Modeling and assessment of project risk dynamics: A case of Addis-Djibouti railway project

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Author's Declaration

I hereby declare that this dissertation has been composed solely by myself and that it has not been, and will not be, submitted in whole or in part to another University for the award of any other degree.

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Supervisor's Declaration

I hereby declare that this dissertation is done under my supervision and that it has not been, and will not be submitted in whole or in part to another University for the award of any other degree.

Kassu Jilcha (Ph.D)

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ABSTRACT

Railway construction projects are characterized by large operations, long construction periods, complex processes, high financial intensity, dynamic environment, multiple stakeholder involvement, and exposure to the external environment. Due to their complexity and dynamic nature as well as the involvement of various stakeholders, the construction projects are exposed to the effects of numerous risk factors leading to delays and cost overruns. Several studies have been conducted on railway construction projects to analyze the impact of project risks. However, few attempts have been made to evaluate the overall dynamics, interrelationships, uncertainty, and feedback effects of risks on project objectives. The purpose of this research is to develop a dynamic risk assessment model that assesses the impact of project risks on delays and cost overruns of the Addis-Djibouti railway construction project.

This research has conducted an extensive literature review on construction project risk assessment and the techniques of risk analysis of railway construction projects. From the literature review and experts' opinion, forty-two construction project risk factors were identified and categorized into design, construction, management, resource, contractual and external risks. A structured questionnaire survey and pairwise comparisons of factors were conducted to obtain the opinions of domain experts on likelihood, impact on delays and cost overruns and interrelationships between risks.

The model was developed using fuzzy synthetic evaluation, Bayesian belief network, fuzzy analytic network process, and system dynamics approach. Fuzzy synthetic evaluation and Bayesian belief network were employed to address uncertainty, subjective judgments, data unavailability, and interrelationships between risks and to determine the likelihood of project risks. A fuzzy analytic network process was also adopted to determine the impact of risks on project time and cost taking into account the interdependence and network of project risks. Then, the overall dynamics and feedback effects of the risks were analyzed using system dynamics. The dynamic risk analysis model was implemented on the case project and it was validated using different modeling tests.

The findings of the research showed that contractor's lack of experience, right-of-way, incomplete contract details, poor quality of construction, payment delays, design changes, lack of coordination, and client's financial difficulties were identified as the significant risks that have a higher impact on delays and cost overruns. Based on their categories, the results showed that design, construction, and management-related risks have a significant impact on project objectives. The result of dynamic risk analysis showed that design-related risks were the most critical risks that had a greater impact on project cost and time.

The proposed model is an effective tool for risk assessment to support project managers, clients, contractors, and stakeholders in decision-making and helps to forecast the impact of risks on delays and cost overruns. The model can be used as a project risk analysis tool for other construction projects to help managers identify significant risks and analyze the interdependence, dynamic, and feedback effects on project objectives. On this basis, it is recommended that design, construction, and management-related risks should be given due attention in managing railway construction projects. Moreover, it is also recommended that project managers should consider the interrelationship, dynamic, and feedback effects of risks to analyze their impact on project cost and time. Further research is needed to analyze the impact of risks on quality and other project objectives.

The research made an original contribution to the body of knowledge in project risk assessment in terms of analyzing project risks in a holistic way taking uncertainty, interdependency, and dynamic and feedback effects of risks into account.

Keywords: Railway construction project; project risk assessment; Project risk modeling; Fuzzy synthetic evaluation; Fuzzy Bayesian belief network; Fuzzy analytic network process; System dynamics

ACKNOWLEDGMENTS

DEDICATION

I dedicate this dissertation to my father, Gashaw Gete

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LIST OF ABBREVIATIONS

AHP	Analytic hierarchy process
ANP	Analytic network process
BBN	Bayesian belief network
CLD	Causal loop diagrams
EPC	Engineering, Procurement and Construction
ERC	Ethiopian Railway Corporation
ETA	Event tree analysis
FAHP	Fuzzy analytic hierarchy process
FANP	Fuzzy analytic network process
FMCS	Fuzzy Monte Carlo Simulation
FMEA	Failure mode effect analysis
FSE	Fuzzy synthetic evaluation
FST	Fuzzy set theory
FTA	Fault tree analysis
MCS	Monte Carlo simulation
SD	System dynamics
SFD	Stock-flow diagram
TFN	Triangular fuzzy number
TOPSIS	Technique for Order Performance by Similarity to Ideal Solution

1. INTRODUCTION

1.1. Background

Rail transport plays a crucial role in the pursuit of economic development, supporting cost-effective transport of freight and passengers and providing emerging economies with the means to integrate into the global economy (Olievschi, 2013). Rail transport is expected to play an increasingly important role in transporting freight over long distances due to its energy efficiency, reduced greenhouse gas emissions, and lower cost.

Railways, when compared to other modes of transportation, are useful in intercity and urban mass transit systems. However, the current state of existing railway infrastructure projects in many African countries is deplorable. This shortfall has harmed the rail systems' ability to play a significant role in economic development (African Development Bank, 2015).

Railway construction projects are characterized by their varying degrees of uniqueness and complexity, large-scale operations, long construction period, complicated processes, high financial intensity, dynamic environments, involvement of numerous stakeholders, and exposure to external environment and weather conditions (Li, Liu, et al., 2014; Sangsomboon & Yan, 2014; Xue et al., 2020). Due to their unique characteristics, these projects are influenced by a significant number of risks, which may have effects on project objectives in terms of cost overruns, schedule delays, failure to meet quality standards, and safety (Andrić et al., 2019). Time overrun is a delay beyond the agreed contract date or the date agreed by the parties to deliver the project (Assaf & Al-Hejji, 2006), and cost overrun is the amount by which actual cost exceeds estimated cost, with cost measured in the local currency, constant prices, and against a consistent baseline (Flyvbjerg et al., 2018).

Evidence indicates that the problem of delays and cost overruns is a global phenomenon in railway infrastructure projects. According to a study conducted by Flyvbjerg et al. (2007; 2002, 2004), covering twenty countries across five continents, nine out of ten transportation infrastructure projects suffer from cost overruns, with the average cost overrun for all project types being 28%. Of the 258 transportation infrastructure projects, rail projects have the largest cost overrun with an average of 44.7%, followed by bridges and tunnels at 33.8%, and roads at 20.4% (Flyvbjerg, 2007). Moreover, the results of the study revealed that cost overruns in railway construction appear to be more prevalent in developing countries. In addition, a cost performance study of Dutch infrastructure projects (Road: 37 projects, Rail: 26 projects, Tunnel: 8 projects, Bridge: 7 projects) revealed that the average cost overrun of projects was 16.5%. Of these infrastructure projects, the average cost overrun of rail projects was 10.6% (Cantarelli et al., 2012). Singh (2010) also investigated the underlying causes of infrastructure project delays and cost overruns in India. According to the findings of the study, 82.79% and 98.36% of the 122 railway construction projects experienced cost and time overruns, respectively. These projects had an average cost and time overrun of 94.84% and 118.08%, respectively. Likewise, a survey of 496 infrastructure projects in India revealed that the total cost overrun was 19.59 % and the average delay was 36.98 months, with railway construction projects experiencing the greatest delay and cost overrun of 36 % and 54%, respectively (Shrivastava et al., 2019).

In Ethiopia, road and railway construction projects experienced delays and cost overruns. Kassa (2020) conducted a study on twenty-five road and three railway construction projects completed between 2014 and 2018 and discovered that 88% and 80% of the road projects experienced delays and cost overruns respectively, whereas all railway construction projects experienced delays and cost overruns. Addis-Djibouti railway construction project suffered project delays of 45.24% and cost overruns of 14.38% (Ayele, 2019), and Addis Ababa Light Rail Transit (AALRT) has a 43.63% delay and 4.01% cost overrun (Kassa,2020).

The pressure on project delays and cost overruns, as well as the need for improved performance in quality, productivity, and cost reduction, necessitate the use of an appropriate and effective risk management approach (Banaitiene & Banaitis, 2012; Xue et al., 2020). Due to the growing importance of risk management, a set of techniques and models to manage the effect of project risks have been developed. Even though the risk has gained immense attention from construction project managers, most of the project risks are not properly identified and their impact on cost and time are not analyzed (Khodeir & Mohamed, 2015). In addition, construction projects are complex and dynamic and involve multiple feedback processes. The components of the project are subject to change as part of the dynamic coordination process, and the dynamic complexity makes the risks of railroad projects highly interrelated (Xue et al., 2020).

This study is conducted based on the data from the Addis-Djibouti railway construction project. This railway project, with a total length of 750.2 km, is East Africa's first modern electrified railway line, and it was started in 2011. The meter-gauge section was replaced with a 1435mm gauge line, and the line was electrified at 25 kV. It was designed to accommodate a passenger train speed of 120 km/h and a freight train speed of 80 km/h. The project includes engineering works on the Sebeta-Djibouti/Negad route as well as in the port, and the contract was engineering-procurement- construction (EPC). The project was divided into three EPC contracts—Sebeta-Mieso, Mieso (excluded)-Dawanle, and Denwale (excluded)-Negad.

Due to the uncertain events, the railway construction project faced delays and cost overruns. To manage the uncertain events effectively, a dependable risk assessment approach was required for the railway project. Even though the railway construction project was managed in a conventional risk management approach, the risk assessment approach implemented for the case project lacks to take into account uncertainty, unavailability of historical data, interdependence, and dynamic and feedback effects of project risks.

Hence, an effective and systemic risk assessment approach is required for the success of construction projects. Therefore, in this paper, key risk factors affecting project duration and cost are identified and an integrated model for risk assessment of railway construction projects is developed.

1.2. Problem statement

Project risks have a significant impact on delays and cost overruns of railway construction projects. Since these factors affect project objectives, it is essential to identify and assess the risks to enhance the overall performance of the construction project (Issa, 2013; Liu et al., 2017), and hence, an effective risk assessment technique is then critical to the success of railway construction projects. The importance of developing a reliable project risk assessment model has long been recognized by practitioners and academicians. However, numerous railway construction projects are still plagued by delays and cost overruns, which can frequently be traced to ineffective identification and assessment of project risks.

For these reasons, different approaches have been implemented to analyze the impact of project risks on project objectives. The common risk analysis techniques employed in railway construction projects are probabilistic, fuzzy-based, multi-criteria decision-making, and hybrid approaches. Probabilistic-based risk assessment techniques adopt probability theory to deal with uncertainties associated with risk events. The techniques used probability distribution to offer estimates of the likelihood of achieving project objectives and the likely range of outcomes of the project (Smith et al., 2014). These methods include Monte Carlo simulation, event tree analysis, fault tree analysis, and failure mode and effect analysis (FMEA). Despite their broad applicability, probabilistic approaches rely heavily on large historical data to define probability density functions and are incapable of modeling subjective uncertainty (Siraj & Fayek, 2020). Based on these facts, fuzzy-based risk analysis approaches have been employed to handle approximate or vague reasoning (Elbarkouky et al., 2016; Islam et al., 2017). However, models based on fuzzy logic alone are unable to handle dynamic effects and interrelationships between project risks (Fayek, 2020). The analytic hierarchy process (AHP) has been used to assess risks of infrastructure projects and rank risks at different hierarchy levels by considering multiple criteria (T. Wang et al., 2016).

Despite their contributions, these risk assessment approaches are mostly static, and risks are assessed separately. The railway construction project, on the other hand, is a complex system with numerous interconnected subsystems. To address these limitations, analytic network process (ANP) (Tavassolirizi et al., 2020), Bayesian belief network (Leśniak & Janowiec, 2019), and structural equation modeling (Liu et al., 2017) approaches have been employed for analyzing the impact of risks of railway construction projects.

However, due to the use of approximate reasoning and expert knowledge, many decision-making processes in construction projects have subjective uncertainties (Fateminia et al., 2021). To overcome these limitations, fuzzy-based methods have been incorporated into the aforementioned methods for analyzing the risks of railway construction projects (Macura et al., 2022; Sarkar & Singh, 2020). Furthermore, most conventional quantitative risk analysis techniques fail to capture the complex interrelationships and causal interactions that exist among risk events and do not account for the dynamic nature of construction risks that results from various feedback processes (Boateng et al., 2012; Wang & Yuan, 2017). As a result, handling project risk dynamics necessitates a different approach based on a holistic and systemic perspective that is capable of capturing feedback and quantifying relevant subjective factors.

Hence, system dynamics (SD) approach has been employed to develop a dynamic risk assessment model for risk assessment in rail infrastructure projects (Xue et al., 2020; Zeng et al., 2022). SD models, however, cannot capture the subjective uncertainty of the factors affecting project objectives. Thus, the SD approach has been coupled with fuzzy set theory to handle the uncertainty and imprecision of input data, as well as the subjectivity of domain experts for construction project risk assessment (Etemadinia & Tavakolan, 2021; Nasirzadeh, Carmichael, et al., 2019; Seresht & Fayek, 2018; Siraj & Fayek, 2020).

However, these risk analysis approaches do not consider the uncertainty of subjective judgments, data unavailability, dynamics and interrelationship of risks, and the indirect effects of risks throughout the life cycle of the project. Moreover, most construction project risk assessments that utilize system dynamics deal with only part of the identified risk factors, and their interrelationships between these factors are formulated without considering the qualitative data and impact of risks on project objectives.

With regards to the increasingly complex dynamics of construction projects and their risks, the tendency goes to use risk quantification and modeling methods to aid managers to control the uncertainties of the Addis-Djibouti railway construction project and the dynamic nature of project risks.

To alleviate the above problems in railway construction project risk assessment, this research answers the following research questions:

- What are the potential risk factors of railway construction projects that have an impact on project time and cost?
- How can interrelationships among project risks be determined and quantified based on likelihood and impact on the project objectives?
- How can causal relationships among project risk factors and their stock-flow diagrams be developed?
- How can the dynamics of risks and their impact on time and cost be evaluated for the railway construction project?

1.3. Research objectives

The overall aim of the research is to develop a dynamic project risk assessment model to analyze the impact of project risks on delays and cost overruns of the Addis-Djibouti railway construction project using combined fuzzy synthetic evaluation, fuzzy Bayesian belief network, fuzzy analytic network process, and system dynamics. To achieve this objective, the study has the following specific objectives:

- To identify the potential risk factors associated with the railway construction project
- To determine the interrelationship between project risks and analyze the impact of risks on delays and cost overruns
- To develop a dynamic project risk assessment model for railway construction projects using integrated system dynamics modeling
- To analyze the interaction and dynamic effect of project risks on project objectives.

1.4. Scope and limitations of the research

1.4.1. Scope of the research

This research focuses on developing a dynamic project risk assessment model that helps to analyze the impact of potential risks on delays and cost overruns of the Addis-Djibouti railway construction project.

1.4.2. Limitations of the research

In carrying out the study, there was a limitation in obtaining adequate records related to the potential project risks and their effect on project objectives. Owing to this, the data analysis was performed and the integrated dynamic risk assessment model was developed based on experts' judgments on the risks and their impact on the time and cost of the railway construction project. Furthermore, since the research is heavily reliant on expert judgments, some elements of subjectivity may influence the reliability of the findings. In addition, Ethiopia's railway construction projects are still in their infancy and there are not enough railway construction projects in the country. Because of the reduction in the number of industry experts, small sample size was used for this study.

1.5. Significance of the research

This study contributes to the existing body of knowledge in the field of risk assessment related to the impact of risks on project objectives and provides a dynamic risk assessment model for railway construction projects.

The outcome of this research has significant implications for practitioners. The comprehensive review of project risk assessment approaches provides a detailed and critical examination of the current methods for risk assessment in uncertain project environments. Practitioners will thus gain comprehensive knowledge about these methods' potential applications, shortcomings, and areas for improvement, which will guide them in how to apply the approaches in specific project contexts. The results of the research are expected to improve project planning and understanding of project dynamics, which may lead to better project risk management in construction projects. The dynamic risk assessment model is useful for project managers to take effective proactive measures and handle the impact of risks on project objectives accordingly. The proposed model makes the construction parties manage their activities considering the potential project risks, their interrelationships, and their dynamic and feedback effects. The integrated dynamic risk assessment approach is also helpful for other construction projects to manage their respective risks by adapting the models to their construction areas.

1.6. Thesis outline

This research has been organized into seven chapters. Chapter one deals with the background of the research including the problem statement, objectives, scope, and its contributions. Chapter two addresses a literature review on risks and risk analysis approaches in construction projects and railway construction projects in particular. The literature related to the potential project risks, risk identification, and analysis approaches are reviewed and the gaps in project risk assessment practices in railway construction projects are identified in this chapter.

Chapter three explains the methodologies employed in this research. This chapter describes the research design, sampling techniques, sample sizes, and the relevant project risk analysis techniques adopted for the research based on the identified literature gaps. The fuzzy logic-based approach called fuzzy synthetic evaluation, fuzzy analytic network process, Bayesian belief network, and system dynamics approaches are explained.

