1K	Housing Complex	$0.00
P1K1F71100	Gypsum Plastering	10	18-Sep-20	29-Sep-20	0	P1K1F71075, P1K	Housing Complex	$9,467.57
P1K1F71125	Ceramic Tiling	4	30-Sep-20	03-Oct-20	30	P1K1F71100, P1K	Housing Complex	$0.00
P1K1F71150	Installation of PVC Windows	2	05-Oct-20	06-Oct-20	30	P1K1F71125, P1K	Housing Complex	$0.00
P1K1F71175	Installation of Unit Doors	1	05-Oct-20	05-Oct-20	31	P1K1F61175, P1K	Housing Complex	$653.45
P1K1F71200	First Coat Painting	5	07-Oct-20	12-Oct-20	30	P1K1F71175, P1K	Housing Complex	$6,928.11
Housing Complex-3.Blocks.2. - Floor Block 2		159	11-Jul-20	18-Jan-21	0		Housing Complex	-149,484.7
P1K21225	Landscaping	3	07-Jan-21	09-Jan-21	0	P1K21235, P1K11	Housing Complex	$0.00
P1K21235	Miscalculation of Completion Time - Second Block	12	23-Dec-20	06-Jan-21	0	P1K2F61200	Housing Complex	$0.00
P1K21245	Changes in Landscaping Project of Second Block	7	11-Jan-21	18-Jan-21	0	P1K21225	Housing Complex	$0.00
Housing Complex-3.Blocks.2. - Floor.1. (New WBS)		87	11-Jul-20	23-Oct-20	25		Housing Complex	$24,914.12
P1K2F11000	Masonry Works	5	11-Jul-20	17-Jul-20	42	P1K1F71000	Housing Complex	$4,647.23
P1K2F11025	Mechanical Installations Under Screed	7	14-Aug-20	21-Aug-20	24	P1K2F11000, P1K	Housing Complex	$0.00
P1K2F11050	Installation of Electrical Conduits	5	18-Jul-20	23-Jul-20	42	P1K1F71050, P1K	Housing Complex	$3,217.76
P1K2F11060	Shortage of Team Work on Electrical Installation - First Floor	5	24-Jul-20	29-Jul-20	42	P1K2F11050	Housing Complex	$0.00
P1K2F11075	Screed works	6	28-Aug-20	03-Sep-20	19	P1K1F71075, P1K	Housing Complex	$0.00
P1K2F11085	Missing Weep Screeds in 2nd Block	3	04-Sep-20	07-Sep-20	19	P1K2F11075	Housing Complex	$0.00
P1K2F11100	Gypsum Plastering	10	30-Sep-20	10-Oct-20	0	P1K1F71100, P1K	Housing Complex	$9,467.57
P1K2F11125	Ceramic Tiling	4	12-Oct-20	15-Oct-20	25	P1K2F11100, P1K	Housing Complex	$0.00
P1K2F11150	Installation of PVC Windows	2	16-Oct-20	17-Oct-20	25	P1K2F11125, P1K	Housing Complex	$0.00
P1K2F11175	Installation of Unit Doors	1	16-Oct-20	16-Oct-20	26	P1K1F71175, P1K	Housing Complex	$653.45
P1K2F11200	First Coat Painting	5	19-Oct-20	23-Oct-20	25	P1K2F11175, P1K	Housing Complex	$6,928.11

Figure C. 3 Activity Tables of the First Alternative (cont'd)

Case Study	Classic Schedule Layout	14-Jul-20 23:22

Activity ID	Activity Name	Origina Duration	Start	Finish	Total Flo al	Predecessors	Calendar	Budgeted Total Cost
Housing Complex-3.Blocks.2. - Floor.2. (New WBS)-1		92	18-Jul-20	05-Nov-20	20		Housing Complex	$24,914.12
P1K2F21000	Masonry Works	5	18-Jul-20	23-Jul-20	45	P1K2F11000	Housing Complex	$4,647.23
P1K2F21010	Misarrangement of Mechanical Installation Team Right After I	7	24-Jul-20	01-Aug-20	45	P1K2F21000	Housing Complex	$0.00
P1K2F21025	Mechanical Instalations Under Screed	7	22-Aug-20	29-Aug-20	29	P1K2F11025, P1K	Housing Complex	$0.00
P1K2F21050	Instalation of Electrical Conduits	5	24-Jul-20	29-Jul-20	54	P1K2F11050, P1K	Housing Complex	$3,217.76
P1K2F21075	Screed Works	4	08-Sep-20	11-Sep-20	22	P1K2F21050, P1K	Housing Complex	$0.00
P1K2F21085	Missing Weep Screeds in 2nd Block	3	12-Sep-20	15-Sep-20	22	P1K2F21075	Housing Complex	$0.00
P1K2F21100	Gypsum Plastering	10	12-Oct-20	22-Oct-20	0	P1K2F11100, P1K	Housing Complex	$9,467.57
P1K2F21125	Ceramic Tiling	4	23-Oct-20	27-Oct-20	20	P1K2F21100, P1K	Housing Complex	$0.00
P1K2F21150	Instalation of PVC Windows	2	28-Oct-20	30-Oct-20	20	P1K2F21125, P1K	Housing Complex	$0.00
P1K2F21175	Instalation of Unit Doors	1	28-Oct-20	28-Oct-20	21	P1K2F11175, P1K	Housing Complex	$653.45
P1K2F21200	First Coat Painting	5	31-Oct-20	05-Nov-20	20	P1K2F21175, P1K	Housing Complex	$6,928.11
Housing Complex-3.Blocks.2. - Floor.3. (New WBS)-2		97	24-Jul-20	17-Nov-20	15		Housing Complex	$24,914.12
P1K2F31000	Masonry Works	5	24-Jul-20	29-Jul-20	57	P1K2F21000	Housing Complex	$4,647.23
P1K2F31025	Mechanical Instalations Under Screed	7	31-Aug-20	07-Sep-20	32	P1K2F31000, P1K	Housing Complex	$0.00
P1K2F31050	Instalation of Electrical Conduits	5	30-Jul-20	06-Aug-20	59	P1K2F21050, P1K	Housing Complex	$3,217.76
P1K2F31075	Screed Works	4	16-Sep-20	19-Sep-20	25	P1K2F31050, P1K	Housing Complex	$0.00
P1K2F31085	Missing Weep Screeds in 2nd Block	3	21-Sep-20	23-Sep-20	25	P1K2F31075	Housing Complex	$0.00
P1K2F31100	Gypsum Plastering	10	23-Oct-20	04-Nov-20	0	P1K2F21100, P1K	Housing Complex	$9,467.57
P1K2F31125	Ceramic Tiling	4	05-Nov-20	09-Nov-20	15	P1K2F31100, P1K	Housing Complex	$0.00
P1K2F31150	Instalation of PVC Windows	2	10-Nov-20	11-Nov-20	15	P1K2F31125, P1K	Housing Complex	$0.00
P1K2F31175	Instalation of Unit Doors	1	10-Nov-20	10-Nov-20	16	P1K2F21175, P1K	Housing Complex	$653.45
P1K2F31200	First Coat Painting	5	12-Nov-20	17-Nov-20	15	P1K2F31175, P1K	Housing Complex	$6,928.11
Housing Complex-3.Blocks.2. - Floor.4. (New WBS)-3		102	30-Jul-20	28-Nov-20	10		Housing Complex	$24,914.12
P1K2F41000	Masonry Works	5	30-Jul-20	06-Aug-20	60	P1K2F31000	Housing Complex	$4,647.23
P1K2F41025	Mechanical Instalations Under Screed	7	08-Sep-20	15-Sep-20	35	P1K2F41000, P1K	Housing Complex	$0.00
P1K2F41050	Instalation of Electrical Conduits	5	07-Aug-20	12-Aug-20	64	P1K2F31050, P1K	Housing Complex	$3,217.76
P1K2F41075	Screed Works	4	24-Sep-20	28-Sep-20	28	P1K2F41050, P1K	Housing Complex	$0.00
P1K2F41085	Missing Weep Screeds in 2nd Block	3	29-Sep-20	01-Oct-20	28	P1K2F41075	Housing Complex	$0.00
P1K2F41100	Gypsum Plastering	10	05-Nov-20	16-Nov-20	0	P1K2F31100, P1K	Housing Complex	$9,467.57
P1K2F41125	Ceramic Tiling	4	17-Nov-20	20-Nov-20	10	P1K2F41100, P1K	Housing Complex	$0.00
P1K2F41150	Instalation of PVC Windows	2	21-Nov-20	23-Nov-20	10	P1K2F41125, P1K	Housing Complex	$0.00
P1K2F41175	Instalation of Unit Doors	1	21-Nov-20	21-Nov-20	11	P1K2F31175, P1K	Housing Complex	$653.45

Figure C. 4 Activity Tables of the First Alternative (cont'd)