The fourth chapter discusses the data analysis and interpretation for the dynamic risk assessment model. This section includes data collected from experts and literature reviews, data analysis for determining the likelihood of occurrence of project risks using fuzzy synthetic evaluation and Bayesian belief network, and data analysis for determining the impact of risks on project time and cost using fuzzy analytic network process. The analysis results are fed into the proposed dynamic risk assessment model for railway construction projects.

Chapter five focuses on dynamic risk assessment model development, model verification, and validation. This chapter discusses the conceptual development of the risk assessment model. The major interdependences and feedback mechanisms that demonstrate the changes in system behavior caused by project risks within the system boundaries are addressed. To establish sufficient confidence in the built model, validation tests are performed to test and verify the consistency of the model structure and the robustness of the models.

Chapter six describes the application of the proposed model to the case project. The developed project risk assessment model is used to simulate the impact of risk on project time and cost and to predict dynamic behavior as the model changes in different scenarios. Sensitivity analysis is also performed, and the results are discussed.

Chapter seven concludes the dissertation. It describes the overall success of the study in addressing the research objectives. The limitations of the proposed model are outlined and recommendations for future improvements and applications are proposed. Three appendices are attached to the paper. Appendix A contains questionnaires for the survey, Appendix B shows conditional probability tables for the Bayesian belief network and Appendix C presents the supermatrices of the fuzzy analytical network model.

2. LITERATURE REVIEW

2.1. Introduction

The objective of this chapter is to review the existing literature related to risk assessment for construction projects. The particular case of railway construction projects is given a closer examination to understand the potential project risks and the models and methods employed for analyzing the impact of risks on project objectives.

2.2. Risks and project objectives

Risk has different meanings to different people; that is, the concept of risk varies according to viewpoint, attitudes, and experience. Engineers, designers, and contractors view risk from the technological perspective; lenders and developers tend to view it from the economic and financial side; health professionals, environmentalists, and chemical engineers take safety and environmental perspective. Risk is therefore generally seen as an abstract concept whose measurement is very difficult.

In construction projects, the risk may be defined as the likelihood of a detrimental event occurring to the project. Since the objectives of construction projects are usually stated as targets established for function, cost, time, and quality, the most important risks in construction are the failure to meet these targets. However, risks are not always associated with negative outcomes. Risks may represent opportunities as well, but the fact that most risks usually have negative outcomes has led individuals to consider only their negative side (Baloi & Price, 2003).

Risk is inherent in all project undertakings, as such, it can never be fully eliminated, although can be effectively managed to mitigate the impacts on the achievement of the project's goals (Nieto-Morote & Ruz-Vila, 2011).

There are several definitions of project risk in the literature. For instance, PMI (2017) defines project risk as an uncertain event or condition that, if it occurs, has a positive or negative effect on a project's objectives. This definition includes two key dimensions of risk: uncertainty and effect on a project's objectives. When assessing the importance of project risk, these two dimensions must both be considered. The uncertainty dimension may be described using the term "probability" and the effect may be called "impact". The definition of project risk also encompasses uncertain events which could affect project objectives negatively, as well as those which could have a positive effect. Other definitions provided by ISO 31000, APM, and other standards and frameworks include uncertain events and their impact on project objectives, which are similar to the above definition. The risk definitions provided by some standards and frameworks are depicted in Table 2.1.

Project risks are uncertain future events or conditions which may or may not occur, but which would matter if they did occur. If these events occur, they affect at least one project objective. Objectives can include scope, schedule, cost, and quality. A risk may have one or more causes and the cause may be a requirement, assumption, constraint, or condition that creates the possibility of negative or positive outcomes (PMI, 2017).

Time and cost overruns are common and global phenomena in construction projects (Larsen et al., 2016). Time overrun is a delay beyond the agreed contract date or the date agreed by the parties to deliver the project (Assaf & Al-Hejji, 2006), and cost overrun is the difference between the final actual cost of a construction project at completion and the contract amount, agreed by and between the client and the contractor during the signing of the contract (Mahamid, 2013). The key success indicators of the construction management system include completing the project within the planned budget and duration, and the required quality (Dey, 2010).

2.3. Railway construction project risk management

All projects are uncertain. Uncertainty is unavoidable because projects are unique and temporary endeavors based on assumptions and constraints that provide the deliverables of the projects to multiple stakeholders with different requirements (PMI, 2009).

As railway construction projects become more complex and competitive, project risk management is becoming an integral part of project success. Due to the complexity of railway construction projects, the occurrence of uncertain events and project risks hampers meeting the objectives of the project.

Project risk management (PRM) is a vital part of project management and helps to identify the potential risks that could adversely affect a construction project and define actions that could minimize their impacts. PRM is defined as a systematic application of management policies, procedures, and practices for the activities of communicating, consulting, establishing the context, and identifying, analyzing, evaluating, treating, monitoring, and reviewing risk (ISO, 2009).

There are several standards/documents in the project risk management area offering different approaches to the subject, as well as more general risk standards that include projects in their scope. The most popular of these include:

- ISO 31000:2018—Risk Management—Principles and Guidelines from the International Organization for Standardization (ISO)
- Practice Standard for Project Risk Management from the Project Management Institute (PMI)
- Project Risk Analysis and Management (PRAM) Guide from the Association for Project Management (APM)
- Risk Analysis and Management for Projects (RAMP) from the UK Institution of Civil Engineers, Faculty of Actuaries, and Institute of Actuaries

The key differences between project risk management standards/frameworks are summarized in Table 2.1, which compares their use of terminology and the different constituent stages of each process (Hillson & Simon, 2012).

Table 2.1. Comparison of risk management standards and frameworks

Standard/framework	Definition of risk	Risk management process
Active Threat and Opportunity Management (ATOM) process (Hillson & Simon, 2012)	Any uncertainty that if it occurs, would have a positive or negative effect on the achievement of one or more objectives	• Initiation • Identification • Assessment • Response planning • Reporting • Implementation • Review • Post-project review
ISO 31000 Risk Management Principles and Guidelines (ISO, 2018)	Effect of uncertainty on objectives	• Communication and consultation • Establishing the context • Risk identification • Risk analysis • Risk evaluation • Risk treatment • Monitoring and review • Recording and reporting
PMI Practice Standard for Project Risk Management (PMI, 2009)	An uncertain event or condition that, if it occurs, has a positive or negative effect on a project's objectives	• Plan risk management • Identity risks • Risk analysis • Plan risk responses • Monitor and control risks
Risk Analysis and Management for Projects [RAMP] (Institution of Civil Engineers, 2005)	A threat (or opportunity) which could affect adversely (or favorably) achievement of the objectives of an investment	• Plan and initiate risk review • Identify risks • Evaluate risk • Assess residual risks • Plan responses to residual risks • Communicate risk response strategy and response plan • Implement strategy and plans • Control risks
Project Risk Analysis and Management [PRAM] (APM, 2004)	An uncertain event or set of circumstances that, should it or they occur, would have an effect on the achievement of one or more of the project's objectives	• Initiate • Identify • Assess • Plan responses • Implement responses

The goal of these models/standards is to provide a systematic approach to risk management that includes: identifying risks, quantifying their effects (qualitative and quantitative risk analysis), developing risk responses, controlling and monitoring risks and risk responses. The ultimate goal of the risk management process is to reduce the impact of risks on project objectives and improve decision-making accordingly.

2.3.1. Project risk identification and classification

Risk identification is the process of finding, recognizing, and describing risks. According to Al-Bahar & Crandall (1990), it is defined as the process of systematically and continuously identifying, categorizing, and assessing the initial significance of risks related to a construction project.

The first step in the risk management process is to identify all events that may have an impact on the success of the project. Although risk identification is the first step in the risk management process, it is not a one-time event. It is an iterative process that happens throughout the project cycle (Martinelli & Milosevic, 2016). If a risk factor is properly identified, it will be easier for the decision-maker to place his/her subjective preference both on the likelihood of occurrence and on the impact of the risk. The objective of risk identification is to identify and classify risk factors that are likely to affect the construction project (Samantra et al., 2017). Table 2.2 explains the techniques presented by PMI (2009) for the risk identification process.

Risk classification attempts to structure the various risks affecting construction projects. Prior research has recommended various approaches for categorizing the risks of construction projects. Risks can be classified according to their source, nature, occurrence at various stages of the project, and impact on project objectives. Some classified project risks according to their nature and magnitude (Chapman & Ward, 2003), and others used a hierarchical structure of risks based on their source and location of impact in the project (Tah & Carr, 2000b). Baloi & Price (2003) identified risk factors impacting project cost performances and categorized them as organization-specific, global, and acts of God. Construction project risks can also be classified as internal and external risks (Khodeir & Mohamed, 2015), construction risk, design risk, payment risk, client risk, and subcontractor risk (Dikmen et al., 2007), and economic, political, law, physical site, construction, designing, materials, financial and human resource risks for the railway construction project (Sangsomboon & Yan, 2014). Moreover, Suh (2000) categorized project risks as technical risk, financial risk, social risk, and political risks, and Patil et al. (2017) also categorized railway construction project risks as financial, design, political, legal, management, material, site, environmental, cultural, construction, external, organizational risks, contractual risks, and human resource-related risks.

Several studies have been conducted in various countries to identify the causes of delays and cost overruns in construction projects. For instance, Steininger et al. (2021) identified changes in scope, price overshoot, geological conditions, and lack of participation as the primary causes of delays and cost overruns in the Stuttgart 21 Railroad Construction Project. According to the results of a study conducted by Wang & Yuan (2011), the main cost overrun risks of construction projects in China were financial difficulties, design variations, inflation in construction material prices, risk of cost estimation, corruption, and inadequate site information. In Iran, Pourrostam & Ismail (2012) identified payment delay by the client, change orders by the client during construction, poor site management, clients' slow decision-making, contractor's financial difficulties, late design review and approval by the client, problems with subcontractors, poor planning and scheduling, mistakes and discrepancies in design documents, and bad weather as the main causes of delays in construction projects.

Shrivastava et al. (2019) also identified financial default of the contractor, lack of technical professionals, lack of coordination with subcontractors, poor planning, scheduling, or resource management, lack of experience, shortage of manpower, low productivity, and inadequate workforce skills as significant causes of delays and cost overruns in Indian railway construction projects. Lin et al. (2011) also identified design delay, administrative interference, substandard quality of construction materials, unskilled labor, and material costs as the main railway construction project risks in India. Furthermore, the main risks that have an impact on delays of construction projects in India were lack of commitment, inefficient site management, poor site coordination, improper planning, lack of clarity in project scope, substandard contract, and lack of communication (Doloi et al., 2012).

Table 2.2. Techniques for risk identification

Technique	Strengths	Weaknesses
Brainstorming	• Allows all participants to speak their minds and contribute to the discussion • Can involve all key stakeholders • Creative generation of ideas	• Requires attendance of key stakeholders at a workshop, therefore can be difficult to arrange and expensive • Prone to Groupthink and other group dynamics • It may produce biased results if dominated by a strong person (often management) • Often not well facilitated • Generates non-risks and duplicates, requires filtering
Cause and effect (Ishikawa) diagrams	• Visual representation of the project promotes structured thinking	• Diagrams can quickly become over-complex
Check lists	• Captures previous experience • Presents a detailed list of risks	• Check list can grow to become unwieldy • Risks not on the list will be missed • Often only includes threats, misses opportunities
Delphi technique	• Captures input from technical experts • Removes sources of bias	• Limited to technical risks • Dependent on the actual expertise of experts • It may take longer time than available due to iterations of the experts' inputs

Technique	Strengths	Weaknesses
Document review	• Exposes detailed project-specific risks • Requires no specialist tools	• Limited to risks contained in project documentation
Interviews	• Addresses risks in detail • Generates engagement of stakeholders	• Time-consuming • Raises non-risks, concerns, issues, worries, etc, so requires filtering
Post-project reviews/Lessons Learned/Historical Information	• Leverages previous experience • Prevents making the same mistakes or missing the same opportunities twice • Enhances the Organizational Process Asset	• Limited to those risks that have occurred previously •
Questionnaire	• Encourages broad thinking to identify risks	• Success depends on the quality of the questions • Limited to the topics covered by the questions •

Moreover, Tipili & Ilyasu (2014) identified inaccurate cost estimates, inadequate program planning, variation by the client, design variation, and price inflation to be the main causes of cost overruns, while tight schedule, bureaucracy of government, design variation, and variation of construction program as the main causes of delays in Nigerian construction projects. El-Razek et al. (2008) identified contractor financing, payment delays, design changes during construction, and lack of professionals as the primary causes of construction project delays in Egypt. Amoatey and Ankrah (2017) identified payment delays, inexperienced contractors, scope changes by the owner, and delays in land acquisition as the main causes of delays in road projects in Ghana.

According to Bekele (2015), design, procurement, and economic risks have a greater impact on cost overruns, whereas contractual and legal, economic, and procurement risks have a significant impact on delays in the AALRT construction project. Moreover, Ewenetu (2015) identified scope changes, variations, and inadequate site investigations as the main causes of cost overruns in the AALRT construction project. Melaku et al. (2021) investigated delays and cost overruns in building and road construction projects in Ethiopia and identified design changes, inflation, material costs, construction material shortage, payment delays as the main risk factors for delays, and inflation, inaccurate cost estimation, variations, material costs and unavailability of resources (labor, materials, and equipment) were identified as the main risk factors for cost overruns.

The main project risk factors that have a significant impact on the time and cost of railway construction projects are depicted in Table 2.3. These project risks are categorized into design, construction, management, resource, contractual and external risks.

- Design risk is the possibility that the design will not meet the requirements of the project. This includes designs that are fundamentally flawed, infeasible, or below customer standards. Poor design can manifest itself as functional defects or hurdles to development that impede project progress. It mainly includes the scope of the contract, design changes, design errors, site investigation, client requirements, and other related factors.
- Management risk is the risk associated with the management skills and experience of the project team and project parties, the availability of project management professionals, and the relationships and coordination between project parties(Siraj & Fayek, 2019).
- Construction risks include issues related to construction methods, tasks, construction delays and disruptions, cost overruns, and construction quality (Siraj & Fayek, 2019).

- Resource-related risks are risks associated with the suitability, condition, availability, quality, and procurement of construction materials and equipment, as well as the availability, skill levels, and performance of workers and subcontractors (Siraj & Fayek, 2019).
- Contractual and legal risks are those associated with a counterparty, such as a contractor, failing to deliver on contractual obligations as well as the risk of litigation related to the railway construction project. These include poorly-tailored contracts, conflicts in contract documents, and disputes and litigations (El-Sayegh & Mansour, 2015).
- External risks are risks that are beyond the control of construction management. These include risks associated with inflation, political instability, unsafe project locations, earthquakes, floods, landslides, etc.

Table 2.3. Railway Construction Project Risks and Categorization

Category	Project Risk Factors	References
Design Risks	Change in scope of work by client	Choudhry et al.,(2014); Renuka et al., (2014); Doloi et al., (2012)
	Incomplete design	Shrivastava et al.,(Shrivastava et al., 2019); Choudhry et al.,(2014)
	Inaccurate project cost estimation	Shrivastava et al.,(Shrivastava et al., 2019); Szymański (2017); Gupta & Thakkar (2018); Choudhry et al.,(2014); Rajakumar (2016)
	Design changes	Patil et al., (2017); Gupta & Thakkar (2018); Choudhry et al.,(2014); Renuka et al., (2014); Rajakumar (2016)
	Inadequate site investigations	Patil et al., (2017); Gupta & Thakkar (2018); Choudhry et al.,(2014); Doloi et al., (2012)
	Design errors	Patil et al., (2017); Shrivastava et al.,(Shrivastava et al., 2019); Abd El-Karim et al.,(2017); Gupta & Thakkar (2018); Rajakumar (2016)
	Misunderstanding of Client's requirements	Shrivastava et al.,(Shrivastava et al., 2019); Doloi et al., (2012); Assaf & Al-Hejji (2006)
Construction Risks	Improper construction methods	Shrivastava et al.,(Shrivastava et al., 2019); Doloi et al., (2012)
	Poor site management and supervision	Shrivastava et al.,(Shrivastava et al., 2019); Choudhry et al.,(2014); Doloi et al., (2012); Assaf & Al-Hejji (2006)
	Poor quality of construction	Shrivastava et al.,(Shrivastava et al., 2019); Abd El-Karim et al.,(2017); Gupta & Thakkar (2018)
	Improper quality control & testing methods	Patil et al., (2017); Doloi et al., (2012)
	Errors during construction	Abd El-Karim et al.,(2017); Gupta & Thakkar (2018); Choudhry et al.,(2014); Doloi et al., (2012)
	Contractor's lack of experience on similar projects	Shrivastava et al.,(Shrivastava et al., 2019); Doloi et al., (2012)
	Delay in inspection by consultant	Shrivastava et al.,(Shrivastava et al., 2019)
	Poor quality of construction materials	Patil et al., (2017); Abd El-Karim et al.,(2017); Lin et al.,(Lin et al., 2011)

Category	Project Risk Factors	References
Management Risks	Delays in producing design documents	Shrivastava et al.,(Shrivastava et al., 2019); Lin et al.,(Lin et al., 2011); Doloi et al., (2012)
	Poor coordination among parties	Shrivastava et al.,(Shrivastava et al., 2019); Gupta & Thakkar (2018)
	Poor project planning & control	Patil et al., (2017); Shrivastava et al.,(Shrivastava et al., 2019); Choudhry et al.,(2014)
	Schedule pressure	Doloi et al., (2012); Taylan et al.,(2014); Han et al.,(2013)
	poor management of material resources, supplies, and personnel	Szymański (2017); Patil et al., (2017)
	Client's experience on similar projects	(Koushki et al., 2005)
	Frequent interference by client	Shrivastava et al.,(Shrivastava et al., 2019)
	Client's financial difficulties	Abd El-Karim et al.,(2017); Choudhry et al.,(2014); Shrivastava et al.,(Shrivastava et al., 2019)
	Delay in decision-making by client	Shrivastava et al.,(Shrivastava et al., 2019); Doloi et al., (2012); Iyer & Sagheer (2010); Rajakumar (2016)
	Payment delay by the client	Patil et al., (2017); Choudhry et al.,(2014); Lin et al.,(Lin et al., 2011); Taylan et al.,(2014)
	Right-of-way	Choudhry et al.,(2014); Doloi et al., (2012); Lin et al.,(Lin et al., 2011)
Resource-Related Risks	Low productivity of plant and equipment	Shrivastava et al.,(Shrivastava et al., 2019); Abd El-Karim et al.,(2017); Gupta & Thakkar (2018)
	Equipment damage	Szymański (2017); Abd El-Karim et al.,(2017); Choudhry et al.,(2014); Subramanyan et al.,(2012); Assaf & Al-Hejji (2006)
	Poor equipment maintenance	Abd El-Karim et al.,(2017)
	Low labor productivity	Shrivastava et al.,(Shrivastava et al., 2019); Abd El-Karim et al.,(2017); Choudhry et al.,(2014); Doloi et al., (2012)
	Inadequate skill of the workforce	Shrivastava et al.,(Shrivastava et al., 2019); Patil et al., (2017); Choudhry et al.,(2014); Lin et al.,(Lin et al., 2011); Doloi et al., (2012); Assaf & Al-Hejji (2006)

Category	Project Risk Factors	References
Contractual and Legal Related Risks	Disputes among the parties of the contract	Patil et al., (2017); Shrivastava et al.,(Shrivastava et al., 2019); Doloi et al., (2012); Rajakumar (2016)
	Breach or modifications of the contract	Shrivastava et al.,(Shrivastava et al., 2019)
	Mistakes and discrepancies in contract documents	Subramanyan et al.,(2012)
	Incomplete contract details	Subramanyan et al.,(2012)
	Bribery and Corruption	Szymański (2017); Abd El-Karim et al.,(2017)
External Risks	Changes in government regulations and laws	Abd El-Karim et al.,(2017); Doloi et al., (2012); Rajakumar (2016); Assaf & Al-Hejji (2006)
	Political instability	Szymański (2017); Choudhry et al.,(2014); Doloi et al., (2012)
	Unsafe project location	Shrivastava et al.,(Shrivastava et al., 2019); Doloi et al., (2012)
	Inflation	Patil et al., (2017); Szymański (2017); Gupta & Thakkar (2018); Choudhry et al.,(2014); Renuka et al., (2014)
	Labor and Material Costs	Patil et al., (2017); Gupta & Thakkar (2018); Choudhry et al.,(2014); Lin et al.,(Lin et al., 2011); Doloi et al., (2012)
	Flood, earthquake, landslide, and unexpected weather conditions	Patil et al., (2017); Abd El-Karim et al.,(2017); Gupta & Thakkar (2018); Doloi et al., (2012)

2.3.2. Project risk analysis

Risk analysis is a process to comprehend the nature of risk and to determine the level of risk (ISO, 2009). It involves consideration of the causes and sources of risk, their consequences, and the likelihood that those consequences can occur and helps project managers get a broad understanding of the level of risk impact and determine the most significant risks influencing the project performance (Li, Wang, et al., 2014).

There are two general approaches widely used in project risk analysis: qualitative risk analysis and quantitative risk analysis. Qualitative risk analysis is a process of prioritizing project risks for further analysis or action by assessing their probability of occurrence and impact as well as other characteristics whereas quantitative risk analysis is a process of numerically analyzing the impact of identified project risks and other sources of uncertainty on overall project objectives (PMI, 2017).

Various researchers have implemented different qualitative and quantitative risk assessment techniques to evaluate the effect of risks on the construction project. On the other hand, other researchers have analyzed current risk assessment methods used in railway and other construction projects to identify shortcomings and suggest an appropriate risk assessment approach. Taroun (2014) conducted a chronological analysis of papers on construction project risk assessment methods implemented between 1980 and 2012 with an emphasis on probability-impact assessment, probabilistic, and AHP approaches. The author argued that the probability-impact assessment tool, which takes the risk cost as a common scale, would be a practicable choice for risk assessment. In addition, Islam et al. (2017) analyzed numerous papers that used fuzzy logic and fuzzy hybrid methods to assess the risks of construction projects. The analysis included the relevant papers published between 2005 and 2017. The authors concluded that fuzzy Bayesian belief network (BBN) and Credal Network approaches are viable techniques for dealing with project uncertainties, limited objective data, and reliance on expert judgment for risk assessment. Although different scholars have conducted a systematic literature review of the project risk assessment, they have not considered the system dynamics methods and their implementations for construction project risk assessment in depth.

Considering the existing literature reviews on railway and other construction project risk analysis approaches, the researcher grouped the refined articles into four categories as shown in Figure 2.1: probabilistic analysis, fuzzy logic, multi-criteria decision-making, and system dynamics approach.

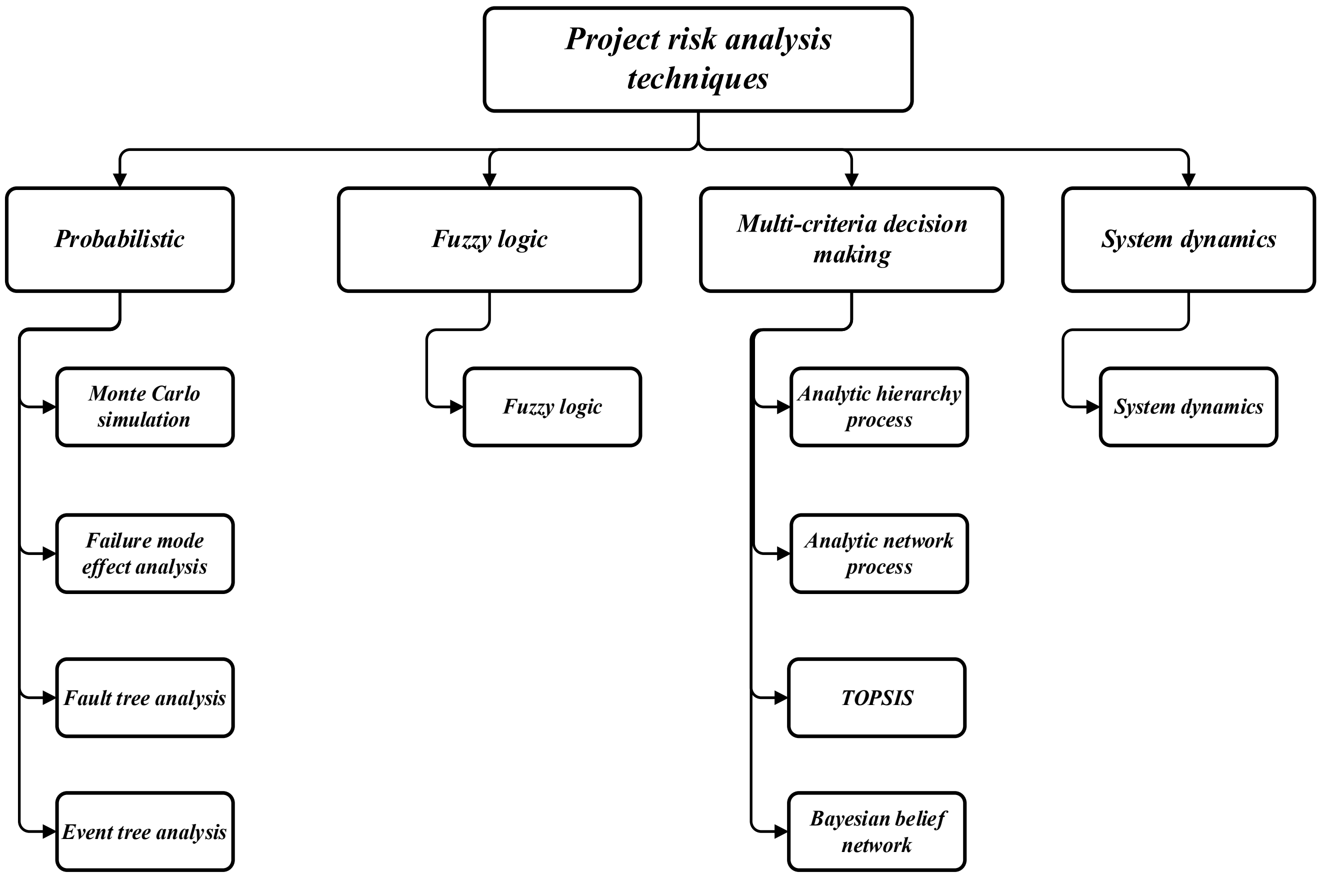

Figure 2.1. Categorization of risk analysis techniques

The first category is a probabilistic analysis that adopts probability theory to analyze the impact of risks on project objectives. The category comprises Monte Carlo simulation (MCS), Failure Mode Effect Analysis (FMEA), Event Tree Analysis (ETA), and fault tree analysis (FTA).

The second category is a fuzzy logic approach which is used to handle uncertainty and imprecise judgments of experts through the use of linguistic variables or fuzzy numbers. Fuzzy logic is a dominant technique used in combination with other approaches to handle uncertainty: fuzzy MCS (FMCS), fuzzy analytic hierarchy process (FAHP), fuzzy Analytic Network Process (FANP), fuzzy Bayesian belief network (FBBN), and fuzzy system dynamics. The third category is multi-criteria decision-making problem analysis approaches that help decision-makers to deal with complex problems. The approaches under this category are AHP, ANP, Technique for Order Performance by Similarity to Ideal Solution (TOPSIS), and BBN.

The fourth category is the system dynamics approach which is used for analyzing the dynamic and feedback effects of project risks. Selected risk analysis approaches for construction projects are depicted in Table 2.4. The table describes the type of risk analysis approaches, their purpose, and their application areas.

Table 2.4. Summary of selected risk analysis techniques for construction projects

Techniques	Purpose	Application Area	Authors
AHP	evaluate sources of risk and uncertainty and prioritize highway construction projects	Highway projects	Zayed et al., (2008)
	To prioritize the risk factors in highway tunnels	Highway Tunnel construction	Zhang et al.,(2011)
	Schedule Delay risk assessment for Nuclear Power Plant construction project	Nuclear Power Plant construction project	Hossen et al., (2015)
ANP	multi-criteria decision-making model for construction project selection	Construction project	Cheng & Li, (2005)
	to assess the risks in Engineering, Procurement, and Construction projects (EPC) projects	Gas Refinery EPC Projects	Rezavalipour et al., (2013)
	to prioritize risks for wind energy projects	Wind Energy Investment	Fera et al., (2017)
	to prioritize risks for European and Middle Eastern Large-scale transport infrastructure projects	Infrastructure projects	Yucelgazi & Yitmen, (2018)
	prioritize the risk responses from the contractors' point of view used in large-scale projects in Europe and the Middle East	Bridge construction	Yücelgazi & Yitmen, (2020)
BBN	to quantify the probability of construction project delays in a developing country	Construction projects	Luu et al., (2009)
	Modeling Risk-Related Knowledge in Tunneling Projects	Tunnel project	Cárdenaset al, (2014)
	Develop a quantitative assessment framework integrating the inference process of Bayesian networks to the traditional	Hospital building project	Khodakarami &Abdi (2014)

Techniques	Purpose	Application Area	Authors
	probabilistic risk analysis to capture uncertainty in project cost analysis		
	Project Complexity and Risk Management (ProCRiM) model for capturing project complexity	Construction project	Qazi et al., (2016)
FST	assess the levels of income risk and cost risk in the real estate investment	Real estate project	Mao & Wu, (2011)
	risk assessment method for metropolitan construction projects	metropolitan construction	Samantra et al., (2017)
FST and HRBS	To evaluate project risk exposure based on project objectives: time, cost, quality, and safety	Construction projects	Tah & Carr (2000)
	To quantify relationships between risk sources and the consequences on project performance measures	Construction projects	Carr & Tah (2001)
FST and Influence diagram	for estimating project cost overrun risk rating	Construction projects	Dikmen et al., (2007)
Fuzzy AHP	To identify risks and provide risk response strategies for future Chinese Public Private Partnerships (PPP) projects	PPP Construction project	Li & Wang (2018)
	Hierarchical risk assessment approach for construction projects	Construction projects	Nieto-Morote&Ruz-Vila, (2011)
	Risk assessment technique for PPPs to simulate the vagueness of human judgment and to improve the assessment accuracy	PPPs	Li & Zou, (2011)
	To evaluate the risk level of a housing project	Housing project	Cebi (2011)

Techniques	Purpose	Application Area	Authors
	Develop a fuzzy AHP (FAHP) model to prioritize construction risks in Brazilian public enterprises	Construction project	Beltrão & Carvalho, (2019)
Fuzzy AHP & Fuzzy TOPSIS	To evaluate the construction projects and their overall risks under incomplete and uncertain situations for projects selection and risk assessment	construction project	Taylan et al., (2014)
Fuzzy AHP FMEA	Develop a risk assessment model for a subway construction project in Iran	Subway construction project	Mohammadi &Tavakolan (2013)
Fuzzy ANP	to evaluate risks of Engineering projects by combining the ANP and fuzzy comprehensive evaluation	Construction Project	Lin & Jianping (2011)
	to establish a project risk evaluation model using fuzzy ANP for urban rail transit	Railway project	Tang et al., (2011)
	prioritize significant risks in freeway PPP projects applying a FANP method	PPP- highway construction projects	Valipour et al., (2015)
Fuzzy ANP and FMEA	Risk evaluation methodology to address the challenges of multi-criteria decision-making problem of project evaluation and selection	Construction projects-Industrial	Yazdani et al., (2019)
Fuzzy Arithmetic	a fuzzy contingency determination model that utilizes a fuzzy arithmetic procedure for construction projects	Construction project	Elbarkouky et al., (2016)
Fuzzy BBN	an FBBN model to analyze the effects of risks on cost overrun in power plant projects	power plant projects	Islam & Nepal (2016)

Techniques	Purpose	Application Area	Authors
Fuzzy FMEA and fuzzy AHP	for assessing the level of criticality of risk events in the construction domain	Construction projects	Abdelgawad&Fayek (2010)
Fuzzy FTA	To conduct fault tree analysis by applying fuzzy logic rather than probability theory for quantitative FTA	pipeline construction project	Abdelgawad&Fayek (2011)
Fuzzy FTA and ETA	Risk assessment methodology for bridge construction projects to identify the main causes of risks and determine the potential outcomes using fuzzy FTA-ETA	bridge construction projects	Abdollahzadeh&Rastgoo(2015)
Fuzzy MCS	FMCS framework for construction project risk analysis	highway project	Sadeghi et al., (2010)
	A hybrid Fuzzy randomness–Monte Carlo simulation (FR-MCS) technique for risk and uncertainty evaluation	PPP-Build-Operate-Transfer (BOT) infrastructure projects	Attarzadeh et al., (2017)
Fuzzy SD	Integrated fuzzy SD model for construction project risk analysis	bridge construction project	Nasirzadeh et al., (2008)
	Integrated fuzzy system dynamics-based approach for the quantitative risk allocation	Water transmission tunnel project	Nasirzadeh et al., (2014)
Fuzzy TOPSIS	Fuzzy TOPSIS method for bridge construction project risk assessment	Bridge construction project	Wang & Elhag, (2006)
fuzzy-fault tree and Delphi method	Quantitative risk assessment framework using fuzzy-fault tree and the Delphi method for Indian BOT road projects	BOT road projects	Thomas et al., (2006)

Techniques	Purpose	Application Area	Authors
Fuzzy FTA and fuzzy ETA	Integrated fuzzy FTA-ETA quantitative risk assessment approach for construction projects	Multistorey building project	Nasirzadeh et al., (2019)
MCS	Schedule and cost risk analysis model for scheduling and cost estimation of a fixed-price design-build construction project	Construction projects	Öztaş & Ökmen, (2004)
	Cost risk analysis of highway megaprojects	Highway	Molenaar (2005)
	Identify and analyze bridge construction project risks in Pakistan	Bridge construction	Choudhry et al., (2014)
	to propose a risk estimation method to be applied in a standardized way on investment projects	Environmental Investment projects	Platon& Constantinescu, (2014)
SD	Evaluate the consequences of different alternative response scenarios to construction project risks in terms of reduction in cost overrun, poor quality, and project delays	construction project	Nasirzadeh et al., (2007)
	To develop a system dynamics model for risk analysis during the project construction process	construction project	Wan & Liu, (2014)
	Cost risk assessment model for analyzing risks and quantifying their impact on the project cost	Airport rehabilitation and expansion project	Li et al., (2014)
	To develop a model to investigate the effect of dynamic risk interactions on schedule delay in infrastructure projects	Infrastructure projects	Wang & Yuan (2017)

2.3.2.1. Probabilistic analysis

Probabilistic risk analysis is a systematic approach to examine the transformation of an undesired initiating event into a set of potential outcomes and their consequences (Lee & McCormick, 2011). Probabilistic-based risk assessment techniques adopt probability theory to deal with uncertainties associated with risk events. For construction project risk assessment, the techniques used probability distribution to offer estimates of the likelihood of achieving project targets and the likely range of outcomes of the project (Smith et al., 2014). These methods include MCS, ETA, FTA, and FMEA.