Case Study	Classic Schedule Layout						14-Jul-20 23:23
Activity ID	Activity Name	Origina Duration	Start	Finish	Total Float	Predecessors	Calendar	Budgeted Total Cost
P1K2F41200	First Coat Painting	5	24-Nov-20	28-Nov-20	10	P1K2F41175, P1K	Housing Complex	$6,928.11
Housing Complex-3.Blocks.2. - Floor.5. (New WBS)-4		107	07-Aug-20	10-Dec-20	5		Housing Complex	$24,914.12
P1K2F51000	Masonry Works	5	07-Aug-20	12-Aug-20	60	P1K2F41000	Housing Complex	$4,647.23
P1K2F51010	Misarrangement of Mechanical Installation Team Right After I	7	13-Aug-20	20-Aug-20	60	P1K2F51000	Housing Complex	$0.00
P1K2F51025	Mechanical Installations Under Screed	7	16-Sep-20	23-Sep-20	38	P1K2F41025, P1K	Housing Complex	$0.00
P1K2F51050	Installation of Electrical Conduits	5	13-Aug-20	18-Aug-20	69	P1K2F41050, P1K	Housing Complex	$3,217.76
P1K2F51075	Screed Works	4	02-Oct-20	06-Oct-20	31	P1K2F51050, P1K	Housing Complex	$0.00
P1K2F51085	Missing Weep Screeds in 2nd Block	3	07-Oct-20	09-Oct-20	31	P1K2F51075	Housing Complex	$0.00
P1K2F51100	Gypsum Plastering	10	17-Nov-20	27-Nov-20	0	P1K2F41100, P1K	Housing Complex	$9,467.57
P1K2F51125	Ceramic Tiling	4	28-Nov-20	02-Dec-20	5	P1K2F51100, P1K	Housing Complex	$0.00
P1K2F51150	Installation of PVC Windows	2	03-Dec-20	04-Dec-20	5	P1K2F51125, P1K	Housing Complex	$0.00
P1K2F51175	Installation of Unit Doors	1	03-Dec-20	03-Dec-20	6	P1K2F41175, P1K	Housing Complex	$653.45
P1K2F51200	First Coat Painting	5	05-Dec-20	10-Dec-20	5	P1K2F51175, P1K	Housing Complex	$6,928.11
Housing Complex-3.Blocks.2. - Floor.6. (New WBS)-5		112	13-Aug-20	22-Dec-20	0		Housing Complex	$24,914.12
P1K2F61000	Masonry Works	5	13-Aug-20	18-Aug-20	72	P1K2F51000	Housing Complex	$4,647.23
P1K2F61025	Mechanical Installations Under Screed	7	24-Sep-20	01-Oct-20	41	P1K2F61000, P1K	Housing Complex	$0.00
P1K2F61050	Installation of Electrical Conduits	5	19-Aug-20	24-Aug-20	74	P1K2F51050, P1K	Housing Complex	$3,217.76
P1K2F61075	Screed Works	4	10-Oct-20	14-Oct-20	34	P1K2F61050, P1K	Housing Complex	$0.00
P1K2F61085	Missing Weep Screeds in 2nd Block	3	15-Oct-20	17-Oct-20	34	P1K2F61075	Housing Complex	$0.00
P1K2F61100	Gypsum Plastering	10	28-Nov-20	09-Dec-20	0	P1K2F51100, P1K	Housing Complex	$9,467.57
P1K2F61125	Ceramic Tiling	4	10-Dec-20	14-Dec-20	0	P1K2F61100, P1K	Housing Complex	$0.00
P1K2F61150	Installation of PVC Windows	2	15-Dec-20	16-Dec-20	0	P1K2F61125, P1K	Housing Complex	$0.00
P1K2F61175	Installation of Unit Doors	1	15-Dec-20	15-Dec-20	1	P1K2F51175, P1K	Housing Complex	$653.45
P1K2F61200	First Coat Painting	5	17-Dec-20	22-Dec-20	0	P1K2F61175, P1K	Housing Complex	$6,928.11

Figure C. 5 Activity Tables of the First Alternative (cont'd)

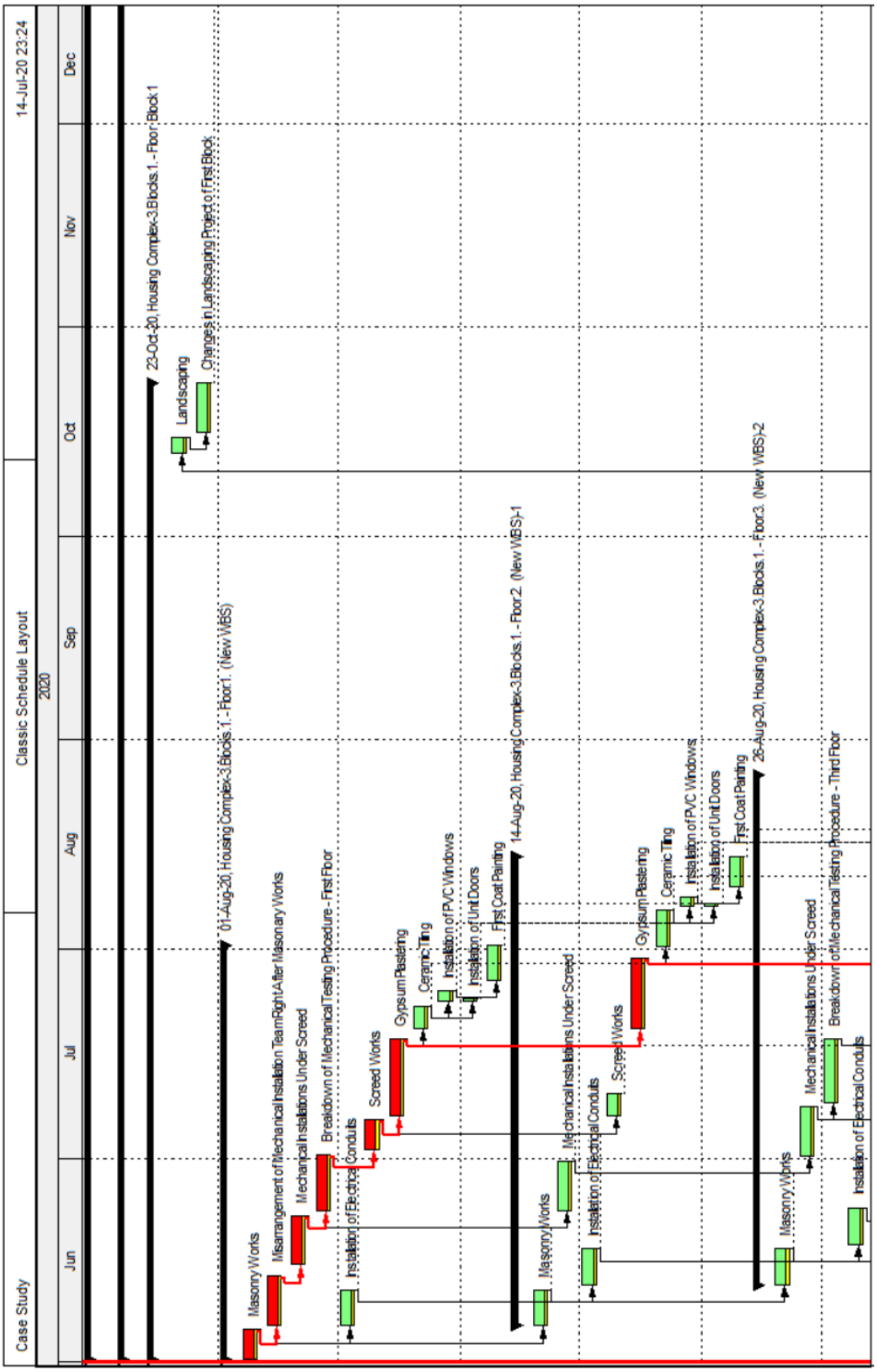

Figure C. 6 Gantt Chart of the First Alternative

D. Primavera P6 Results According to the Second Alternative Method

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Activity ID	Activity Name	Original Duration	Start	Finish	Total Float	Predecessors	Calendar	Budgeted Total Cost
Housing Complex-1 Case Study		184	01-Jun-20	06-Jan-21	0		Housing Complex	323,883.56
Housing Complex-1.Blocks Blocks		184	01-Jun-20	06-Jan-21	0		Housing Complex	323,883.56
Housing Complex-1.Blocks.1.- Floor Block 1		115	01-Jun-20	15-Oct-20	61		Housing Complex	1,174,398.85
PIK11225	Landscaping	3	07-Oct-20	09-Oct-20	61	PIK1F71200	Housing Complex	$0.00
PIK11235	Changes in Landscaping Project of First Block	5	10-Oct-20	15-Oct-20	61	PIK11225	Housing Complex	$0.00
Housing Complex-1.Blocks.1.- Floor1. (New WBS)		47	01-Jun-20	25-Jul-20	60		Housing Complex	$24,914.12
PIK1F11000	Masonry Works	5	01-Jun-20	05-Jun-20	0		Housing Complex	$4,647.23
PIK1F11010	Misarrangement of Mechanical Installation Team Right After	5	06-Jun-20	11-Jun-20	0	PIK1F11000	Housing Complex	$0.00
PIK1F11025	Mechanical Installations Under Screed	7	12-Jun-20	19-Jun-20	0	PIK1F11010	Housing Complex	$0.00
PIK1F11035	Breakdown of Mechanical Testing Procedure - First Floor	5	20-Jun-20	25-Jun-20	0	PIK1F11025	Housing Complex	$0.00
PIK1F11050	Installation of Electrical Conduits	5	06-Jun-20	11-Jun-20	12	PIK1F11000	Housing Complex	$3,217.76
PIK1F11075	Screed Works	4	26-Jun-20	30-Jun-20	0	PIK1F11050, PIK	Housing Complex	$0.00
PIK1F11100	Gypsum Plastering	10	01-Jul-20	11-Jul-20	0	PIK1F11075	Housing Complex	$9,467.57
PIK1F11125	Ceramic Tiling	4	13-Jul-20	17-Jul-20	60	PIK1F11100	Housing Complex	$0.00
PIK1F11150	Installation of PVC Windows	2	18-Jul-20	20-Jul-20	60	PIK1F11125	Housing Complex	$0.00
PIK1F11175	Installation of Unit Doors	1	18-Jul-20	18-Jul-20	61	PIK1F11125	Housing Complex	$653.45
PIK1F11200	First Coat Painting	5	21-Jul-20	25-Jul-20	60	PIK1F11175, PIK	Housing Complex	$6,928.11
Housing Complex-1.Blocks.1.- Floor2. (New WBS)-1		52	06-Jun-20	03-Aug-20	55		Housing Complex	$24,914.12
PIK1F21000	Masonry Works	5	06-Jun-20	11-Jun-20	13	PIK1F11000	Housing Complex	$4,647.23
PIK1F21025	Mechanical Installations Under Screed	7	20-Jun-20	27-Jun-20	6	PIK1F21000, PIK	Housing Complex	$0.00
PIK1F21050	Installation of Electrical Conduits	5	12-Jun-20	17-Jun-20	17	PIK1F11050, PIK	Housing Complex	$3,217.76
PIK1F21075	Screed Works	4	01-Jul-20	04-Jul-20	6	PIK1F21050, PIK	Housing Complex	$0.00
PIK1F21100	Gypsum Plastering	10	13-Jul-20	24-Jul-20	0	PIK1F21075, PIK	Housing Complex	$9,467.57
PIK1F21125	Ceramic Tiling	4	25-Jul-20	29-Jul-20	55	PIK1F21100, PIK	Housing Complex	$0.00
PIK1F21150	Installation of PVC Windows	2	30-Jul-20	01-Aug-20	55	PIK1F21125, PIK	Housing Complex	$0.00
PIK1F21175	Installation of Unit Doors	1	30-Jul-20	30-Jul-20	56	PIK1F11175, PIK	Housing Complex	$653.45
PIK1F21200	First Coat Painting	5	04-Aug-20	08-Aug-20	55	PIK1F21175, PIK	Housing Complex	$6,928.11
Housing Complex-1.Blocks.1.- Floor3. (New WBS)-2		57	12-Jun-20	20-Aug-20	50		Housing Complex	$24,914.12
PIK1F31000	Masonry Works	5	12-Jun-20	17-Jun-20	15	PIK1F21000	Housing Complex	$4,647.23
PIK1F31025	Mechanical Installations Under Screed	7	29-Jun-20	06-Jul-20	6	PIK1F31000, PIK	Housing Complex	$0.00
PIK1F31035	Breakdown of Mechanical Testing Procedure - Third Floor	5	07-Jul-20	11-Jul-20	6	PIK1F31025	Housing Complex	$0.00
PIK1F31050	Installation of Electrical Conduits	5	18-Jun-20	23-Jun-20	18	PIK1F21050, PIK	Housing Complex	$3,217.76

Figure D. 1 Activity Tables of the Second Alternative

Case Study	Classic Schedule Layout	14-Jul-20 23:27

Activity ID	Activity Name	Origina Duration	Start	Finish	Total Float	Predecessors	Calendar	Budgeted Total Cost
P1K1F31060	Shortage of Team Work on Electrical Installation - Third Floor	4	24-Jun-20	27-Jun-20	18	P1K1F31050	Housing Complex	$0.00
P1K1F31075	Screed Works	4	13-Jul-20	17-Jul-20	6	P1K1F21075, P1K	Housing Complex	$0.00
P1K1F31100	Gypsum Plastering	10	25-Jul-20	07-Aug-20	0	P1K1F31075, P1K	Housing Complex	$9,467.57
P1K1F31125	Ceramic Tiling	4	08-Aug-20	12-Aug-20	50	P1K1F31100, P1K	Housing Complex	$0.00
P1K1F31150	Installation of PVC Windows	2	13-Aug-20	14-Aug-20	50	P1K1F31125, P1K	Housing Complex	$0.00
P1K1F31175	Installation of Unit Doors	1	13-Aug-20	13-Aug-20	51	P1K1F21175, P1K	Housing Complex	$653.45
P1K1F31200	First Coat Painting	5	15-Aug-20	20-Aug-20	50	P1K1F31175, P1K	Housing Complex	$6,928.11
Housing Complex-1.Blocks.1. - Floor.4. (New WBS)-3		62	18-Jun-20	01-Sep-20	45		Housing Complex	$24,914.12
P1K1F41000	Masonry Works	5	18-Jun-20	23-Jun-20	20	P1K1F31000	Housing Complex	$4,647.23
P1K1F41010	Misarrangement of Mechanical Installation Team Right After I	5	24-Jun-20	29-Jun-20	20	P1K1F41000	Housing Complex	$0.00
P1K1F41025	Mechanical Installations Under Screed	7	07-Jul-20	14-Jul-20	14	P1K1F41000, P1K	Housing Complex	$0.00
P1K1F41050	Installation of Electrical Conduits	5	24-Jun-20	29-Jun-20	27	P1K1F31050, P1K	Housing Complex	$3,217.76
P1K1F41075	Screed Works	4	18-Jul-20	22-Jul-20	12	P1K1F41050, P1K	Housing Complex	$0.00
P1K1F41100	Gypsum Plastering	10	08-Aug-20	19-Aug-20	0	P1K1F41075, P1K	Housing Complex	$9,467.57
P1K1F41125	Ceramic Tiling	4	20-Aug-20	24-Aug-20	45	P1K1F41100, P1K	Housing Complex	$0.00
P1K1F41150	Installation of PVC Windows	2	25-Aug-20	26-Aug-20	45	P1K1F41125, P1K	Housing Complex	$0.00
P1K1F41175	Installation of Unit Doors	1	25-Aug-20	25-Aug-20	46	P1K1F31175, P1K	Housing Complex	$653.45
P1K1F41200	First Coat Painting	5	27-Aug-20	01-Sep-20	45	P1K1F41175, P1K	Housing Complex	$6,928.11
Housing Complex-1.Blocks.1. - Floor.5. (New WBS)-4		67	24-Jun-20	12-Sep-20	40		Housing Complex	$24,914.12
P1K1F51000	Masonry Works	5	24-Jun-20	29-Jun-20	28	P1K1F41000	Housing Complex	$4,647.23
P1K1F51025	Mechanical Installations Under Screed	7	16-Jul-20	23-Jul-20	17	P1K1F51000, P1K	Housing Complex	$0.00
P1K1F51050	Installation of Electrical Conduits	5	30-Jun-20	04-Jul-20	28	P1K1F41050, P1K	Housing Complex	$3,217.76
P1K1F51060	Shortage of Team Work on Electrical Installation - Fifth Floor	4	06-Jul-20	09-Jul-20	28	P1K1F51050	Housing Complex	$0.00
P1K1F51075	Screed Works	4	24-Jul-20	28-Jul-20	17	P1K1F41075, P1K	Housing Complex	$0.00
P1K1F51100	Gypsum Plastering	10	20-Aug-20	31-Aug-20	0	P1K1F51075, P1K	Housing Complex	$9,467.57
P1K1F51125	Ceramic Tiling	4	01-Sep-20	04-Sep-20	40	P1K1F51100, P1K	Housing Complex	$0.00
P1K1F51150	Installation of PVC Windows	2	05-Sep-20	07-Sep-20	40	P1K1F51125, P1K	Housing Complex	$0.00
P1K1F51175	Installation of Unit Doors	1	05-Sep-20	05-Sep-20	41	P1K1F41175, P1K	Housing Complex	$653.45
P1K1F51200	First Coat Painting	5	08-Sep-20	12-Sep-20	40	P1K1F51175, P1K	Housing Complex	$6,928.11
Housing Complex-1.Blocks.1. - Floor.6. (New WBS)-5		72	30-Jun-20	24-Sep-20	35		Housing Complex	$24,914.12
P1K1F61000	Masonry Works	5	30-Jun-20	04-Jul-20	33	P1K1F51000	Housing Complex	$4,647.23
P1K1F61025	Mechanical Installations Under Screed	7	24-Jul-20	01-Aug-20	18	P1K1F61000, P1K	Housing Complex	$0.00
P1K1F61050	Installation of Electrical Conduits	5	06-Jul-20	10-Jul-20	37	P1K1F51050, P1K	Housing Complex	$3,217.76

Figure D. 2 Activity Tables of the Second Alternative (cont'd)