2.3.2.1.1. Monte Carlo simulation

MCS is a probabilistic risk analysis technique based on multiple uncertain activity combinations to evaluate uncertainty (Hendradewa, 2019). The approach adopts random sampling and statistical modeling to estimate mathematical functions and mimic the operations of complex systems (Harrison, 2010). Using a random number generator and the related cumulative distribution function, MCS generates artificial variable values and then utilizes the results to extract values from the probability distribution that describes the behavior of the stochastic variable (Platon & Constantinescu, 2014; Purnus & Bodea, 2013).

MCS is a common risk analysis technique for construction projects (Sadeghi et al., 2010). It was adopted for scheduling and cost estimation of a fixed-price design-build construction project (Öztaş & Ökmen, 2004), for evaluating the impact of environmental risks on technical and economic objectives of energy investment projects (Olaru et al., 2014). Moreover, the technique was employed for analyzing the cost risk of highway megaprojects (Molenaar, 2005) and for identifying and analyzing the risks of bridge construction (Choudhry et al., 2014).

Even though MCS is employed for problems involving random variables with known or assumed probability distributions (Smith et al., 2014), some variables are estimated based on expert judgment and extracted from historical data. For these reasons, researchers have proposed fuzzy MCS approaches to deal with the limitations of MCS for construction project risk analysis. A fuzzy MCS was developed to analyze risks for highway construction projects (Sadeghi et al., 2010) and road and bridge construction projects (Attarzadeh et al., 2017).

2.3.2.1.2. Failure mode and effects analysis

FMEA is a risk assessment tool for various engineering and management problems (Yazdani et al., 2019). It is an inductive modeling approach for identifying failure modes in a system, analyzing main causes, assessing failure impact, and formulating corrective actions (Mohammadi & Tavakolan, 2013). Risk priority number is used as a weighted assessment number for prioritizing the risk items and it is the product of an occurrence rating, a severity rating, and a detection rating (Ayyub, 2014). However, it is difficult to determine the precise values of these risk factors when there is unavailable or imprecise information. Hence, to make the analysis more consistent and logical, fuzzy logic was introduced to assess the factors in linguistic form(Sharma et al., 2005).

Different researchers adopted FMEA and fuzzy FMEA for risk assessment; for instance, a fuzzy FMEA has been developed for determining construction project risk magnitude (Roghanian et al., 2015). Wang, Chin, et al., (2009) also used a fuzzy FMEA method to evaluate risk factors, and their relative weights linguistically and fuzzy risk priority numbers were calculated for the prioritization of failure modes. Moreover, in order to overcome the drawbacks of FMEA, it was integrated with FST and AHP to deal with uncertainty and to determine the relative weight of the risk impacts on the objectives of the project (Abdelgawad & Fayek, 2010; Mohammadi & Tavakolan, 2013). In these hybrid models, fuzzy numbers of linguistic variables are used to determine the ratings of risk factors (occurrence, severity, and detection) and AHP to assess the relative weight of risk impacts on project objectives.

2.3.2.1.3. Event tree analysis and fault tree analysis

ETA is an inductive modeling approach for identifying various possible outcomes of a given initiating event (Huang et al., 2001). In this approach, probabilistic data of initiating events and pivotal events are used to measure the probability of success and failure (Ayyub, 2014). FTA is a deductive graphical model for constructing logical combinations of parallel events and a series of potential causes leading to the occurrence of undesired events called the top event (Ayyub, 2014).

To handle uncertainty and vagueness, ETA and FTA are integrated with FST. For these reasons, fuzzy FTA was adopted to calculate the fuzzy likelihood of drilling failure for pipeline construction projects (Abdelgawad & Fayek, 2011) and to establish a risk probability and impact assessment framework for Indian BOT road projects (Thomas et al., 2006). On the other hand, fuzzy FTA-ETA was used to identify the main causes of risks and to determine the possible outcomes of the risk event for construction projects (Abdollahzadeh & Rastgoo, 2015; Nasirzadeh, Ghasem Kashi, et al., 2019).

2.3.2.2. Fuzzy logic

Since uncertainty in construction projects typically emerges from either partial information, inherent imprecision, or fuzziness in parameter estimates (Thomas et al., 2006), probabilistic approaches cannot address these uncertainties. Based on these facts, the fuzzy set theory (FST) was introduced by Zadeh (Zadeh, 1965) to deal with approximate rather than precise reasoning (Li, 2013).

Following the introduction of FST, many risk assessment methods have adopted the method as a risk modeling and analytical tool to address vague, imprecise, and complex risk analysis problems (Nieto-Morote & Ruz-Vila, 2011). Fuzzy risk assessment is a preferred method to measure risk ratings where risk impacts are vague and described by subjective judgment rather than by objective data (Dikmen et al., 2007).

Many researchers used this approach to analyze and assess construction project risks. FST and hierarchical risk breakdown structure were used to evaluate project risk exposure based on project objectives: time, cost, quality, and safety (Carr & Tah, 2001; Tah & Carr, 2000a). FST was also used to assess risks for metropolitan construction projects (Samantra et al., 2017). It was also integrated with influence diagrams to estimate cost overrun risk ratings for international construction projects (Dikmen et al., 2007).

2.3.2.3. Multi-criteria decision-making approaches

The multi-criteria decision-making (MCDM) approach is a decision-making analysis method that has been developed since the 1970s and is a study of approaches that concern multiple conflicting criteria (Wu et al., 2012). MCDM techniques (AHP, ANP, TOPSIS, etc) have the common goal of helping decision-makers to address complex issues, and the steps followed are identifying objectives, identifying options for achieving objectives, identifying criteria to be used to compare options, analyzing options, making choices and feedback (Kubler et al., 2016).

2.3.2.3.1. Analytic hierarchy process

AHP is an MCDM technique that allows subjective and objective factors (Dey, 2012) and helps to evaluate complex multi-criteria alternatives (Wu et al., 2012). AHP analyzes the MCDM problem by creating a hierarchy of criteria and subcriteria that could be either quantitative or qualitative. This can be achieved by making pairwise comparisons between those criteria, which are determined by experts in the relevant sector (Chan & Wang, 2013; Dey, 2012).

Numerous studies used AHP to evaluate risks in various areas of application. It was employed to analyze the schedule delay risk for the nuclear power plant construction project (Hossen et al., 2015), to rank the construction project risk factors for the construction of highway tunnels (Zhang et al., 2011), and to evaluate sources of risk and prioritize highway construction projects in China (Zayed et al., 2008).

In order to improve the effectiveness of project risk assessment, the AHP approach has been integrated with other methods. A decision support system using AHP and Decision Tree Analysis was developed to manage the risks of construction projects (Dey, 2001). The system helps identify risk factors, analyze their impacts on different activities and create cost-effective responses to mitigate quantified risks.

Although AHP models are designed to capture expert knowledge or opinions, the inputs of the models are subjective and rely on the information available and the reliability of the sources. As a consequence, fuzzy logic linguistic expressions are regarded as natural representations of judgments in vague, imprecise, and uncertain contexts(Chan & Wang, 2013).

Fuzzy AHP was used for resolving the risks associated with construction projects in complicated circumstances. For instance, the approach was employed for assessing the risk level of housing projects (Cebi, 2011) and for analyzing the overall risk factors for building rehabilitation projects (Nieto-Morote & Ruz-Vila, 2011). The fuzzy AHP also provides the ability to overcome complex risk assessments of PPP projects. This integrated technique has been used for modeling the vagueness of human judgment and to improve the accuracy of risk assessment for expressway projects (Li & Zou, 2011), for risk evaluation model for PPP projects in China (Li & Wang, 2018), and for ranking the risks of public construction projects in Brazil (Beltrão & Carvalho, 2019).

Although it is an effective approach to prioritize alternatives and select options for improvement, the method does not consider the interaction between criteria. AHP does not explicitly consider the interactions within various factors/clusters and to address the limitations of AHP models, ANP has been used to fix the issue of dependency among alternatives or criteria (Chan & Wang, 2013).

2.3.2.3.2. Analytic network process

The independence between the higher and lower-level elements and the independence within the level assumptions of AHP makes the calculation easier to analyze MCDM problems (Saaty, 1994). However, the complexity of the decision-making problems arising from the interdependence between higher and lower-level elements, as well as within the level, make it difficult for the elements to be hierarchically structured using AHP. To address these limitations of AHP, Saaty (1996) proposed an ANP that can deal with the complexity and dynamic nature of decision problems by considering dependency and feedback in the decision-making system. Comparing their structure, ANP is a nonlinear structure for establishing interrelationships between criteria in different clusters or within the same cluster, while AHP is a hierarchical and linear structure with the goal at the top level and the alternatives at the bottom level (Lin, 2012). ANP is used to handle numerous, correlated and conflicting criteria (Sayyadi & Awasthi, 2018).

The ANP process has two parts, as shown in Figure 2.2. The first part is a control hierarchy or network of criteria and subcriteria that controls the interactions. The second part consists of a network of influences among the elements and clusters. In ANP, there are outer-dependence and/or inner-dependence between the elements and clusters (Gang Kou et al, 2013). Outer-dependence is the dependence between components but in a way to allow for feedback circuits. Inner-dependence is the interdependence within a component combined with feedback between components (Meade & Sarkis, 1999).

Various studies have been conducted to provide a solution for MCDM problems using ANP. It has been utilized to empirically prioritize a set of projects for selecting construction projects in Australia (Cheng & Li, 2005), and to prioritize risks for wind energy installation projects (Fera et al., 2017) and large-scale transport infrastructure projects (Yucelgazi & Yitmen, 2018). Likewise, risk responses from the contractors' point of view were prioritized using ANP for bridge construction projects (Yücelgazi & Yitmen, 2020).

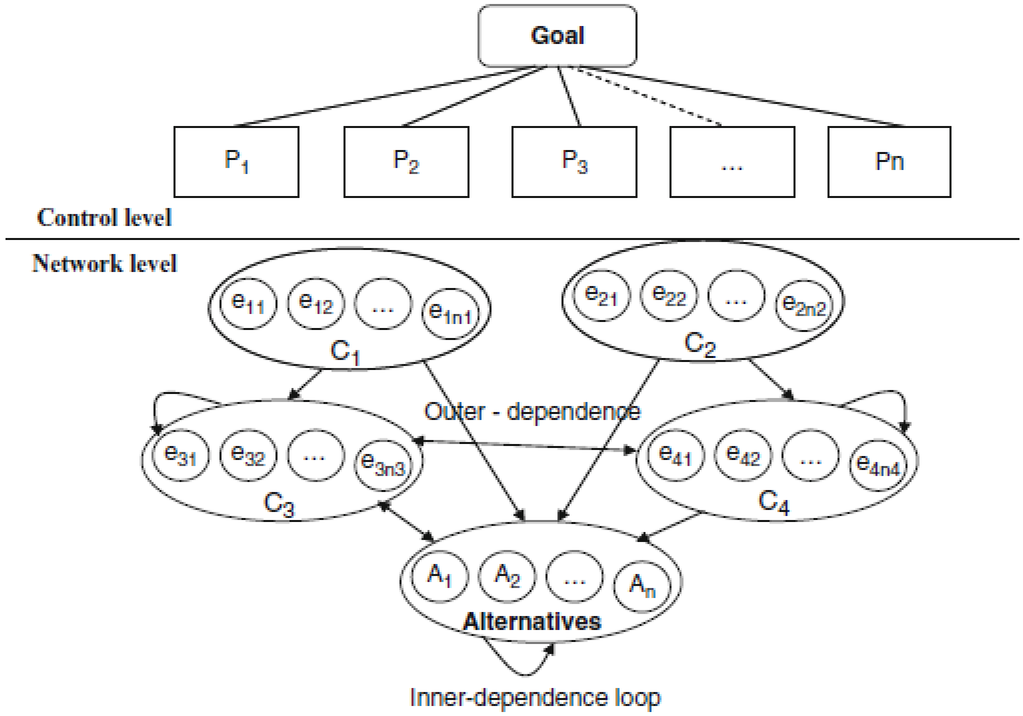

Figure 2.2. The structure of ANP

However, since construction projects are risk-prone and reliant on expert judgment and experience, it is often difficult to measure subjective or qualitative information using probabilistic approaches (Thomas et al., 2006; Islam & Nepal, 2016). As a result, various researchers employed fuzzy logic to deal with vague and uncertain project risks and their impact on the project objectives (Thomas et al., 2006; Abdelgawad& Fayek,2011). Thus, the integration of fuzzy logic with ANP can handle uncertain parameters and information in the pairwise comparison of ANP. Fuzzy ANP was utilized to assess the risk impact on highway construction projects in Iran (Valipour et al., 2015); to analyze the risks of a campus construction project (Lin & Jianping, 2011), to establish a risk evaluation system for the urban rail project in China (Tang et al., 2011) and also to develop a risk evaluation methodology to address the challenges of the MCDM project evaluation problem (Yazdani et al.,2019).

2.3.2.3.3. Technique for order performance by similarity to ideal solution

TOPSIS is a technique to evaluate the performance of alternatives through similarity with the ideal solution (Chan & Wang, 2013). The main concept of this technique is to define the positive ideal solution and the negative ideal solution. The positive ideal solution is the one that maximizes the benefit criteria and minimizes the cost criteria, while the negative ideal solution maximizes the cost criteria and minimizes the benefit criteria (Abdullah & Nashwan, 2015). The idea behind TOPSIS is to select the option that best achieves a balance between two conditions: to be as close as possible to the positive ideal solution and to be as far as possible from the negative ideal solution (Emrouznejad & Ho, 2017). Even though TOPSIS is an appropriate method for project selection, bid, and risk assessment (Islam et al., 2017; Taylan et al., 2014), it has a drawback of the inability to handle vague and uncertain problems (Krohling & Campanharo, 2011). Hence, FST was integrated with TOPSIS to overcome these limitations and the fuzzy TOPSIS was then applied to solve various MCDM problems in bridge risk assessment (Y. M. Wang & Elhag, 2006). Moreover, the FAHP-TOPSIS combination inherits the advantages of TOPSIS: it allows the use of evaluation parameters with varied scales and units, including negative values (Emrouznejad & Ho, 2017). A fuzzy AHP and fuzzy TOPSIS integrated approach were adopted to prioritize and categorize project risks (Taylan et al., 2014). Fuzzy AHP was utilized to weigh fuzzy linguistic variables of construction project overall risk and fuzzy TOPSIS was used to solve group decision-making problems under the fuzzy environment.

Although TOPSIS and fuzzy TOPSIS approaches are simple to compute and understand, they do not take into account the hierarchical structure between the main subcriteria (Kahraman et al., 2007). Moreover, the TOPSIS techniques do not analyze different criteria comparatively (Ertuğrul & Karakaşoğlu, 2008) and hence they are more effective in one-tier decision-making problems than multi-tier problems (Bottani & Rizzi, 2006).