Case Study	Classic Schedule Layout	14-Jul-20 23:27

Activity ID	Activity Name	Origina Duration	Start	Finish	Total Float	Predecessors	Calendar	Budgeted Total Cost
P1K1F61075	Screed Works	4	04-Aug-20	07-Aug-20	20	P1K1F61050, P1K	Housing Complex	$0.00
P1K1F61100	Gypsum Plastering	10	01-Sep-20	11-Sep-20	0	P1K1F61075, P1K	Housing Complex	$9,467.57
P1K1F61125	Ceramic Tiling	4	12-Sep-20	16-Sep-20	35	P1K1F61100, P1K	Housing Complex	$0.00
P1K1F61150	Installation of PVC Windows	2	17-Sep-20	18-Sep-20	35	P1K1F61125, P1K	Housing Complex	$0.00
P1K1F61175	Installation of Unit Doors	1	17-Sep-20	17-Sep-20	36	P1K1F51175, P1K	Housing Complex	$653.45
P1K1F61200	First Coat Painting	5	19-Sep-20	24-Sep-20	35	P1K1F61175, P1K	Housing Complex	$6,928.11
Housing Complex-1.Blocks.1. - Floor.7. (New WBS)-6		77	06-Jul-20	06-Oct-20	30		Housing Complex	$24,914.12
P1K1F71000	Masonry Works	5	06-Jul-20	10-Jul-20	35	P1K1F61000	Housing Complex	$4,647.23
P1K1F71025	Mechanical Installations Under Screed	7	04-Aug-20	11-Aug-20	18	P1K1F71000, P1K	Housing Complex	$0.00
P1K1F71035	Breakdown of Mechanical Testing Procedure - Seventh Flo	5	12-Aug-20	17-Aug-20	18	P1K1F71025	Housing Complex	$0.00
P1K1F71050	Installation of Electrical Conduits	5	11-Jul-20	17-Jul-20	39	P1K1F61050, P1K	Housing Complex	$3,217.76
P1K1F71075	Screed works	4	18-Aug-20	21-Aug-20	18	P1K1F71050, P1K	Housing Complex	$0.00
P1K1F71100	Gypsum Plastering	10	12-Sep-20	23-Sep-20	0	P1K1F71075, P1K	Housing Complex	$9,467.57
P1K1F71125	Ceramic Tiling	4	24-Sep-20	28-Sep-20	30	P1K1F71100, P1K	Housing Complex	$0.00
P1K1F71150	Installation of PVC Windows	2	29-Sep-20	30-Sep-20	30	P1K1F71125, P1K	Housing Complex	$0.00
P1K1F71175	Installation of Unit Doors	1	29-Sep-20	29-Sep-20	31	P1K1F61175, P1K	Housing Complex	$653.45
P1K1F71200	First Coat Painting	5	01-Oct-20	06-Oct-20	30	P1K1F71175, P1K	Housing Complex	$6,928.11
Housing Complex-1.Blocks.2. - Floor Block 2		149	11-Jul-20	06-Jan-21	0		Housing Complex	:149,484.7:
P1K21225	Landscaping	3	28-Dec-20	30-Dec-20	0	P1K21235, P1K11:	Housing Complex	$0.00
P1K21235	Miscalculation of Completion Time - Second Block	9	17-Dec-20	26-Dec-20	0	P1K2F61200	Housing Complex	$0.00
P1K21245	Changes in Landscaping Project of Second Block	5	31-Dec-20	06-Jan-21	0	P1K21225	Housing Complex	$0.00
Housing Complex-1.Blocks.2. - Floor.1. (New WBS)		82	11-Jul-20	17-Oct-20	25		Housing Complex	$24,914.12
P1K2F11000	Masonry Works	5	11-Jul-20	17-Jul-20	39	P1K1F71000	Housing Complex	$4,647.23
P1K2F11025	Mechanical Installations Under Screed	7	12-Aug-20	19-Aug-20	22	P1K2F11000, P1K	Housing Complex	$0.00
P1K2F11050	Installation of Electrical Conduits	5	18-Jul-20	23-Jul-20	39	P1K1F71050, P1K	Housing Complex	$3,217.76
P1K2F11060	Shortage of Team Work on Electrical Installation - First Floor	4	24-Jul-20	28-Jul-20	39	P1K2F11050	Housing Complex	$0.00
P1K2F11075	Screed works	6	22-Aug-20	28-Aug-20	20	P1K1F71075, P1K	Housing Complex	$0.00
P1K2F11085	Missing Weep Screeds in 2nd Block	2	29-Aug-20	31-Aug-20	20	P1K2F11075	Housing Complex	$0.00
P1K2F11100	Gypsum Plastering	10	24-Sep-20	05-Oct-20	0	P1K1F71100, P1K	Housing Complex	$9,467.57
P1K2F11125	Ceramic Tiling	4	06-Oct-20	09-Oct-20	25	P1K2F11100, P1K	Housing Complex	$0.00
P1K2F11150	Installation of PVC Windows	2	10-Oct-20	12-Oct-20	25	P1K2F11125, P1K	Housing Complex	$0.00
P1K2F11175	Installation of Unit Doors	1	10-Oct-20	10-Oct-20	26	P1K1F71175, P1K	Housing Complex	$653.45
P1K2F11200	First Coat Painting	5	13-Oct-20	17-Oct-20	25	P1K2F11175, P1K	Housing Complex	$6,928.11

Figure D. 3 Activity Tables of the Second Alternative (cont'd)

Case Study	Classic Schedule Layout	14-Jul-20 23:28

Activity ID	Activity Name	Origina Duration	Start	Finish	Total Float	Predecessors	Calendar	Budgeted Total Cost
Housing Complex-1.Blocks.2. - Floor.2. (New WBS)-1		87	18-Jul-20	30-Oct-20	20		Housing Complex	$24,914.12
P1K2F21000	Masonry Works	5	18-Jul-20	23-Jul-20	43	P1K2F11000	Housing Complex	$4,647.23
P1K2F21010	Misarrangement of Mechanical Installation Team Right After I	5	24-Jul-20	29-Jul-20	43	P1K2F21000	Housing Complex	$0.00
P1K2F21025	Mechanical Installations Under Screed	7	20-Aug-20	27-Aug-20	27	P1K2F11025, P1K	Housing Complex	$0.00
P1K2F21050	Installation of Electrical Conduits	5	24-Jul-20	29-Jul-20	50	P1K2F11050, P1K	Housing Complex	$3,217.76
P1K2F21075	Screed Works	4	01-Sep-20	04-Sep-20	24	P1K2F21050, P1K	Housing Complex	$0.00
P1K2F21085	Missing Weep Screeds in 2nd Block	2	05-Sep-20	07-Sep-20	24	P1K2F21075	Housing Complex	$0.00
P1K2F21100	Gypsum Plastering	10	06-Oct-20	16-Oct-20	0	P1K2F11100, P1K	Housing Complex	$9,467.57
P1K2F21125	Ceramic Tiling	4	17-Oct-20	21-Oct-20	20	P1K2F21100, P1K	Housing Complex	$0.00
P1K2F21150	Installation of PVC Windows	2	22-Oct-20	23-Oct-20	20	P1K2F21125, P1K	Housing Complex	$0.00
P1K2F21175	Installation of Unit Doors	1	22-Oct-20	22-Oct-20	21	P1K2F11175, P1K	Housing Complex	$653.45
P1K2F21200	First Coat Painting	5	24-Oct-20	30-Oct-20	20	P1K2F21175, P1K	Housing Complex	$6,928.11
Housing Complex-1.Blocks.2. - Floor.3. (New WBS)-2		92	24-Jul-20	11-Nov-20	15		Housing Complex	$24,914.12
P1K2F31000	Masonry Works	5	24-Jul-20	29-Jul-20	53	P1K2F21000	Housing Complex	$4,647.23
P1K2F31025	Mechanical Installations Under Screed	7	28-Aug-20	04-Sep-20	30	P1K2F31000, P1K	Housing Complex	$0.00
P1K2F31050	Installation of Electrical Conduits	5	30-Jul-20	06-Aug-20	55	P1K2F21050, P1K	Housing Complex	$3,217.76
P1K2F31075	Screed Works	4	08-Sep-20	11-Sep-20	28	P1K2F31050, P1K	Housing Complex	$0.00
P1K2F31085	Missing Weep Screeds in 2nd Block	2	12-Sep-20	14-Sep-20	28	P1K2F31075	Housing Complex	$0.00
P1K2F31100	Gypsum Plastering	10	17-Oct-20	28-Oct-20	0	P1K2F21100, P1K	Housing Complex	$9,467.57
P1K2F31125	Ceramic Tiling	4	30-Oct-20	03-Nov-20	15	P1K2F31100, P1K	Housing Complex	$0.00
P1K2F31150	Installation of PVC Windows	2	04-Nov-20	05-Nov-20	15	P1K2F31125, P1K	Housing Complex	$0.00
P1K2F31175	Installation of Unit Doors	1	04-Nov-20	04-Nov-20	16	P1K2F21175, P1K	Housing Complex	$653.45
P1K2F31200	First Coat Painting	5	06-Nov-20	11-Nov-20	15	P1K2F31175, P1K	Housing Complex	$6,928.11
Housing Complex-1.Blocks.2. - Floor.4. (New WBS)-3		97	30-Jul-20	23-Nov-20	10		Housing Complex	$24,914.12
P1K2F41000	Masonry Works	5	30-Jul-20	06-Aug-20	58	P1K2F31000	Housing Complex	$4,647.23
P1K2F41025	Mechanical Installations Under Screed	7	05-Sep-20	12-Sep-20	33	P1K2F41000, P1K	Housing Complex	$0.00
P1K2F41050	Installation of Electrical Conduits	5	07-Aug-20	12-Aug-20	60	P1K2F31050, P1K	Housing Complex	$3,217.76
P1K2F41075	Screed Works	4	15-Sep-20	18-Sep-20	32	P1K2F41050, P1K	Housing Complex	$0.00
P1K2F41085	Missing Weep Screeds in 2nd Block	2	19-Sep-20	21-Sep-20	32	P1K2F41075	Housing Complex	$0.00
P1K2F41100	Gypsum Plastering	10	30-Oct-20	10-Nov-20	0	P1K2F31100, P1K	Housing Complex	$9,467.57
P1K2F41125	Ceramic Tiling	4	11-Nov-20	14-Nov-20	10	P1K2F41100, P1K	Housing Complex	$0.00
P1K2F41150	Installation of PVC Windows	2	16-Nov-20	17-Nov-20	10	P1K2F41125, P1K	Housing Complex	$0.00
P1K2F41175	Installation of Unit Doors	1	16-Nov-20	16-Nov-20	11	P1K2F31175, P1K	Housing Complex	$653.45

Figure D. 4 Activity Tables of the Second Alternative (cont'd)

Case Study	Classic Schedule Layout	14-Jul-20 23:29

Activity ID	Activity Name	Origina Duration	Start	Finish	Total Float	Predecessors	Calendar	Budgeted Total Cost
P1K2F41200	First Coat Painting	5	18-Nov-20	23-Nov-20	10	P1K2F41175, P1K	Housing Complex	$6,928.11
Housing Complex-1.Blocks.2. - Floor.5. (New WBS)-4		102	07-Aug-20	04-Dec-20	5		Housing Complex	$24,914.12
P1K2F51000	Masonry Works	5	07-Aug-20	12-Aug-20	58	P1K2F41000	Housing Complex	$4,647.23
P1K2F51010	Misarrangement of Mechanical Installation Team Right After I	5	13-Aug-20	18-Aug-20	58	P1K2F51000	Housing Complex	$0.00
P1K2F51025	Mechanical Installations Under Screed	7	14-Sep-20	21-Sep-20	36	P1K2F41025, P1K	Housing Complex	$0.00
P1K2F51050	Installation of Electrical Conduits	5	13-Aug-20	18-Aug-20	65	P1K2F41050, P1K	Housing Complex	$3,217.76
P1K2F51075	Screed Works	4	22-Sep-20	25-Sep-20	36	P1K2F51050, P1K	Housing Complex	$0.00
P1K2F51085	Missing Weep Screeds in 2nd Block	2	26-Sep-20	28-Sep-20	36	P1K2F51075	Housing Complex	$0.00
P1K2F51100	Gypsum Plastering	10	11-Nov-20	21-Nov-20	0	P1K2F41100, P1K	Housing Complex	$9,467.57
P1K2F51125	Ceramic Tiling	4	23-Nov-20	26-Nov-20	5	P1K2F51100, P1K	Housing Complex	$0.00
P1K2F51150	Installation of PVC Windows	2	27-Nov-20	28-Nov-20	5	P1K2F51125, P1K	Housing Complex	$0.00
P1K2F51175	Installation of Unit Doors	1	27-Nov-20	27-Nov-20	6	P1K2F41175, P1K	Housing Complex	$653.45
P1K2F51200	First Coat Painting	5	30-Nov-20	04-Dec-20	5	P1K2F51175, P1K	Housing Complex	$6,928.11
Housing Complex-1.Blocks.2. - Floor.6. (New WBS)-5		107	13-Aug-20	16-Dec-20	0		Housing Complex	$24,914.12
P1K2F61000	Masonry Works	5	13-Aug-20	18-Aug-20	68	P1K2F51000	Housing Complex	$4,647.23
P1K2F61025	Mechanical Installations Under Screed	7	22-Sep-20	29-Sep-20	39	P1K2F61000, P1K	Housing Complex	$0.00
P1K2F61050	Installation of Electrical Conduits	5	19-Aug-20	24-Aug-20	70	P1K2F51050, P1K	Housing Complex	$3,217.76
P1K2F61075	Screed Works	4	30-Sep-20	03-Oct-20	39	P1K2F61050, P1K	Housing Complex	$0.00
P1K2F61085	Missing Weep Screeds in 2nd Block	2	05-Oct-20	06-Oct-20	39	P1K2F61075	Housing Complex	$0.00
P1K2F61100	Gypsum Plastering	10	23-Nov-20	03-Dec-20	0	P1K2F51100, P1K	Housing Complex	$9,467.57
P1K2F61125	Ceramic Tiling	4	04-Dec-20	08-Dec-20	0	P1K2F61100, P1K	Housing Complex	$0.00
P1K2F61150	Installation of PVC Windows	2	09-Dec-20	10-Dec-20	0	P1K2F61125, P1K	Housing Complex	$0.00
P1K2F61175	Installation of Unit Doors	1	09-Dec-20	09-Dec-20	1	P1K2F51175, P1K	Housing Complex	$653.45
P1K2F61200	First Coat Painting	5	11-Dec-20	16-Dec-20	0	P1K2F61175, P1K	Housing Complex	$6,928.11

Figure D. 5 Activity Tables of the Second Alternative (cont'd)