2.3.2.3.4. Bayesian belief network

BBN is a directed acyclic graph in which the nodes represent the probabilistic system variables and the arcs represent dependency or causal relationships between variables (Oliva et al., 2009). There are three important elements in the development of a BBN: nodes (key factors), networks, and conditional probabilities. The nodes that are the starting ones and do not have an inward arrow are referred to as the parent nodes, while the nodes which have inward arrows connected to them are the child nodes (Khodakarami & Abdi, 2014). BNs can be described in terms of a qualitative component, consisting of the causal structure of the system variables, and a quantitative component, consisting of the conditional probability tables (CPTs) assigned to variable nodes (Aliabadi et al., 2020; Kjærulff & Madsen, 2013).

Various researchers employed the BBN approach for construction project risk assessment; for instance, it was used to quantify the likelihood of construction delays (Luu et al., 2009) and to develop a framework for quantifying uncertainty in project cost for a hospital building project (Khodakarami & Abdi, 2014). In the case of large-scale engineering projects, BBN was also used to develop a model called Project Complexity and Risk Management (ProCRiM) that helps capture the interdependence between project complexity, complexity-induced risks, and project objectives in construction projects (Qazi et al., 2016).

BBN uses probability to assess uncertainty; however, due to inadequate data, vagueness, and incomplete knowledge, it is difficult to obtain accurate information (Zhang et al., 2016). Thus, fuzzy logic is incorporated with BBN to enable the conditional probabilities to be defined as ranges rather than as crisp values. Fuzzy BBN has been employed as a prominent approach for analyzing safety and risks. Islam& Nepal (2016) proposed an FBBN model to analyze the effects of risks on cost overruns in power plant projects; Kabir et al.,(2016) utilized a fuzzy BBN to develop a safety assessment model for analyzing Oil and Gas pipeline failure in Canada; Zhang et al.,(2016) used FBN for safety risk analysis to conduct the causal analysis of pipeline safety in tunnel construction projects and Wang and Chen (2017) used the approach for safety risk analysis in metro construction projects in China.

Risk assessment models using BBN are advantageous as they use inputs from historical data and expert judgment for causal relationships and probability distribution and have the ability to update the CPTs and the belief of the nodes when new information is available (Kabir et al., 2016). BBN is an efficient modeling method for capturing the interdependence of risks (Nepal & Yadav, 2015). It is then used to solve complex and uncertain relationships between numerous risk factors (Cárdenas et al., 2014; Islam & Nepal, 2016). However, the cause-effect network relationship formation and CPTs assignment are laborious to implement (Cárdenas et al., 2014). In addition, as BBN is a directed acyclic graph, the feedback loops, delays, and dynamic effects of risk factors and their CPs over time cannot be handled.

2.3.2.4. System dynamics

System dynamics was developed by Jay W. Forrester at the end of the 1950s as a modeling tool for large real-world systems (Forrester, 1961). It is defined by Coyle (1996) as: “an approach that deals with the time-dependent behavior of managed systems to describe the system and understanding, through qualitative and quantitative models, how information feedback governs its behavior and designing robust information feedback structures and control policies through simulation and optimization". The SD approach reflects feedback processes together with stock and flow structures, time delays, and nonlinearities (Sterman, 2000).

SD modeling is useful for managing and simulating processes that have two major characteristics: (1) they involve changes over time and (2) they allow feedback-the transmission and receipt of information (Nasirzadeh & Nojedehi, 2013). SD is a feedback-based methodology that can easily handle the nonlinearity and time-delay and multi-loop structures of complex and dynamic systems. Feedback, accumulations (stocks), rates (flows), and time delays are key elements of SD. Stocks are an accumulation or aggregation of something. Flows are rates that feed in and out of stock and have the same units of stock per unit of time.

SD modeling can be applied adequately to construction domain problems. The reason is that construction projects (Sterman, 1992):

- are extremely complex, consisting of multiple interdependent components
- are highly dynamic
- involve multiple feedback processes
- involve nonlinear relationships
- involve both hard (quantitative) and soft (qualitative) data.

SD is suited to handle these situations more than any other modeling process (Nasirzadeh et al., 2008b).

Due to these advantages, SD has been proposed for risk management that requires a systemic approach for feedback capture and quantification of subjective factors (Rodrigues, 2001). The approach has also been used as a possible solution to deal with the complexity of projects in different areas of application. SD has been used to develop a model to capture the dynamics of design errors and to assess their negative impact on delays for building projects (Han et al., 2013), and also used to analyze the effect of risk interactions on infrastructure project schedule performance (Wang & Yuan, 2017; Xu et al., 2018). The approach has also been utilized to evaluate the consequences of alternative response scenarios and analyze the impact of project risks on cost, quality, and delay (Nasirzadeh et al., 2007), to evaluate risk interactions and measure their effect on the cost of the construction project (Li, Wang, et al., 2014) and to develop a risk analysis model during the project construction phase (Wan & Liu, 2014).

However, SD models are unable to deal with vague and uncertain information about risk factors. Hence, fuzzy logic has been integrated with SD to deal with these drawbacks. A fuzzy SD approach was developed to model and quantify interrelated risks in terms of their effect on project time and cost for a bridge construction project (Nasirzadeh et al., 2008a).

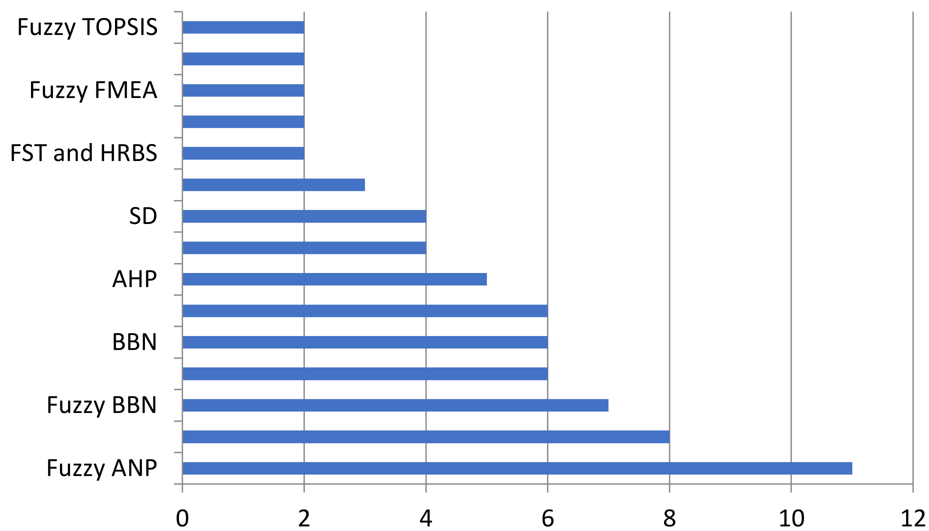

Figure 2.3. Summary of main construction project risk analysis techniques

In summary, the key risk analysis methods used for construction project risk management are shown in Figure 2.3. The Figure shows that most of the techniques used to assess construction project risks are hybrid techniques, which are mostly integrated with fuzzy logic. Moreover, the advantages and limitations of the existing risk analysis techniques are listed in Table 2.5.

Table 2.5. Summary of project risk analysis technique advantages and limitations

Techniques	Advantages	Drawbacks
Probabilistic	Used when the uncertainty is known	Not used when there is a lack of data
FMEA	Identify and present component failure modes, causes, and effects in a readable format.	Time-consuming difficult and tedious for complex multi-layered systems
FTA	highly systematic and flexible approach	Uncertainties in the probabilities of base events Fault trees can only deal with binary states
MCS	relatively simple to develop models can be easily understood	the accuracy relies on the number of simulations large and complex models may be challenging
FST	handles uncertainty, used when there is a lack of information	cannot handle the causal relationships and dependencies
AHP	Used for the hierarchical structure of elements	Unable to deal with interactions, dependencies, and feedback between higher and lower-level elements
ANP	deal with the complexity of decision problems considering dependency and feedback	constructing a pairwise matrix for a large number of risks is laborious and lengthy
TOPSIS	capture additional risk evaluation criteria (e.g., risk detectability and vulnerability)	unable to handle vague and uncertain problems do not analyze different criteria comparatively
BBN	deal with complex relationships, and update new information to the system	require a lot of time and effort require an exact probability of each risk factor cannot deal with feedback effects
SD	dynamic and feedback effects causal relationships and dependencies among risks Capture long-run behavioral patterns and trends	highly dependent on the developer Easy to conceptualize erroneous CLDs & SFDs

2.4. Literature gaps and discussion

Different risk assessment approaches have been implemented to analyze the impact of construction project risks on project objectives. This paper reviewed various studies that used different techniques (probabilistic, fuzzy logic, MCDM, and SD) to assess the risks of the railway and other construction projects.

Probabilistic methods have been used to measure the probability of delay or cost by treating risk cost as an estimation variance (Taroun, 2014). Construction project risk assessment researchers have implemented probabilistic approaches to analyze project risk using probability theory. In general, these approaches are used to address the uncertainty of variables that result from randomness (Thomas et al., 2006).

However, since construction projects are risk-prone and reliant on expert judgment and experience, it is often difficult to measure subjective or qualitative information using probabilistic approaches. As a result, various researchers employed fuzzy logic to deal with vague and uncertain project risks and their impact on the project objectives (Abdelgawad & Fayek, 2011; Thomas et al., 2006). On the other hand, to understand and rank risks in different hierarchy levels by considering MCDM problems, AHP was utilized for project risk assessment. Furthermore, AHP was combined with FST to handle uncertainty and with TOPSIS to determine variable weights. However, due to the complexity and dynamic nature of project risks, fuzzy AHP cannot overcome relationships, dependencies, and feedback between higher and lower-level elements and are also unable to determine the impact of risks in different phases of the project life cycle (Islam et al., 2017). Owing to this, the ANP approach was introduced to deal with the interdependence of complex decision-making factors and to help decision-makers determine the relationship between decision-making levels and their corresponding attributes (Saaty, 1996). However, developing and constructing a pairwise matrix for a large number of risks is laborious and lengthy. In addition, the ANP and FANP approaches are unable to update when new information/data is available (Kabir et al., 2016). Hence, BBN was adopted to deal with the limitations of ANP and FANP for risk assessment (Kabir et al., 2016; Li et al., 2012). Fuzzy BBN has been utilized as an approach to handle uncertainty, vagueness, and imprecision of data, deal with complex relationships, and update new information to the system. However, FBBN techniques depend on experts, require a lot of time and effort

(Zhang et al., 2016), and are unable to deal with feedback effects. On the other hand, the SD approach for project risk assessment was used to assess the dynamic effect of project risks and their feedback effects (Wan & Liu, 2014; Wang & Yuan, 2017). These techniques are also combined with FST to address the uncertainty and imprecision of input data as well as the subjectivity of experts.

In short, the results of this review on railway construction project risk assessment differ in part from the previous reviews (Islam et al., 2017; Taroun, 2014). Islam et al.,(2017) conducted a literature review based on papers that employed fuzzy and hybrid techniques published between 2005 and 2017 and concluded that FBBN had the greatest potential to overcome limitations in addressing project uncertainties, limited objective data, and reliance on expert judgment. Moreover, Taroun (2014) focused on related publications between 1980 and 2012 that employed probability-impact assessment, probabilistic and AHP approaches, and concluded that the probability-impact assessment approach is an effective and practical risk assessment method for construction projects. However, uncertainty, vagueness, and imprecise information cannot be addressed through probability-impact assessment approaches and feedback effects of project risks cannot be handled through fuzzy BBN techniques. In addition, most of the previous railway construction project risk assessment studies have not adequately considered the SD approach as a tool that can deal with the dynamic and feedback effects of project risks. As a consequence, this review concludes that hybrid risk analysis methods addressing uncertainty, causal relationship, likelihood and impact, dynamic and feedback effects, and correlated and conflicting criteria are viable approaches for risk assessment of railway construction projects.

2.5. Summary

This paper reviewed risk assessment approaches related to railway construction projects. The review is conducted on publications that adopted different risk assessment techniques for construction projects. These publications were compiled from Science Direct, Emerald Insight, Taylor & Francis, Springer, and Google scholars that were published over the last two decades (January 2000 and March 2020). The probabilistic, fuzzy logic, MCDM, and SD methods adopted for the construction project risk assessment were reviewed and their respective limitations were identified.

The result of the review indicated that the fuzzy logic approach was a dominant method that was integrated with other approaches for dealing with uncertainty and vagueness. More specifically, the MCDM, fuzzy ANP, and fuzzy AHP methods were primarily used for risk assessment of construction projects. However, they were unable to update the emergence of new information/data. It was also tiresome and time-consuming to create a pairwise matrix for a large number of project risks. Hence, a BBN was adopted to deal with the limitations of FANP or FAHP. However, BBN and FBBN cannot handle the dynamic and feedback effects over time. Hence, system dynamic approaches have been suggested to analyze both the dynamics and the feedback effects of project risks. Nonetheless, SD was unable to correlate and prioritize risk factors based on their impact on project objectives. To bridge the gap in implementing an effective risk assessment methodology for railway construction projects, a hybrid approach that can address the probability and impact of risks, uncertainty, causal relationship as well as dynamic and feedback effect of risks is recommended.

3. RESEARCH DESIGN AND METHODOLOGY

3.1. Introduction

This chapter describes how to achieve the research objectives. This part also details the general research design, sources of relevant data, data collection methods, sampling design, and approaches to data analysis. In addition, the reliability and validity of the data collection instrument are presented.

3.2. Research design

The process for conducting the research began with identifying the problem and research gaps. Railway construction project risk identification is the first task of the research. This was achieved through extensive literature reviews, discussions with experts in the railway construction industry, and reviews of ERC documents.

After completing the risk identification task, the target population and the sample size were determined based on the objectives of the research. Moreover, a questionnaire was developed to assess the perceptions of the client, consultants, and contractors on the impact of project risks on delays and cost overruns for the Addis-Djibouti railway construction project. Data was collected from the employer (ERC), the client representative (CIECC), and contractors involved in the construction of the railway project. Following data collection, the data was analyzed using integrated risk analysis methodologies, and a dynamic risk assessment model for railway construction projects was developed. Due to the nature of the research, both quantitative and qualitative approaches are used for data analysis. The overall process used to carry out the research is depicted in Figure 3.1.

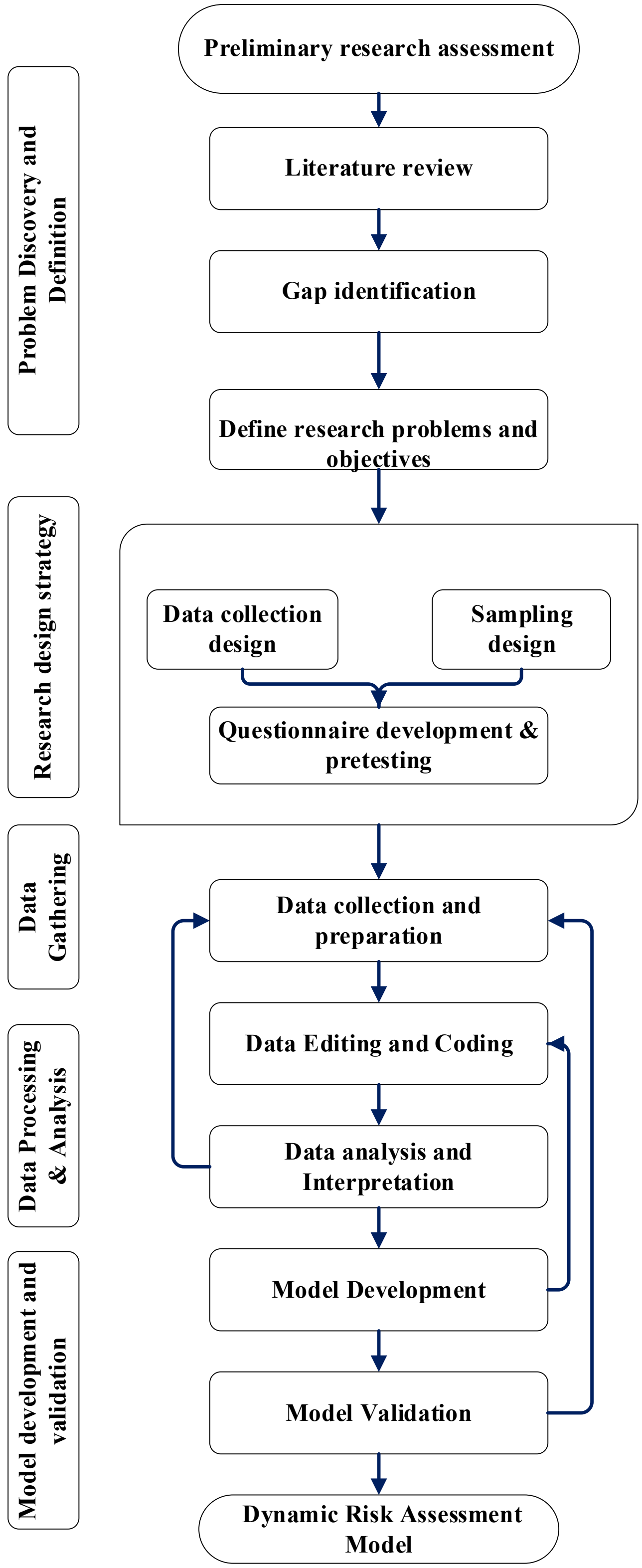

Figure 3.1. Flowchart of the research process (author design)

3.3. Data sources

Data sources can be broadly categorized into primary and secondary data sources.