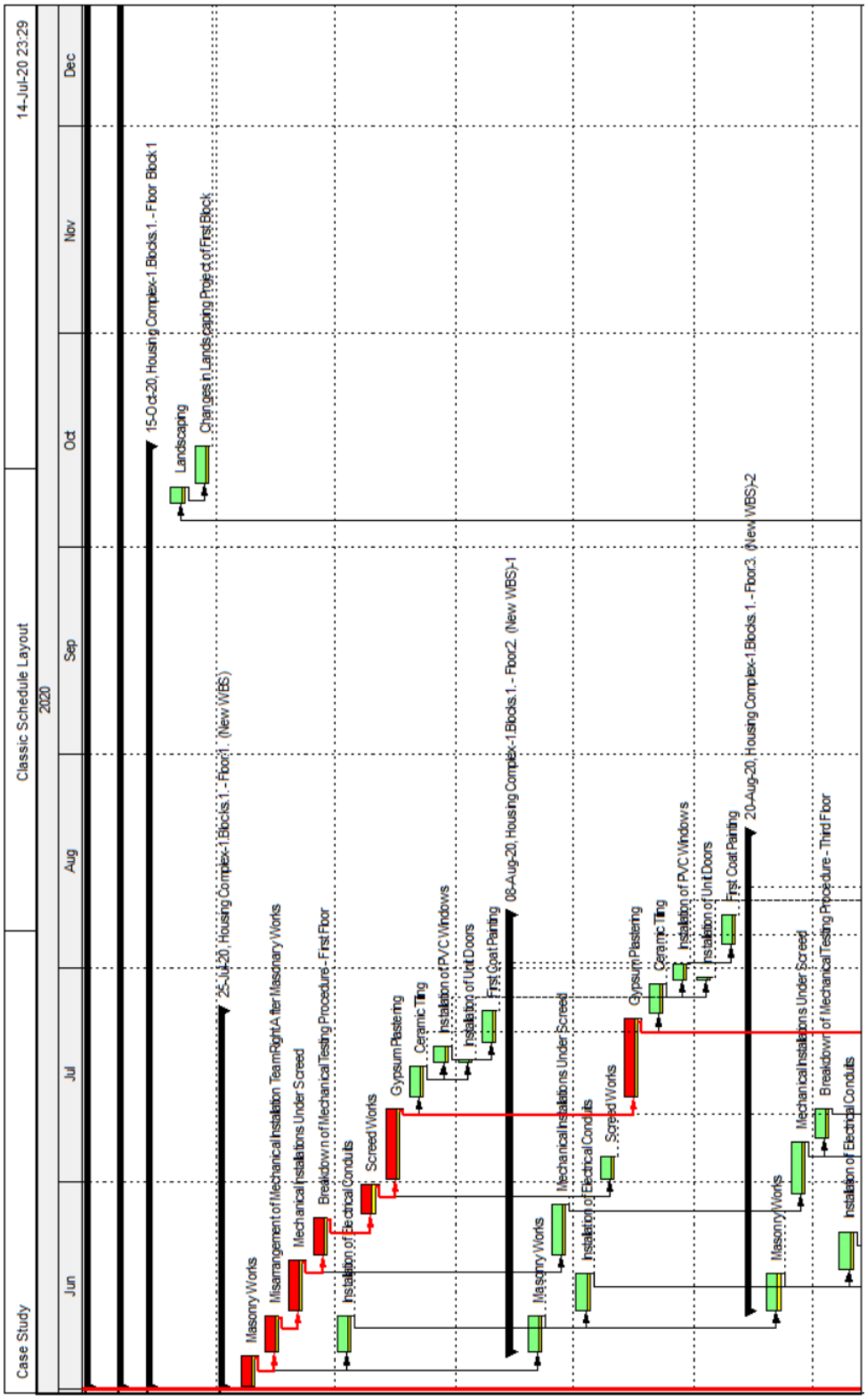

Figure D. 6 Gantt Chart of the Second Alternative

E. Primavera P6 Results According to the Third Alternative Method

Case Study | Classic Schedule Layout | 15-Sep-20 13:45

Activity ID	Activity Name	Original Duration	Start	Finish	Total Float	Predecessors	Calendar	eted Total
Housing Complex-4 Case Study		182	01-Jun-20	04-Jan-21	0		Housing Complex	3,56
Housing Complex-4.Blocks Blocks		182	01-Jun-20	04-Jan-21	0		Housing Complex	3,88
Housing Complex-4.Blocks.1. - Floor Block 1		114	01-Jun-20	14-Oct-20	61		Housing Complex	4,39
P1K11225	Landscaping	3	07-Oct-20	09-Oct-20	61	P1K1F71200	Housing Complex	0,0
P1K11235	Changes in Landscaping Project of First Block	4	10-Oct-20	14-Oct-20	61	P1K11225	Housing Complex	0,0
Housing Complex-4.Blocks.1. - Floor1. (New WBS)		47	01-Jun-20	25-Jul-20	60		Housing Complex	,914
P1K1F11000	Masonry Works	5	01-Jun-20	05-Jun-20	0		Housing Complex	,647
P1K1F11010	Misarrangement of Mechanical Installation Team	5	06-Jun-20	11-Jun-20	0	P1K1F11000	Housing Complex	0,0
P1K1F11025	Mechanical Installations Under Screed	7	12-Jun-20	19-Jun-20	0	P1K1F11010	Housing Complex	0,0
P1K1F11035	Breakdown of Mechanical Testing Procedure - Fir	5	20-Jun-20	25-Jun-20	0	P1K1F11025	Housing Complex	0,0
P1K1F11050	Installation of Electrical Conduits	5	06-Jun-20	11-Jun-20	12	P1K1F11000	Housing Complex	,217
P1K1F11075	Screed Works	4	26-Jun-20	30-Jun-20	0	P1K1F11050,	Housing Complex	0,0
P1K1F11100	Gypsum Plastering	10	01-Jul-20	11-Jul-20	0	P1K1F11075	Housing Complex	,467
P1K1F11125	Ceramic Tiling	4	13-Jul-20	17-Jul-20	60	P1K1F11100	Housing Complex	0,0
P1K1F11150	Installation of PVC Windows	2	18-Jul-20	20-Jul-20	60	P1K1F11125	Housing Complex	0,0
P1K1F11175	Installation of Unit Doors	1	18-Jul-20	18-Jul-20	61	P1K1F11125	Housing Complex	,53
P1K1F11200	First Coat Painting	5	21-Jul-20	25-Jul-20	60	P1K1F11175,	Housing Complex	,928
Housing Complex-4.Blocks.1. - Floor2. (New WBS)-1		52	06-Jun-20	08-Aug-20	55		Housing Complex	,914
P1K1F21000	Masonry Works	5	06-Jun-20	11-Jun-20	13	P1K1F11000	Housing Complex	,647
P1K1F21025	Mechanical Installations Under Screed	7	20-Jun-20	27-Jun-20	6	P1K1F21000,	Housing Complex	0,0
P1K1F21050	Installation of Electrical Conduits	5	12-Jun-20	17-Jun-20	17	P1K1F11050,	Housing Complex	,217
P1K1F21075	Screed Works	4	01-Jul-20	04-Jul-20	6	P1K1F21050,	Housing Complex	0,0
P1K1F21100	Gypsum Plastering	10	13-Jul-20	24-Jul-20	0	P1K1F21075,	Housing Complex	,467
P1K1F21125	Ceramic Tiling	4	25-Jul-20	29-Jul-20	55	P1K1F21100,	Housing Complex	0,0
P1K1F21150	Installation of PVC Windows	2	30-Jul-20	01-Aug-20	55	P1K1F21125,	Housing Complex	0,0
P1K1F21175	Installation of Unit Doors	1	30-Jul-20	30-Jul-20	56	P1K1F11175,	Housing Complex	,53
P1K1F21200	First Coat Painting	5	04-Aug-20	08-Aug-20	55	P1K1F21175,	Housing Complex	,928
Housing Complex-4.Blocks.1. - Floor3. (New WBS)-2		57	12-Jun-20	20-Aug-20	50		Housing Complex	,914
P1K1F31000	Masonry Works	5	12-Jun-20	17-Jun-20	15	P1K1F21000	Housing Complex	,647
P1K1F31025	Mechanical Installations Under Screed	7	29-Jun-20	06-Jul-20	6	P1K1F31000,	Housing Complex	0,0
P1K1F31035	Breakdown of Mechanical Testing Procedure - Th	5	07-Jul-20	11-Jul-20	6	P1K1F31025	Housing Complex	0,0
P1K1F31050	Installation of Electrical Conduits	5	18-Jun-20	23-Jun-20	18	P1K1F21050,	Housing Complex	,217

Figure E. 1 Activity Tables of the Third Alternative

Case Study	Classic Schedule Layout	15-Sep-20 13:45

Activity ID	Activity Name	Original Duration	Start	Finish	Total Float	Predecessors	Calendar	Total
P1K1F31060	Shortage of Team Work on Electrical Installation -	4	24-Jun-20	27-Jun-20	18	P1K1F31050	Housing Complex	0.0
P1K1F31075	Screed Works	4	13-Jul-20	17-Jul-20	6	P1K1F21075,	Housing Complex	0.0
P1K1F31100	Gypsum Plastering	10	25-Jul-20	07-Aug-20	0	P1K1F31075,	Housing Complex	467
P1K1F31125	Ceramic Tiling	4	08-Aug-20	12-Aug-20	50	P1K1F31100,	Housing Complex	0.0
P1K1F31150	Installation of PVC Windows	2	13-Aug-20	14-Aug-20	50	P1K1F31125,	Housing Complex	0.0
P1K1F31175	Installation of Unit Doors	1	13-Aug-20	13-Aug-20	51	P1K1F21175,	Housing Complex	53.4
P1K1F31200	First Coat Painting	5	15-Aug-20	20-Aug-20	50	P1K1F31175,	Housing Complex	,928
Housing Complex-4.Blocks.1.-Floor.4. (New WBS)-3		62	18-Jun-20	01-Sep-20	45		Housing Complex	,914
P1K1F41000	Masonry Works	5	18-Jun-20	23-Jun-20	20	P1K1F31000	Housing Complex	647
P1K1F41010	Misarrangement of Mechanical Installation Team	5	24-Jun-20	29-Jun-20	20	P1K1F41000	Housing Complex	0.0
P1K1F41025	Mechanical Installations Under Screed	7	07-Jul-20	14-Jul-20	14	P1K1F41000,	Housing Complex	0.0
P1K1F41050	Installation of Electrical Conduits	5	24-Jun-20	29-Jun-20	27	P1K1F31050,	Housing Complex	217
P1K1F41075	Screed Works	4	18-Jul-20	22-Jul-20	12	P1K1F41050,	Housing Complex	0.0
P1K1F41100	Gypsum Plastering	10	08-Aug-20	19-Aug-20	0	P1K1F41075,	Housing Complex	467
P1K1F41125	Ceramic Tiling	4	20-Aug-20	24-Aug-20	45	P1K1F41100,	Housing Complex	0.0
P1K1F41150	Installation of PVC Windows	2	25-Aug-20	26-Aug-20	45	P1K1F41125,	Housing Complex	0.0
P1K1F41175	Installation of Unit Doors	1	25-Aug-20	25-Aug-20	46	P1K1F31175,	Housing Complex	53.4
P1K1F41200	First Coat Painting	5	27-Aug-20	01-Sep-20	45	P1K1F41175,	Housing Complex	,928
Housing Complex-4.Blocks.1.-Floor.5. (New WBS)-4		67	24-Jun-20	12-Sep-20	40		Housing Complex	,914
P1K1F51000	Masonry Works	5	24-Jun-20	29-Jun-20	28	P1K1F41000	Housing Complex	647
P1K1F51025	Mechanical Installations Under Screed	7	16-Jul-20	23-Jul-20	17	P1K1F51000,	Housing Complex	0.0
P1K1F51050	Installation of Electrical Conduits	5	30-Jun-20	04-Jul-20	28	P1K1F41050,	Housing Complex	217
P1K1F51060	Shortage of Team Work on Electrical Installation -	4	06-Jul-20	09-Jul-20	28	P1K1F51050	Housing Complex	0.0
P1K1F51075	Screed Works	4	24-Jul-20	28-Jul-20	17	P1K1F41075,	Housing Complex	0.0
P1K1F51100	Gypsum Plastering	10	20-Aug-20	31-Aug-20	0	P1K1F51075,	Housing Complex	467
P1K1F51125	Ceramic Tiling	4	01-Sep-20	04-Sep-20	40	P1K1F51100,	Housing Complex	0.0
P1K1F51150	Installation of PVC Windows	2	05-Sep-20	07-Sep-20	40	P1K1F51125,	Housing Complex	0.0
P1K1F51175	Installation of Unit Doors	1	05-Sep-20	05-Sep-20	41	P1K1F41175,	Housing Complex	53.4
P1K1F51200	First Coat Painting	5	08-Sep-20	12-Sep-20	40	P1K1F51175,	Housing Complex	,928
Housing Complex-4.Blocks.1.-Floor.6. (New WBS)-5		72	30-Jun-20	24-Sep-20	35		Housing Complex	,914
P1K1F61000	Masonry Works	5	30-Jun-20	04-Jul-20	33	P1K1F51000	Housing Complex	647
P1K1F61025	Mechanical Installations Under Screed	7	24-Jul-20	01-Aug-20	18	P1K1F61000,	Housing Complex	0.0
P1K1F61050	Installation of Electrical Conduits	5	06-Jul-20	10-Jul-20	37	P1K1F51050,	Housing Complex	217

Figure E. 2 Activity Tables of the Third Alternative (cont'd)

Case Study	Classic Schedule Layout	15-Sep-20 13:45

Activity ID	Activity Name	Original Duration	Start	Finish	Total Float	Predecessors	Calendar	Total
P1K1F61075	Screed Works	4	04-Aug-20	07-Aug-20	20	P1K1F61050,	Housing Complex	0.0
P1K1F61100	Gypsum Plastering	10	01-Sep-20	11-Sep-20	0	P1K1F61075,	Housing Complex	467
P1K1F61125	Ceramic Tiling	4	12-Sep-20	16-Sep-20	35	P1K1F61100,	Housing Complex	0.0
P1K1F61150	Installation of PVC Windows	2	17-Sep-20	18-Sep-20	35	P1K1F61125,	Housing Complex	0.0
P1K1F61175	Installation of Unit Doors	1	17-Sep-20	17-Sep-20	36	P1K1F51175,	Housing Complex	53.
P1K1F61200	First Coat Painting	5	19-Sep-20	24-Sep-20	35	P1K1F61175,	Housing Complex	928
Housing Complex-4.Blocks.1. - Floor.7. (New WBS)-6		**77**	**06-Jul-20**	**06-Oct-20**	**30**		**Housing Complex**	**914**
P1K1F71000	Masonry Works	5	06-Jul-20	10-Jul-20	35	P1K1F61000	Housing Complex	647
P1K1F71025	Mechanical Installations Under Screed	7	04-Aug-20	11-Aug-20	18	P1K1F71000,	Housing Complex	0.0
P1K1F71035	Breakdown of Mechanical Testing Procedure - Se	5	12-Aug-20	17-Aug-20	18	P1K1F71025	Housing Complex	0.0
P1K1F71050	Installation of Electrical Conduits	5	11-Jul-20	17-Jul-20	39	P1K1F61050,	Housing Complex	217
P1K1F71075	Screed works	4	18-Aug-20	21-Aug-20	18	P1K1F71050,	Housing Complex	0.0
P1K1F71100	Gypsum Plastering	10	12-Sep-20	23-Sep-20	0	P1K1F71075,	Housing Complex	467
P1K1F71125	Ceramic Tiling	4	24-Sep-20	28-Sep-20	30	P1K1F71100,	Housing Complex	0.0
P1K1F71150	Installation of PVC Windows	2	29-Sep-20	30-Sep-20	30	P1K1F71125,	Housing Complex	0.0
P1K1F71175	Installation of Unit Doors	1	29-Sep-20	29-Sep-20	31	P1K1F61175,	Housing Complex	53.
P1K1F71200	First Coat Painting	5	01-Oct-20	06-Oct-20	30	P1K1F71175,	Housing Complex	928
Housing Complex-4.Blocks.2. - Floor Block 2		**147**	**11-Jul-20**	**04-Jan-21**	**0**		**Housing Complex**	**9,48**
P1K21225	Landscaping	3	26-Dec-20	29-Dec-20	0	P1K21235,P1	Housing Complex	0.0
P1K21235	Miscalculation of Completion Time - Second Bloc	8	17-Dec-20	25-Dec-20	0	P1K2F61200	Housing Complex	0.0
P1K21245	Changes in Landscaping Project of Second Bloc	4	30-Dec-20	04-Jan-21	0	P1K21225	Housing Complex	0.0
Housing Complex-4.Blocks.2. - Floor.1. (New WBS)		**82**	**11-Jul-20**	**17-Oct-20**	**25**		**Housing Complex**	**914**
P1K2F11000	Masonry Works	5	11-Jul-20	17-Jul-20	39	P1K1F71000	Housing Complex	647
P1K2F11025	Mechanical Installations Under Screed	7	12-Aug-20	19-Aug-20	22	P1K2F11000,	Housing Complex	0.0
P1K2F11050	Installation of Electrical Conduits	5	18-Jul-20	23-Jul-20	39	P1K1F71050,	Housing Complex	217
P1K2F11060	Shortage of Team Work on Electrical Installation - I	4	24-Jul-20	28-Jul-20	39	P1K2F11050	Housing Complex	0.0
P1K2F11075	Screed works	6	22-Aug-20	28-Aug-20	20	P1K1F71075,	Housing Complex	0.0
P1K2F11085	Missing Weep Screeds in 2nd Block	2	29-Aug-20	31-Aug-20	20	P1K2F11075	Housing Complex	0.0
P1K2F11100	Gypsum Plastering	10	24-Sep-20	05-Oct-20	0	P1K1F71100,	Housing Complex	467
P1K2F11125	Ceramic Tiling	4	06-Oct-20	09-Oct-20	25	P1K2F11100,	Housing Complex	0.0
P1K2F11150	Installation of PVC Windows	2	10-Oct-20	12-Oct-20	25	P1K2F11125,	Housing Complex	0.0
P1K2F11175	Installation of Unit Doors	1	10-Oct-20	10-Oct-20	26	P1K1F71175,	Housing Complex	53.
P1K2F11200	First Coat Painting	5	13-Oct-20	17-Oct-20	25	P1K2F11175,	Housing Complex	928

Figure E. 3 Activity Tables of the Third Alternative (cont'd)

Case Study	Classic Schedule Layout						15-Sep-20 13:45
Activity ID	Activity Name	Original Duration	Start	Finish	Total Float	Predecessors	Calendar	eted Total
Housing Complex-4.Blocks.2. - Floor.2. (New WBS)-1		87	18-Jul-20	30-Oct-20	20		Housing Complex	,914
P1K2F21000	Masonry Works	5	18-Jul-20	23-Jul-20	43	P1K2F11000	Housing Complex	,647
P1K2F21010	Misarrangement of Mechanical Installation Team	5	24-Jul-20	29-Jul-20	43	P1K2F21000	Housing Complex	0.0
P1K2F21025	Mechanical Installations Under Screed	7	20-Aug-20	27-Aug-20	27	P1K2F11025,	Housing Complex	0.0
P1K2F21050	Installation of Electrical Conduits	5	24-Jul-20	29-Jul-20	50	P1K2F11050,	Housing Complex	,217
P1K2F21075	Screed Works	4	01-Sep-20	04-Sep-20	24	P1K2F21050,	Housing Complex	0.0
P1K2F21085	Missing Weep Screeds in 2nd Block	2	05-Sep-20	07-Sep-20	24	P1K2F21075	Housing Complex	0.0
P1K2F21100	Gypsum Plastering	10	06-Oct-20	16-Oct-20	0	P1K2F11100,	Housing Complex	,467
P1K2F21125	Ceramic Tiling	4	17-Oct-20	21-Oct-20	20	P1K2F21100,	Housing Complex	0.0
P1K2F21150	Installation of PVC Windows	2	22-Oct-20	23-Oct-20	20	P1K2F21125,	Housing Complex	0.0
P1K2F21175	Installation of Unit Doors	1	22-Oct-20	22-Oct-20	21	P1K2F11175,	Housing Complex	53.4
P1K2F21200	First Coat Painting	5	24-Oct-20	30-Oct-20	20	P1K2F21175,	Housing Complex	,928
Housing Complex-4.Blocks.2. - Floor.3. (New WBS)-2		92	24-Jul-20	11-Nov-20	15		Housing Complex	,914
P1K2F31000	Masonry Works	5	24-Jul-20	29-Jul-20	53	P1K2F21000	Housing Complex	,647
P1K2F31025	Mechanical Installations Under Screed	7	28-Aug-20	04-Sep-20	30	P1K2F31000,	Housing Complex	0.0
P1K2F31050	Installation of Electrical Conduits	5	30-Jul-20	06-Aug-20	55	P1K2F21050,	Housing Complex	,217
P1K2F31075	Screed Works	4	08-Sep-20	11-Sep-20	28	P1K2F31050,	Housing Complex	0.0
P1K2F31085	Missing Weep Screeds in 2nd Block	2	12-Sep-20	14-Sep-20	28	P1K2F31075	Housing Complex	0.0
P1K2F31100	Gypsum Plastering	10	17-Oct-20	28-Oct-20	0	P1K2F21100,	Housing Complex	,467
P1K2F31125	Ceramic Tiling	4	30-Oct-20	03-Nov-20	15	P1K2F31100,	Housing Complex	0.0
P1K2F31150	Installation of PVC Windows	2	04-Nov-20	05-Nov-20	15	P1K2F31125,	Housing Complex	0.0
P1K2F31175	Installation of Unit Doors	1	04-Nov-20	04-Nov-20	16	P1K2F21175,	Housing Complex	53.4
P1K2F31200	First Coat Painting	5	06-Nov-20	11-Nov-20	15	P1K2F31175,	Housing Complex	,928
Housing Complex-4.Blocks.2. - Floor.4. (New WBS)-3		97	30-Jul-20	23-Nov-20	10		Housing Complex	,914
P1K2F41000	Masonry Works	5	30-Jul-20	06-Aug-20	58	P1K2F31000	Housing Complex	,647
P1K2F41025	Mechanical Installations Under Screed	7	05-Sep-20	12-Sep-20	33	P1K2F41000,	Housing Complex	0.0
P1K2F41050	Installation of Electrical Conduits	5	07-Aug-20	12-Aug-20	60	P1K2F31050,	Housing Complex	,217
P1K2F41075	Screed Works	4	15-Sep-20	18-Sep-20	32	P1K2F41050,	Housing Complex	0.0
P1K2F41085	Missing Weep Screeds in 2nd Block	2	19-Sep-20	21-Sep-20	32	P1K2F41075	Housing Complex	0.0
P1K2F41100	Gypsum Plastering	10	30-Oct-20	10-Nov-20	0	P1K2F31100,	Housing Complex	,467
P1K2F41125	Ceramic Tiling	4	11-Nov-20	14-Nov-20	10	P1K2F41100,	Housing Complex	0.0
P1K2F41150	Installation of PVC Windows	2	16-Nov-20	17-Nov-20	10	P1K2F41125,	Housing Complex	0.0
P1K2F41175	Installation of Unit Doors	1	16-Nov-20	16-Nov-20	11	P1K2F31175,	Housing Complex	53.4