3.3.1. Primary data sources

Primary data can be collected in a variety of ways. However, self-administered surveys, interviews, field observation, and experiments are the most commonly used methods (Salkind, 2010). Since the information has not been vetted or interpreted by a third party, primary sources are always the most authoritative (Cooper & Schindler, 2014). In addition, the analysis that is directly related to the occurrence of an event makes primary data more dependable and decision-making more reliable. For this research, questionnaires, interviews, and expert discussions were employed to collect primary data from respondents.

3.3.2. Secondary data sources

A desk review was conducted to collect data from various secondary sources. Secondary data sources included related literature on project risk assessment, reports of ERC, and project documents of the Addis-Djibouti railway construction project. For the review, credible journals, proceedings, books, and related websites were considered. The majority of the research articles were obtained from Science Direct, Springer Link, Emerald Insight, and Taylor & Francis.

3.4. Sampling design

The target population for this research is contractors, client representatives, and employer of the Addis-Djibouti railway construction project. This includes experts, engineers, and contract administrators of the railway construction project.

The sampling techniques that have been used to collect relevant data from respondents are random sampling and purposive sampling. Respondents of the railway project were selected based on their position, experience, and expertise level, and were randomly selected from the group.

It is essential to determine the appropriate sample size before data collection. The calculation of the required sample size includes an assessment of the feasibility of the research objective (Thiétart, 2001). The respondents of these stakeholders included project managers, contract administrators, engineers, and experts that have experience in railway construction projects. The sample size of respondents was determined using the following formula proposed by Yamane (1967):

$$n = \frac{N}{1 + N(e)^2} \tag{3.1}$$

Based on this formula the sample size has been determined as,

$$n = \frac{86}{1 + 86(0.05)^2} = 71$$

Where n is the sample size, N is the population size (86), and e is the estimated standard error which is 5% for a 95% confidence level. The sample size for this study was calculated to be seventy-one respondents, and hence, a total of seventy-one questionnaires were distributed to respondents.

3.5. Data collection techniques

The primary activity in research is data collection about the phenomenon being studied. For this purpose, different data collection methods are used. Various data collection methods such as literature review, interviews, discussions, questionnaires, and relevant document analysis are used for this study.

3.5.1. Literature review

A systematic review of the literature on the risk assessment of the railway construction project was carried out in this paper. The main phases of the Preferred Reporting Items for Systematic Review and Meta-Analysis (PRISMA) procedure, including the literature search, the selection of qualifying papers, and the extraction and categorization of data, were followed in the review process. A combination of keywords has been used to search for related articles from Science Direct, Emerald Insight, Taylor & Francis, Springer, and Google scholar. The keywords used to search the relevant literature were “risk analysis” OR “risk assessment”, “railway construction project risk analysis” OR “railway construction project risk assessment”, “construction project risk analysis techniques”, “construction project risk assessment” and “Construction project risk management”.

The search from these sources covered papers published between January 2000 and March 2020. As a result, according to the search strategy, a total of 544 publications were found in these sources. Of these, a total of 362 papers were retained after duplicate elimination. The next task was to pick the publications that are relevant to the scope of the topic. Publications that used various risk analysis methods to assess the risks of construction projects were chosen. Finally, one hundred and seventeen publications that comply with the inclusion criteria were considered eligible for this review after the title, abstract and full-text screening. Out of these 108 articles are used for analysis while the remaining nine publications and books are used as a reference in this paper. The required data was then extracted from the selected 108 papers. These papers were classified according to the project risk analysis methods adopted for construction projects.

Project risk factors that have an impact on railway construction project objectives are identified from the literature, experts and ERC reports. These factors are categorized into design risks, construction risks, management risks, resource risks, contractual & legal risks, and external risks. These risk factors were reviewed by railway construction industry experts to ensure accuracy and completeness.

3.5.2. Questionnaire survey

After completing the risk identification task, a comprehensive survey was developed to quantitatively evaluate each risk factor from the perspective of railway construction projects in Ethiopia. The questionnaire was developed to assess the perceptions of clients, consultants, and contractors on the occurrence, impact on time, and cost of risk factors of the railway construction project. The questionnaire was divided into two main sections and designed to rate risk factors. The first section asks for general company/respondent information and the second section asks the participants to rate the identified risks' likelihood and their impact on project objectives.

For this research, the respondents were asked to rate the likelihood of occurrence of risks using a 5-point scale, with 1 indicating very unlikely, 2 suggesting unlikely, 3 indicating medium, 4 indicating likely, and 5 indicating very likely.

The data collection phase of the research process usually begins with pretests. As a result, in this study, the data collection system was pretested at the beginning of the collection phase, and the tests were conducted on thirteen randomly selected respondents to confirm the clarity of the instructions, relevance of the potential project risks, and ambiguity of the questions.

As shown in Table 3.1, thirty-one questionnaires were distributed to the client, and 27 questionnaires are filled out and returned to the researcher. Twenty-five questionnaires were also distributed to the contractors and 15 questionnaires were filled and returned. On the other hand, 15 engineers of the consultant were involved in the survey and 10 valid questionnaires were returned.

Table 3.1. Company type of the survey respondents

Company	Distributed Questionnaire	Returned	Percentage
Client	31	27	87.1%
Contractor	25	15	60%
Consultant	15	10	66.7%
Total	71	52	73.24%

The positions of respondents are categorized into four main groups, namely: Engineers, contract administrators, project managers and technical experts. are clustered into four groups (Table 3.2). Most of the respondents were Engineers who account for 80.77% and followed by project managers who account for 9.62%. Ccontract administrators represented 5.77% of the respondents' proportion and the remaining 3.85% share of respondents was held by technical experts.

The work experiences of the respondents were also presented in Table 3.2, which implies that most respondents (61.54%) have work experience between 5 and 10 years followed by a work experience of less than 5 years (17.31%). The survey result of educational background of the respondents showed that most of the respondents were BSc holders who account for 63.46% and followed by MSc degree holders who account for 36.54%.

Table 3.2. Demographic information of respondents

	Category	No. of responses	Percentage
Organization	Client	27	51.92%
	Contractor	15	28.84%
	Consultant	10	19.23%
Position	Engineers	42	80.77%
	Contract administrators	3	5.77%
	Project managers	5	9.62%
	Technical Experts	2	3.85%
Experience	Less than 5 years	9	17.31%
	5-10 years	32	61.54%
	10-15 years	8	15.38%
	More than 15 years	3	5.77%
Educational background	Diploma	-	
	BSc	33	63.46%
	MSc	19	36.54%
	Ph.D	-	

3.5.3. Focus group discussions and Interviews

In this research, six experts from the client (two), contractors (two), and consultant (two) are chosen based on their experience in railway construction projects, and their opinions on identified project risks are used to review the final list of risk factors and their opinions on the interrelationships between project risks. The discussions were conducted with experts including engineers and project managers with more than five years of experience working in railway construction projects.

3.5.4. Data collection procedure

First, the study proposal was developed and gets approval from the advisor. After the proposal approval, a formal letter was sent to ERC to request permission to carry out the study. Once the permission was granted by ERC, the draft survey questionnaire was pilot tested and feedback from the respondents was incorporated into the final questionnaire. The participants of the pilot test indicated some unclear questions and some technical words to be cleared before the questionnaire was distributed. The questionnaires were then reviewed and distributed to respondents via email and in person. Respondents were given ten days to fill in the questionnaire, after which, the researcher collected fifty-two questionnaires for data analysis.

3.6. Reliability and validity

To determine the rigor of a study, quantitative researchers employ a variety of criteria for evaluating methods to measure variables. The two most crucial requirements are reliability and validity.

3.6.1. Reliability

Reliability is defined as the ability of a measuring instrument to measure the concept in a consistent manner (Hinton, 2005). It refers to the consistency or dependability of a measurement technique, and it is concerned with the consistency or stability of the score obtained from a measure or assessment over time and across settings or conditions (Marczyk et al., 2005). Internal consistency test was conducted in this study to determine if participants were responding to the various items of a questionnaire consistently. It describes the extent to which all of the items in a test assess the same concept or construct, and it is thus related to the inter-relatedness of the test items. A reliability coefficient, such as Cronbach's alpha, was used to measure internal consistency (Cronbach, 1951), and reliability values of 0.7 or above are regarded as adequate (Badri et al., 1995). The internal consistency analysis for each criterion was performed using the SPSS reliability program. The test results showed that Cronbach's alpha values for likelihood, impact on time, and impact on cost were 0.889, 0.879, and 0.915 respectively. These values indicate a high degree of internal consistency among the respondents, as well as the instrument's reliability.

3.6.2. Validity

Validity is the degree to which a test or instrument measures what it purports to measure (Nunnally & Bernstein, 1994). In this research, content validity was used to test the relevance of the data collection instruments to the construct being measured. The measurement is valid if there is a general agreement between the subject and the researcher that the instrument has measurement elements that cover all aspects of the measurement variable. Therefore, the content validity depends on how well the researcher created the measurement element to cover the content area of the measured variable (Nunnally & Bernstein, 1994; Saraph et al., 1989). Since the questionnaire for the study was designed based on a systematic literature review and the opinions of the railway construction industry experts, it was concluded that the instrument had good content validity.

3.7. Data analysis

In this study, both qualitative and quantitative methods were used to identify and analyze the impact of risk factors on railway construction projects. All the data gathered from the structured questionnaires were checked for completeness and consistency and are coded and entered into Microsoft Excel and statistical analysis software package SPSS version 23.0 for analysis.

Due to the imprecise nature of many factors that affect construction projects and a general lack of data for their proper quantification, fuzzy logic was used in many construction applications. The measurement of construction factors is often subjective and uncertain, where actual data are not available or when the data come from the experience and judgment of those in the industry. Hence fuzzy logic was employed to alleviate the effect of uncertain and unavailable relevant data in railway construction project risk assessment. The BBN was developed to determine the probabilities of risk factors. The analytical network was developed and the priority values (normalized eigenvalues) of the pairwise comparison matrices of ANP. The interrelationships of the project risk factors are determined and analyzed using causal loop diagrams and the dynamics of risk impacts on project time and cost are analyzed using stock-flow diagrams. The tools that are used for data analysis of the dissertation are Microsoft Excel, Netica 6.09, Superdecision 3.2.0, and Vensim ® DSS version 9.3.0.

3.8. Ethical consideration

Ethical clearance was obtained from the African Railway Center of Excellence, Institute of Technology, Addis Ababa University. An official letter was written from the center to the ERC. The study's objective was disclosed to the participants. Research participants were told that the information they provided would be treated confidentially and their identities would not be disclosed in connection with the information they provided. Declarations of consent were obtained from each participant. The respondents' replies and privacy were not individually examined and included in the report.

3.9. Summary

The research design and methodology chapter described the overall process of the research as well as the methods used to analyze the effect of project risks on delays and cost overruns in the railway construction project. This chapter comprises the processes from problem formulation to the development of a risk assessment model. The chapter also describes data sources, data collection, and data analysis approaches employed for the research. FSE, BBN, FANP, and SD approaches have been integrated to handle the uncertainties caused by subjective judgment, vagueness, risk interdependence, and dynamic effects of risks of the railway construction project. The proposed integrated risk assessment approach will be discussed and implemented in the following chapters.

4. RISK ASSESSMENT USING FUZZY SYNTHETIC EVALUATION, BAYESIAN BELIEF NETWORK, AND FUZZY ANALYTIC PROCESS

4.1. Introduction

In this chapter, the magnitude of project risks and their effect on delays and cost overruns are determined based on the likelihood of occurrence and impact on the project objectives of the railway construction project. Fuzzy synthetic evaluation and fuzzy Bayesian belief network are employed to determine the probability of occurrence and a fuzzy analytic network process was adopted for determining the impact of project risks on the project objectives. The overall effect of project risks was determined and used as input for the dynamic risk assessment model.

4.2. A fuzzy synthetic evaluation model for risk assessment

The fuzzy set concept was first introduced by Zadeh (1965) to handle vagueness in human judgment. The FST can also operate on inaccurate data to deal with approximate reasoning. Since uncertainty in construction projects usually resulted from partial information, imprecision, or fuzziness of parameter estimates (Thomas et al., 2006), probabilistic approaches cannot handle these uncertainties. Due to these facts, FST was introduced as an appropriate technique to handle uncertainty and vagueness that result from subjective judgment, and unavailable and imprecise information (Pedrycz et al., 2011).

The fuzzy synthetic evaluation (FSE) approach is an FST application that seeks to offer a synthetic evaluation of a factor in relation to an objective in a multi-criteria fuzzy decision environment (Mu et al., 2014). As risk assessments in railway construction projects are often multi-layered, fuzzy in nature, and require subjective judgment, it is suitable to use the FSE approach in this study to develop a fuzzy risk assessment model. The modified procedures of FSE model development are:

a) Determine a set of basic criteria/factors
b) Determine a set of grade alternatives
c) Determine the weight of each risk factor/criterion
d) Establish a fuzzy evaluation matrix of risk factors for each criterion
e) Compute the fuzzy evaluation matrix by considering the weight vectors

f) Determine the weight of project duration and cost:

g) Convert the membership function to a triangular membership function

h) Defuzzification

4.2.1. Risk identification and classification

The project risks that affect the cost and duration of railway construction projects are identified using a literature review, expert opinions, document reviews, and ERC reports. Risk factors are then categorized into design risks (DS), construction (CN), management (MN), resources (RS), contractual & legal (CL), and external (EX) related risk factors. The identified project risks and their category are depicted in Table 2.3.

4.2.2. Determine risk evaluation criteria and grade alternatives

The criteria for assessing project risks are likelihood of occurrence, impact on time, and cost whereas the factors are all forty-two risk factors under design, construction, management, resource, contractual, and external risk categories. In this research, the likelihood of occurrence was taken as the criteria for evaluating the impact of the project risks. The grade alternatives for likelihood of occurrence, e_1=rare; e_2=unlikely; e_3=possible; e_4=likely; and e_5=almost certain; and for impact on time and cost, e_1=very low; e_2=low; e_3=moderate; e_4=high; and e_5=very high.

4.2.3. Determine weights for the project risk factors and risk categories

Based on the mean evaluations, weighted risk factors were computed. The following equation was used to determine the weightings for each risk factor and category:

$$W_i = \frac{A_i}{\sum_{i=1}^{5} A_i} \tag{4.1}$$

where:

W_i represents the weighting of a risk factor;

A_i represents the mean ratings of a risk factor;

Table 4.1 shows the weights for each risk factor and category.

Table 4.1. Weight of risk factors and categories

Risk Code	Likelihood			Time			Cost		
	Mean value	Weight of risk factor	Weight of risk category	Mean value	Weight of risk factor	Weight of risk category	Mean value	Weight of risk factor	Weight of risk category
DS01	2.731	0.138		2.731	0.141		2.269	0.151	
DS02	2.750	0.139		2.904	0.150		2.000	0.134	
DS03	2.885	0.146		2.750	0.142		2.212	0.148	
DS04	2.962	0.150	0.178	2.981	0.154	0.160	2.462	0.164	0.174
DS05	2.827	0.143		2.769	0.143		1.981	0.132	
DS06	2.865	0.145		2.750	0.142		2.250	0.150	
DS07	2.788	0.141		2.462	0.127		1.808	0.121	
CN01	2.731	0.124		2.827	0.117		2.192	0.129	
CN02	2.962	0.135		3.058	0.126		2.212	0.130	
CN03	2.865	0.130		3.096	0.128		2.000	0.118	
CN04	2.827	0.129	0.197	3.058	0.126	0.200	1.731	0.102	0.197
CN05	2.673	0.122		3.250	0.134		2.654	0.156	
CN06	2.404	0.109		3.058	0.126		2.038	0.120	
MN02	2.827	0.096		3.231	0.102		2.019	0.097	
MN03	2.750	0.093		2.788	0.088		1.846	0.088	
MN04	2.692	0.091		2.808	0.089		1.962	0.094	
MN05	2.712	0.092		2.692	0.085		1.750	0.084	
MN06	2.769	0.094	0.265	2.577	0.081	0.263	1.788	0.086	0.243
MN07	2.788	0.094		2.673	0.084		1.731	0.083	
RS01	2.654	0.192		2.481	0.187		1.692	0.183	
RS02	2.846	0.206	0.124	2.692	0.203	0.110	1.923	0.208	0.107
RS03	2.827	0.205		2.788	0.210		1.865	0.202	
RS04	2.615	0.189		2.577	0.194		1.827	0.198	
RS05	2.865	0.208		2.731	0.206		1.923	0.208	
CL01	2.423	0.195		2.635	0.205		2.096	0.190	
CL02	2.481	0.199		2.519	0.196		2.231	0.202	
CL03	2.385	0.192	0.112	2.500	0.195	0.106	2.096	0.190	0.129
CL04	2.750	0.221		2.788	0.217		2.750	0.249	
CL05	2.404	0.193		2.404	0.187		1.885	0.170	
EX01	1.981	0.142		2.846	0.147		1.885	0.148	
EX02	2.019	0.145		3.462	0.179		2.154	0.169	
EX03	2.423	0.174	0.125	3.019	0.156	0.160	2.327	0.182	0.149
EX04	2.615	0.187		3.231	0.167		2.231	0.175	
EX05	2.538	0.182		3.385	0.175		2.192	0.172	
EX06	2.385	0.171		3.404	0.176		1.981	0.155	

4.2.4. Establish membership function for project risks

The fuzzy evaluation matrix is composed of membership functions of evaluations for specific risk criteria. The expert judgment of the likelihood and impact of project risks is used to develop a membership function for each risk factor (Liu et al., 2013). Expert evaluation can be used to determine the membership function for each risk factor. For example, the results of the survey on the probability of design changes occurring showed that 4% of the respondents rated the probability of their occurrence as rare, 23% as unlikely, 46% as possible, 27% as likely, and 0% as almost certain, so the membership function of the probability of a design change is calculated as:

$$DS04 = \frac{0.04}{\text{Rare}} + \frac{0.23}{\text{unlikely}} + \frac{0.46}{\text{Possible}} + \frac{0.27}{\text{likely}} + \frac{0.00}{\text{Almost certain}}$$
$$= \frac{0.04}{1} + \frac{0.23}{2} + \frac{0.46}{3} + \frac{0.27}{4} + \frac{0.00}{5}$$

It can also be written as (0.04, 0.23, 0.46, 0.27, 0.00). Similarly, the membership functions of all the other project risks for the railway construction project are derived (Table 4.2).

4.2.5. Compute fuzzy evaluation matrix using the weight vector

The fuzzy composition of the weighting vectors and the fuzzy evaluation matrices are used to compute the evaluation results. Based on the weighting and membership function of each risk factor obtained from the aforementioned process, the risk index can be obtained through a fuzzy evaluation model. To determine the results of the FSE, a model that considers many criteria/factors with minimal difference in weight models was adopted for this study (Xu et al., 2010):

$$\text{Model: } M(\cdot,\oplus), b_j = min\left(1, \sum_{i=1}^{m} w_i \times r_{ij}\right) \forall b_j \in B \qquad (4.2)$$

where, $\boldsymbol{w_i}$ the weighting of a risk factor; r_{ij} the membership function of a factor and; $\oplus$the sum of the product of weighting and membership function.

Following the development of appropriate weightings for the risk factors and categories for the railway construction project, and the establishment of fuzzy membership functions for each risk factor, the FSE model for each category was developed.

The membership function of occurrence probability of design risk category of the railway construction project is calculated as:

$$= [0.138 \quad 0.139 \quad 0.146 \quad 0.15 \quad 0.143 \quad 0.145 \quad 0.141] * \begin{bmatrix} 0.06 & 0.40 & 0.31 & 0.21 & 0.02 \\ 0.04 & 0.37 & 0.40 & 0.19 & 0.00 \\ 0.06 & 0.25 & 0.44 & 0.25 & 0.00 \\ 0.04 & 0.23 & 0.46 & 0.27 & 0.00 \\ 0.00 & 0.35 & 0.48 & 0.17 & 0.00 \\ 0.02 & 0.33 & 0.42 & 0.23 & 0.00 \\ 0.02 & 0.40 & 0.35 & 0.23 & 0.00 \end{bmatrix}$$

= (0.03,0.33,0.41,0.22,0.00)

The likelihood of occurrence and impact of risk categories (i.e., construction risk, management risk, resource risk, contractual and legal risk, and external risk) are calculated, and the results of these risk category membership functions are shown in Table 4.3.

Table 4.2. Membership functions of risk factors likelihood of occurrence, impact on time and cost

Risk code	Likelihood of occurrence MF	Impact on duration MF	Impact on cost MF
DS01	(0.06,0.40,0.31,0.21,0.02)	(0.00,0.35,0.58,0.08,0.00)	(0.15,0.46,0.37,0.00,0.02)
DS02	(0.04,0.37,0.40,0.19,0.00)	(0.00,0.27,0.56,0.17,0.00)	(0.29,0.46,0.23,0.00,0.02)
DS03	(0.06,0.25,0.44,0.25,0.00)	(0.00,0.38,0.48,0.13,0.00)	(0.29,0.29,0.37,0.04,0.02)
DS04	(0.04,0.23,0.46,0.27,0.00)	(0.00,0.23,0.56,0.21,0.00)	(0.10,0.40,0.46,0.02,0.02)
DS05	(0.00,0.35,0.48,0.17,0.00)	(0.00,0.44,0.35,0.21,0.00)	(0.38,0.31,0.27,0.02,0.02)
CN02	(0.15,0.27,0.23,0.15,0.19)	(0.00,0.31,0.44,0.13,0.12)	(0.19,0.44,0.35,0.00,0.02)
CN03	(0.15,0.21,0.35,0.19,0.10)	(0.00,0.27,0.40,0.29,0.04)	(0.29,0.46,0.21,0.04,0.00)
CN04	(0.12,0.33,0.29,0.15,0.12)	(0.00,0.31,0.44,0.13,0.12)	(0.52,0.31,0.12,0.04,0.02)
CN05	(0.15,0.35,0.23,0.21,0.06)	(0.00,0.31,0.29,0.25,0.15)	(0.04,0.37,0.52,0.06,0.02)
MN01	(0.10,0.35,0.37,0.17,0.02)	(0.00,0.42,0.40,0.17,0.00)	(0.33,0.44,0.21,0.00,0.02)
MN02	(0.00,0.38,0.42,0.17,0.02)	(0.00,0.23,0.42,0.23,0.12)	(0.29,0.42,0.27,0.02,0.00)
MN03	(0.10,0.35,0.31,0.21,0.04)	(0.13,0.31,0.33,0.10,0.13)	(0.35,0.46,0.19,0.00,0.00)
MN04	(0.08,0.35,0.40,0.15,0.02)	(0.12,0.31,0.33,0.15,0.10)	(0.37,0.31,0.33,0.00,0.00)
MN05	(0.10,0.42,0.27,0.10,0.12)	(0.23,0.25,0.21,0.21,0.10)	(0.54,0.17,0.29,0.00,0.00)
MN08	(0.04,0.65,0.27,0.04,0.00)	(0.00,0.48,0.19,0.17,0.15)	(0.42,0.31,0.23,0.00,0.04)
MN09	(0.00,0.44,0.54,0.02,0.00)	(0.00,0.48,0.23,0.13,0.15)	(0.52,0.31,0.15,0.00,0.02)
MN10	(0.00,0.42,0.56,0.02,0.00)	(0.00,0.44,0.29,0.27,0.00)	(0.37,0.37,0.25,0.00,0.02)
MN11	(0.00,0.25,0.65,0.10,0.00)	(0.00,0.31,0.17,0.35,0.17)	(0.15,0.42,0.40,0.00,0.02)
RS01	(0.27,0.21,0.23,0.17,0.12)	(0.19,0.35,0.31,0.10,0.06)	(0.50,0.31,0.19,0.00,0.00)
RS02	(0.13,0.25,0.35,0.17,0.10)	(0.12,0.40,0.25,0.13,0.10)	(0.35,0.40,0.23,0.02,0.00)
RS03	(0.19,0.13,0.40,0.19,0.08)	(0.12,0.37,0.27,0.12,0.13)	(0.29,0.56,0.15,0.00,0.00)
RS04	(0.10,0.35,0.42,0.12,0.02)	(0.15,0.35,0.33,0.12,0.06)	(0.44,0.35,0.17,0.02,0.02)
RS05	(0.08,0.29,0.40,0.15,0.08)	(0.15,0.29,0.33,0.13,0.10)	(0.37,0.40,0.19,0.02,0.02)
CL01	(0.27,0.29,0.19,0.25,0.00)	(0.15,0.33,0.25,0.27,0.00)	(0.33,0.31,0.33,0.02,0.02)
CL02	(0.25,0.27,0.23,0.25,0.00)	(0.08,0.48,0.29,0.15,0.00)	(0.21,0.38,0.38,0.00,0.02)
CL05	(0.21,0.38,0.19,0.21,0.00)	(0.21,0.33,0.31,0.15,0.00)	(0.37,0.44,0.15,0.02,0.02)
EX01	(0.27,0.48,0.25,0.00,0.00)	(0.00,0.35,0.50,0.12,0.04)	(0.37,0.42,0.19,0.00,0.02)
EX02	(0.23,0.52,0.25,0.00,0.00)	(0.00,0.15,0.31,0.46,0.08)	(0.27,0.38,0.31,0.00,0.04)
EX03	(0.04,0.54,0.38,0.04,0.00)	(0.00,0.27,0.48,0.21,0.04)	(0.17,0.40,0.37,0.04,0.02)

Table 4.3. Membership functions of risk category

Risk Category	Membership Functions		
	Likelihood	Time	Cost
Design	(0.03,0.33,0.41,0.22,0.00)	(0.00,0.37,0.49,0.14,0.00)	(0.27,0.37,0.33,0.02,0.02)
Construction	(0.12,0.33,0.32,0.16,0.08)	(0.01,0.32,0.39,0.18,0.09)	(0.28,0.34,0.33,0.04,0.01)
Management	(0.05,0.38,0.44,0.11,0.02)	(0.07,0.35,0.28,0.20,0.10)	(0.38,0.34,0.26,0.00,0.01)
Resource	(0.15,0.25,0.36,0.16,0.08)	(0.15,0.35,0.30,0.12,0.09)	(0.39,0.41,0.19,0.01,0.01)
Contractual and legal	(0.19,0.34,0.26,0.21,0.00)	(0.10,0.37,0.37,0.16,0.00)	(0.23,0.37,0.34,0.05,0.01)
External	(0.10,0.46,0.43,0.01,0.00)	(0.00,0.21,0.41,0.30,0.08)	(0.25,0.40,0.32,0.01,0.02)

4.2.6. Triangular membership function, defuzzification, and evaluation

Different types of fuzzy number membership functions (triangular, trapezoidal, and Gaussian) are used in decision-making to interpret linguistic data in numerical form. Membership functions with triangular shapes are frequently used to provide more precise results (Zhang et al., 2016) and they are also very effective for solving MCDM problems when the available information is imprecise (Beltrão & Carvalho, 2019). Fuzzy models using triangular fuzzy numbers are also employed successfully in construction risk analysis (Nieto-Morote & Ruz-Vila, 2011).

Hence, triangular fuzzy numbers (TFNs) are used for representing the likelihood and the impact of project risks on cost and time. TFNs can be represented as (l/m, m/u). The parameters l, m, and u denote the smallest, most promising, and largest possible values that describe a fuzzy event, respectively (Dağdeviren & Yüksel, 2010).

The membership function of TFN is defined as:

$$\mu\left(x/\widetilde{M}\right) = \begin{cases} 0, x < l \\ \dfrac{x-l}{m-l}, l \leq x \leq m \\ \dfrac{u-x}{u-m}, m \leq x \leq u \\ 0, x > u \end{cases} \quad (4.3)$$

Let fuzzy set $\widetilde{\boldsymbol{A}}_1$ be (l_1, m_1, u_1) and $\widetilde{\boldsymbol{A}}_2$ be (l_2,m_2,u_2), hence the operations on fuzzy numbers (addition, subtraction, multiplication, and division) are defined as (Zhang et al., 2016):

$$\begin{cases} \tilde{A}_1 \oplus \tilde{A}_2 = (l_1 + l_2\,, m_1 + m_2, u_1 + u_2) \\ \tilde{A}_1 \ominus \tilde{A}_2 = (l_1 - l_2\,, l_1 - l_2, u_1 - u_2) \\ \tilde{A}_1 \otimes \tilde{A}_2 = (l_1 l_2\,, m_1 m_2, u_1 u_2) \\ \tilde{A}_1 \emptyset \tilde{A}_2 = (l_1/u_2,, m_1/m_2, u_1\,/l_2\,) \end{cases} \tag{4.4}$$

where $\oplus$,$\ominus$,$\otimes$ $\boldsymbol{and}$ $\emptyset$ are the symbols of fuzzy number addition, subtraction, multiplication, and division respectively.

Experts prefer to use linguistic expression rather than numerical judgment to define the likelihood of risk occurrence and its impact. The proposed approach defines five linguistic grades to capture these linguistic expressions (Table 4.4).

Table 4.4. Linguistic scales of occurrence likelihood and impact of risks

Linguistic scale		
Likelihood of occurrence	Impact	Triangular fuzzy scale
Rare	Very Low	(0,0,0.25)
Unlikely	Low	(0,0.25,0.5)
Possible	Moderate	(0.25,0.5,0.75)
Likely	High	(0.5,0.75,1)
Almost certain	Very High	(0.75,1,1)

The crisp value is useful for calculating the degree of risks and evaluating the rank of project risks. The crisp value $\boldsymbol{\mu_{\tilde{a}}}$ corresponding to the triangular fuzzy number $\boldsymbol{\mu_{\tilde{a}}}$ = (l, m, u) is calculated as (Rahmani et al., 2016):

$$\mu_{\tilde{a}} = 1/3(l + m + u) \tag{4.5}$$

Following the determination of the membership functions of the likelihood of occurrence, impact on time, and cost, they are converted into TFNs. The TFNs are then defuzzified using Eq. (4.5), and the resulting crisp values of the likelihood for risk factors are shown in Table 4.5.

Table 4.5. Likelihood of risk factors

Risk Code	Likelihood	Risk Code	Likelihood
DS01	0.4359	RS01	0.4263
DS02	0.4407	RS02	0.4647
DS03	0.4760	RS03	0.4663
DS04	0.4936	RS04	0.4103
DS05	0.4567	RS05	0.4663
DS06	0.4679	CL01	0.3782
CN02	0.4872	CL04	0.4375
CN03	0.4712	CL05	0.3686
CN04	0.4567	MN01	0.4247
CN05	0.4263	MN02	0.4551
CN06	0.3638	MN03	0.4423
CN07	0.4423	MN04	0.4279
CN08	0.4359	MN05	0.4263
EX01	0.2676	MN06	0.4423
EX02	0.2740	MN07	0.4503
EX05	0.3862	MN10	0.3990
EX06	0.3510	MN11	0.4615

4.3. Bayesian belief network for risk assessment

A Bayesian network (BN) is a directed acyclic graph (DAG) in which the nodes represent the variables and the arcs represent the dependencies or causal relationships among the variables (Oliva et al., 2009; Pearl, 1988).

BNs can be described in terms of a qualitative component, consisting of the causal structure of the system variables, and a quantitative component, consisting of the CPTs assigned to variable nodes (Aliabadi et al., 2020; Kjærulff & Madsen, 2013). There are three important elements in the development of a BBN (Liu, Kuo, et al., 2013): nodes (factors), networks (causal relationships), and conditional probabilities (uncertainty causal relationships). The nodes that are the starting ones and do not have an inward arrow are termed the parent nodes, whereas the nodes which have inward arrows connected to them are the child nodes (Islam et al.,2017; Khodakarami & Abdi, 2014).

BBN provides a model representation of the joint distribution of a set of variables in terms of conditional and prior probabilities. The following conditions must be met to model a probability distribution for a BN: Each variable is conditionally independent of all non-parent nodes in the graph, and the probability of each of its states is determined only by the values of all its parents' states. This implies that the probability of the network given its dependency structure is:

$$P(X_1 \dots X_n) = \prod_{i=1}^{n} P\big(X_i \mid \text{ parents } (X_i)\big)$$

BBNs are based on conditional probability theory which was developed in the late 1700s by Thomas Bayes. He discovered a basic law of probability which was then called Bayes' theorem. The Bayes' rule for performing this calculation:

$$P(B \mid A) = \frac{P(A, \mathrm{B})}{P(A)}$$

It reads, "the conditional probability of event B occurring, given an observable event A is invoked is equal to the joint probability of events A and B divided by the marginal probability of event A." (Grover, 2016).

where, P (A, B) is the probability of the joint event A∧B.