Figure E. 4 Activity Tables of the Third Alternative (cont'd)

Case Study	Classic Schedule Layout						15-Sep-20 13:45
Activity ID	Activity Name	Original Duration	Start	Finish	Total Float	Predecessors	Calendar	eted Total
P1K2F41200	First Coat Painting	5	18-Nov-20	23-Nov-20	10	P1K2F41175,	Housing Complex	,928
Housing Complex-4.Blocks.2.-Floor.5. (New WBS)-4		102	07-Aug-20	04-Dec-20	5		Housing Complex	,914
P1K2F51000	Masonry Works	5	07-Aug-20	12-Aug-20	58	P1K2F41000	Housing Complex	,647
P1K2F51010	Misarrangement of Mechanical Installation Team	5	13-Aug-20	18-Aug-20	58	P1K2F51000	Housing Complex	0.00
P1K2F51025	Mechanical Installations Under Screed	7	14-Sep-20	21-Sep-20	36	P1K2F41025,	Housing Complex	0.00
P1K2F51050	Installation of Electrical Conduits	5	13-Aug-20	18-Aug-20	65	P1K2F41050,	Housing Complex	,217
P1K2F51075	Screed Works	4	22-Sep-20	25-Sep-20	36	P1K2F51050,	Housing Complex	0.00
P1K2F51085	Missing Weep Screeds in 2nd Block	2	26-Sep-20	28-Sep-20	36	P1K2F51075	Housing Complex	0.00
P1K2F51100	Gypsum Plastering	10	11-Nov-20	21-Nov-20	0	P1K2F41100,	Housing Complex	,467
P1K2F51125	Ceramic Tiling	4	23-Nov-20	26-Nov-20	5	P1K2F51100,	Housing Complex	0.00
P1K2F51150	Installation of PVC Windows	2	27-Nov-20	28-Nov-20	5	P1K2F51125,	Housing Complex	0.00
P1K2F51175	Installation of Unit Doors	1	27-Nov-20	27-Nov-20	6	P1K2F41175,	Housing Complex	53.4
P1K2F51200	First Coat Painting	5	30-Nov-20	04-Dec-20	5	P1K2F51175,	Housing Complex	,928
Housing Complex-4.Blocks.2.-Floor.6. (New WBS)-5		107	13-Aug-20	16-Dec-20	0		Housing Complex	,914
P1K2F61000	Masonry Works	5	13-Aug-20	18-Aug-20	68	P1K2F51000	Housing Complex	,647
P1K2F61025	Mechanical Installations Under Screed	7	22-Sep-20	29-Sep-20	39	P1K2F61000,	Housing Complex	0.00
P1K2F61050	Installation of Electrical Conduits	5	19-Aug-20	24-Aug-20	70	P1K2F51050,	Housing Complex	,217
P1K2F61075	Screed Works	4	30-Sep-20	03-Oct-20	39	P1K2F61050,	Housing Complex	0.00
P1K2F61085	Missing Weep Screeds in 2nd Block	2	05-Oct-20	06-Oct-20	39	P1K2F61075	Housing Complex	0.00
P1K2F61100	Gypsum Plastering	10	23-Nov-20	03-Dec-20	0	P1K2F51100,	Housing Complex	,467
P1K2F61125	Ceramic Tiling	4	04-Dec-20	08-Dec-20	0	P1K2F61100,	Housing Complex	0.00
P1K2F61150	Installation of PVC Windows	2	09-Dec-20	10-Dec-20	0	P1K2F61125,	Housing Complex	0.00
P1K2F61175	Installation of Unit Doors	1	09-Dec-20	09-Dec-20	1	P1K2F51175,	Housing Complex	53.4
P1K2F61200	First Coat Painting	5	11-Dec-20	16-Dec-20	0	P1K2F61175,	Housing Complex	,928

Figure E. 5 Activity Tables of the Third Alternative (cont'd)

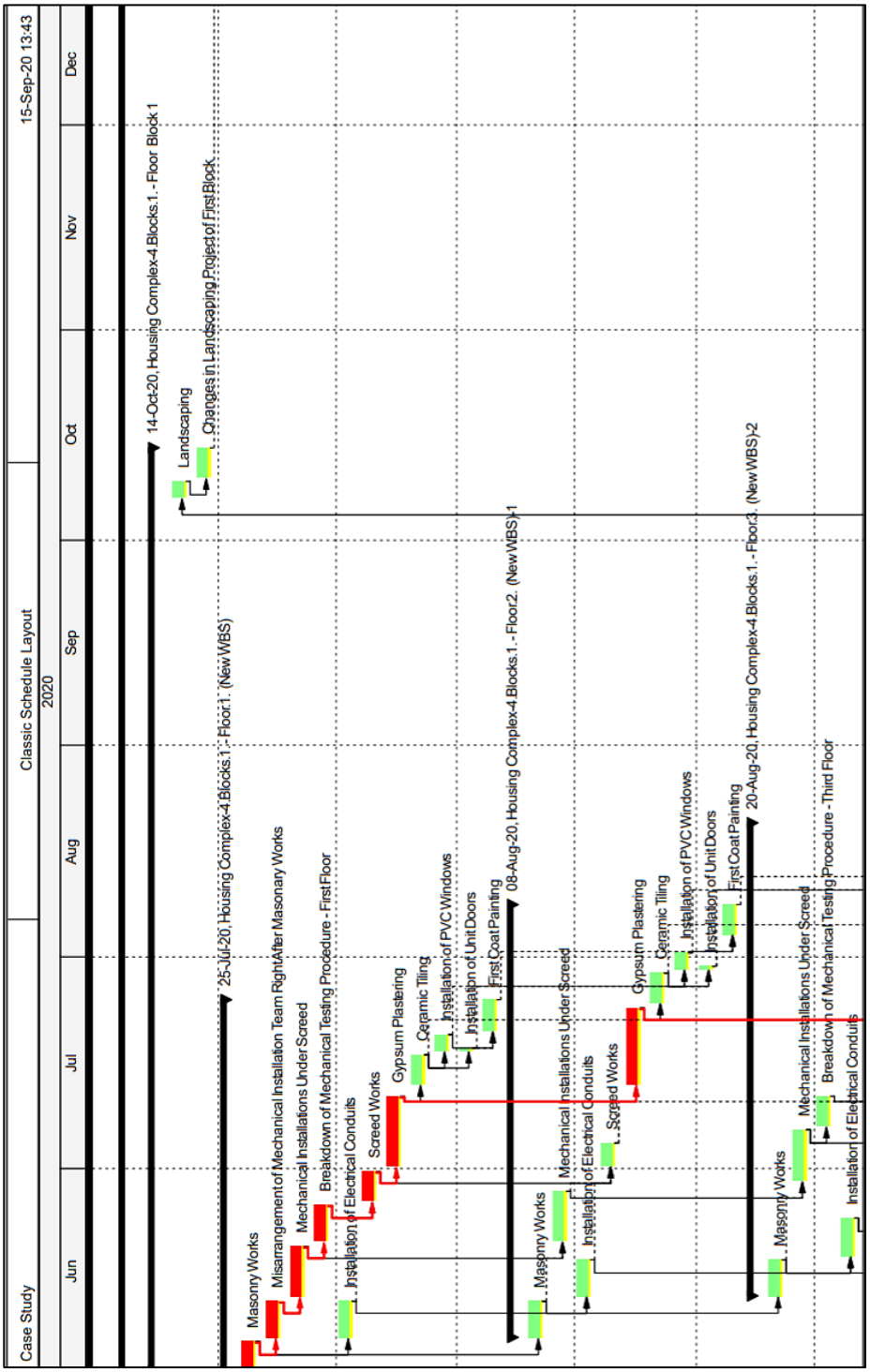

Figure E. 6 Gantt Chart of the Third Alternative