A BN is a compact probabilistic model for handling uncertainty in expert systems. The procedures employed for determining the probability of occurrences of project risks are described below.

4.3.1. Construction of BBN for risk assessment

The BN for the railway construction project is constructed based on the inputs of expert judgments on probabilities as well as causality relationships among the identified project risk factors. This network includes risk variables (parent and child nodes), arrows for causality relationships, states (Yes, No), and probability estimates for the construction of the BBN risk assessment model.

a. Identify relevant variables

Identifying variables that reflect the major features of the project risk analysis model is critical in BBN model building. The key variables related to the risk assessment of railway construction projects are represented by Bayesian variables. Each variable describes a set of states that represent all the possible different situations of the variable. Table 4.6 describes various risk factors of the railway construction project and their associated Bayesian states. These variables are considered relevant within the context of risk assessment in the Addis-Djibouti railway construction project.

b. Define the relationship among variables and states of the variables

The project risks of railway construction projects are interrelated and have a causality relationship among them. The next step in developing a project risk assessment model is to map the identified variables to a graphical structure that captures their influences on other variables. The causal relationships of the risk factors are determined by the experts in the industry. These relationships are depicted using an adjacency matrix which is developed based on the opinions of railway construction project professionals. The causal linkages between variables answer the following questions: i. What other factors (if any) have a direct impact on this variable? and ii. What additional variables (if any) are impacted directly by this variable? The adjacency matrix that showed the causal linkages between variables is depicted in Table 4.7. The overall graphical representation of the proposed BBN structure for project risk assessment for the railway construction project is shown in Figure 4.1. The BBN models were developed with Netica 6.09 software.

Table 4.6. Relevant variables for Bayesian belief network

Risk code	Variables	Risk code	Variables
EX01	Change in government regulations	CL04	Incomplete contract details
MN07	Client interference	DS02	Incomplete design
MN08	Client's financial difficulty	EX04	Inflation
MN06	Client's lack of experience	EX05	Labor and material costs
CN06	Contractors' lack of experience	RS04	Labor productivity
DS03	Cost underestimation	MN02	Lack of coordination
MN09	Delay in decision-making by client	MN05	Management of materials
DS04	Design change	MN10	Payment delays
MN01	Design delay	EX02	Political instability
DS06	Design error	CN02	Poor site management
RS02	Equipment damage	RS01	Productivity of plant and equipment
RS03	Equipment maintenance	PC	Project cost
CN05	Errors during construction	PD	Project duration
EX06	Force majeure	MN03	Project planning & control
CN04	Improper quality control and testing methods	CN03	Quality of construction
CN01	Improper construction method	CN08	Quality of construction materials
DS05	Inadequate site investigation	MN11	Right-of-way
RS05	Inadequate skill of the workforce	MN04	Schedule pressure
EX03	Unsafe project location	DS01	Scope change

The proposed BBN risk assessment model has 38 nodes, 76 states, 352 CPs, and 49 links. In this model, nodes are elicited from literature and reports on the risks of railway construction projects. The links that reveal the causal relationships between the nodes are determined by domain experts. The prior and CPs were estimated based on expert knowledge.

A node is defined as a random variable that takes a set of mutually exclusive values or states according to a probability distribution (Gambelli et al., 2017). The states that describe the occurrence of risks in the railway construction project are Yes (Y) and No (N). Yes (Y) describes the state at which the occurrence probability of the identified risk variable while No (N) describes the probability of the non-occurrence of the identified risk.

c. Prior and conditional probabilities

Following the construction of the BN for project risk assessment, domain experts were requested to make judgments on the probabilities associated with all nodes of the BN and provide prior and conditional probability values. Each node is assigned a CPT that contains CPs and quantifies the uncertain impact that the parent has on the node. A node without a parent has a prior probability value across all possible states.

BNs need to assign initial probabilities to the risk assessment model, and these probabilities are usually obtained from historical data, expert judgment, or a combination of both. However, converting knowledge levels into probability assignments is a core problem in Bayesian model development.

In addition, creating CPT is the most difficult part of the modeling process. The CPT structure grows if the nodes in the BBN have multiple parent nodes, or if each parent and child nodes have multiple states. The number of probability distributions needed to populate a CPT on a specific BN increases exponentially with the number of parent nodes associated with the child nodes.

The elicited conditional probability values defined by experts can be inconsistent, especially under complex and large CPT conditions. Conventional BBNs can only handle crisp values of prior and CPs which are often difficult to obtain. Since the fuzzy linguistic approach can take decision-makers' pessimistic/optimistic evaluation into account, linguistic values, whose membership functions are typically characterized by TFNs, are recommended to assess prior and CPs rather than conventional crisp values (Kabir et al., 2016). Therefore, in this study, the fuzzy logic system is designed to determine both prior and CPs of risk factors. The FSE technique was used to derive the prior probabilities of the BBN model, while FAHP was employed to calculate the CPs for all of the arcs in the BBN. Hence, based on the available data and experience in railway construction projects, the experts determined fuzzy prior probabilities and fuzzy CPs for the parent and child nodes, respectively. The conditional probability values for the project risk assessment model were obtained by adding weights to the values of the variables based on the number of parents and the strength of the relationship between parents and children.

Table 4.7. Adjacency matrix of project risk factors

	CL0	CN	CN	CN	CN	CN	CN	CN	DS0	DS0	DS0	DS0	DS0	DS0	DS0	EX0	EX0	EX0	EX0	EX0	EX0	MN	MN	MN	MN	MN	MN	MN	MN	MN	MN	PC	PD	RS0	RS0	RS0	RS0	RS0
CL04																																X	X					
CN01				X																																		
CN02		X			X			X																														
CN03																																	X					
CN04						X																																
CN05				X																																		
CN06															X									X														
CN08				X																																		
DS01												X																										
DS02																																	X					
DS03																																X						
DS04																						X																
DS05											X			X																	X							
DS06																						X																
DS07										X				X																								
EX01									X																													
EX02																		X																				
EX03													X																									
EX04																				X																		
EX05																																X						
EX06																																	X					
MN01																																	X					
MN02																																					X	

MN03			X										X										X			X											
MN04				X																																	
MN05																																				X	
MN06	X								X																				X								
MN08																														X							
MN09																														X							
MN10																																	X				
MN11																									X												
PC																																					
PD																																X					
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RS02																																		X			
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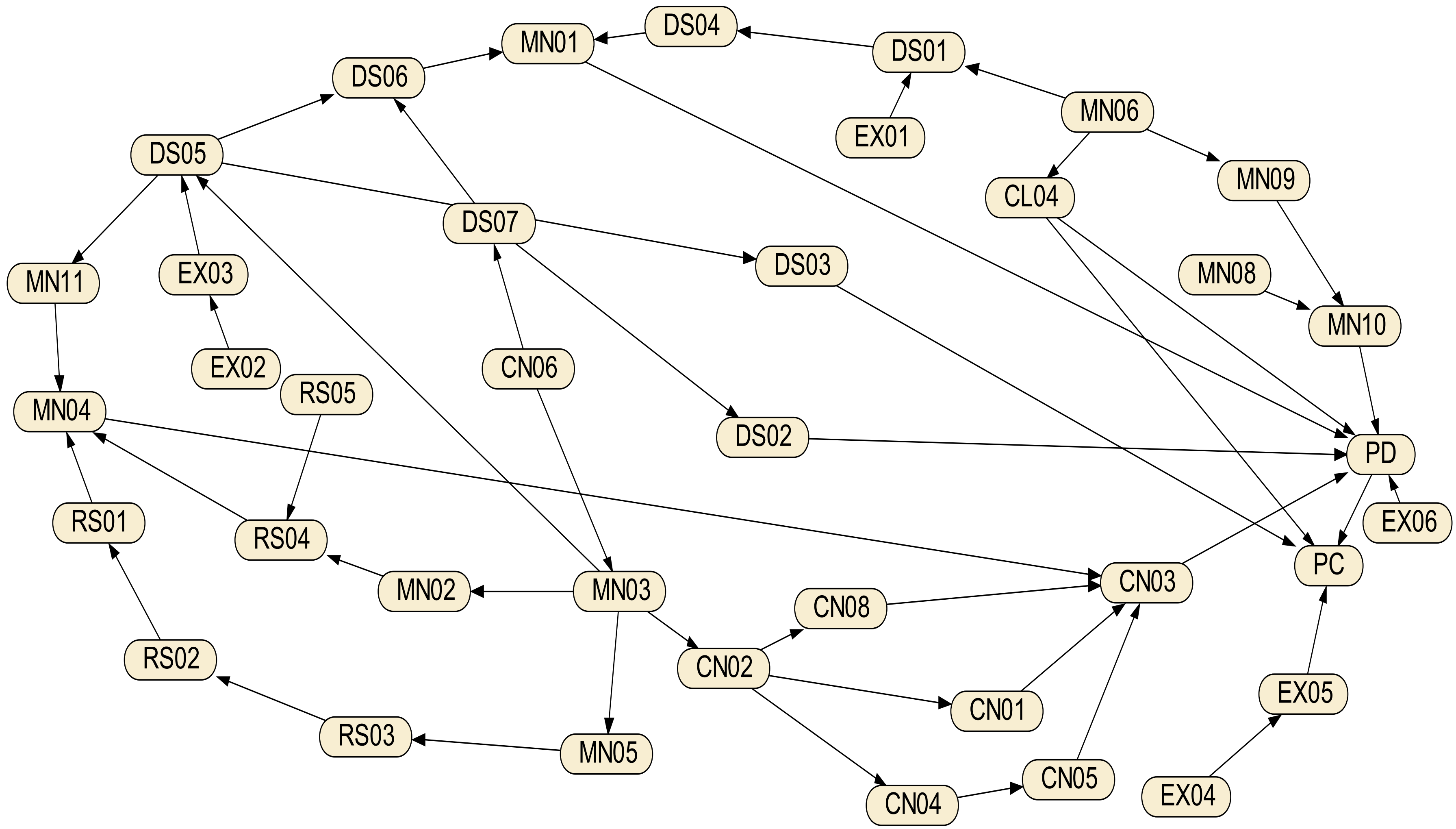

Figure 4.1. BBN model for project risk assessment

d. Posterior probabilities -BN inference and results analysis

The posterior probabilities of the variables are determined using the proposed structure of the BBN model, prior probabilities, and CPs. However, because the model has so many nodes, calculating the probabilities by hand is laborious. The posterior probability values of the remaining risk factors are calculated and are shown in Table 4.8.

Table 4.8. Posterior probabilities of the parent and child nodes

Variables	Marginal probability	Variables	Marginal probability
Incomplete contract details	0.454	Design delay	0.434
Improper construction method	0.389	Lack of coordination	0.409
Poor site management	0.398	Project planning and control	0.387
Quality of construction	0.405	Schedule pressure	0.405
Improper quality control and testing methods	0.388	Management of materials resources and personnel	0.332
Errors during construction	0.430	Client's lack of experience	0.442
Contractors' lack of experience	0.364	Client's financial difficulty	0.330
Quality of construction materials	0.369	Delay in decision-making by client	0.626
Scope change	0.390	Payment delays	0.432
Incomplete design	0.424	Right-of-way	0.444
Cost underestimation	0.339	Productivity of plant and equipment	0.337
Design change	0.401	Equipment damage	0.319
Inadequate site investigation	0.368	Equipment maintenance	0.299
Design error	0.393	Labor productivity	0.462
Misunderstanding client’s requirements	0.391	Inadequate skill of workforce	0.466
Change in government regulations	0.268	Inflation	0.405
Political instability	0.274	Labor and material costs	0.415
Unsafe project location	0.292	Force majeure	0.351

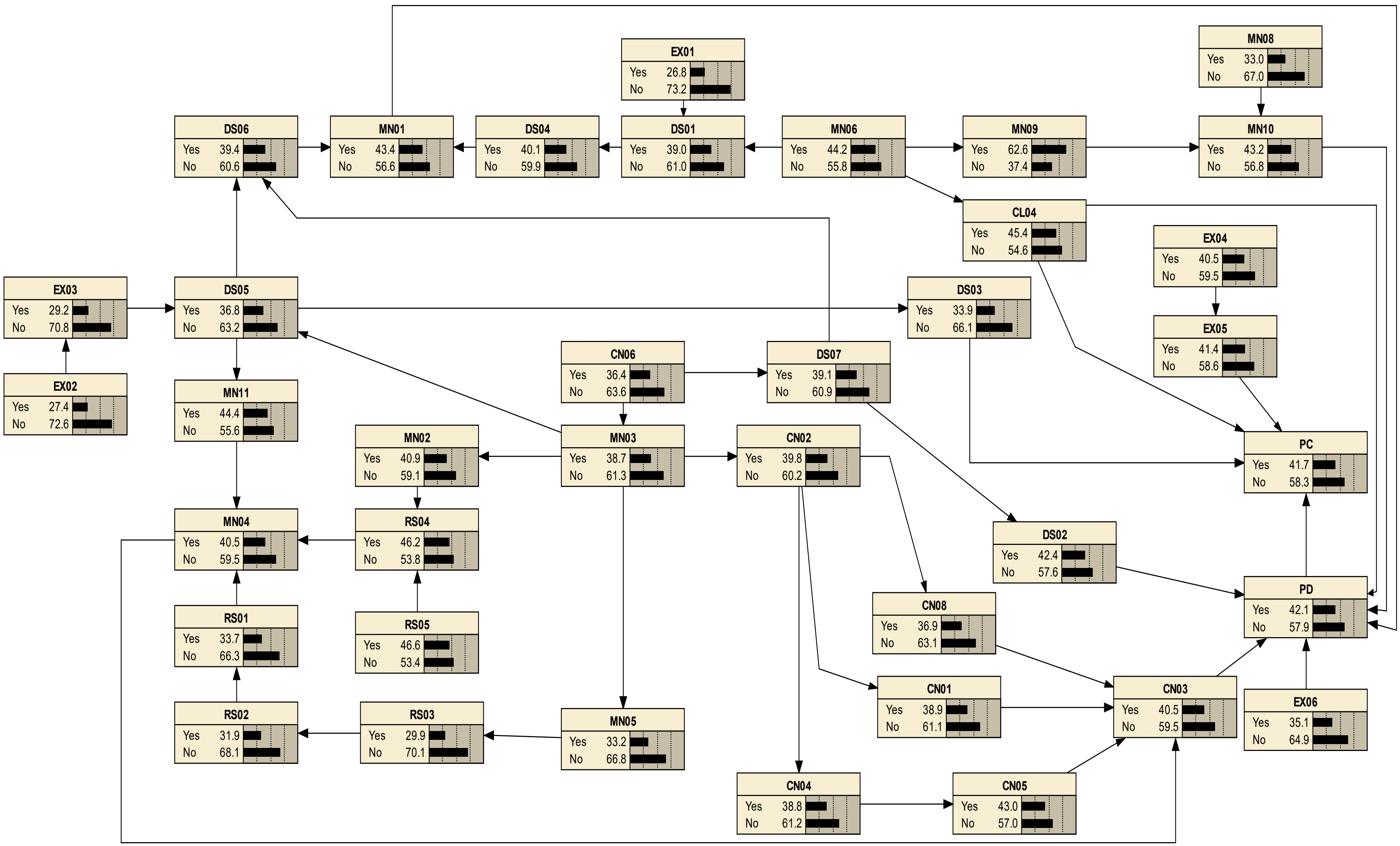

Figure 4.2. Result of Bayesian network for project risk assessment

4.4. Fuzzy analytic network process model for risk assessment

Since railway construction projects are risk-prone and reliant on expert judgment and experience, fuzzy logic has been integrated with ANP to addresses the uncertainty, data unavailability, interrelationships between risks, and subjective judgments of experts on rating the impact of risks on project objectives. The fuzzy ANP was employed for analyzing the impact of project risks on delays and cost overruns of the Addis-Djibouti railway construction project. In this model, the risks are assessed based on their interdependencies and the extent of the impact on project time and cost. The process of ANP comprises four major steps: (1) Network model construction; (2) Pairwise comparisons; (3) Supermatrix formation (4) Final priorities

4.4.1. Analytic network model construction

Following the identification and categorization of major risks, a network structure was established to create a mutual influence between risk factors. The problem is decomposed into a network where nodes correspond to clusters. The elements in a cluster may influence some or all the elements of any other cluster. These relationships are represented by arcs with directions.

The ANP model of railway construction project risk factors is constructed and depicted in Figure 4.3. As shown in the Figure, the overall network model has been decomposed into subnetwork models. This includes the ANP network models for:

a. Design-related risk factors cluster,
b. Construction-related risk factors cluster,
c. Management-related risk factors cluster,
d. Resource-related risk factors cluster,
e. Contractual & legal related risk factors cluster,
f. External risk factors cluster.

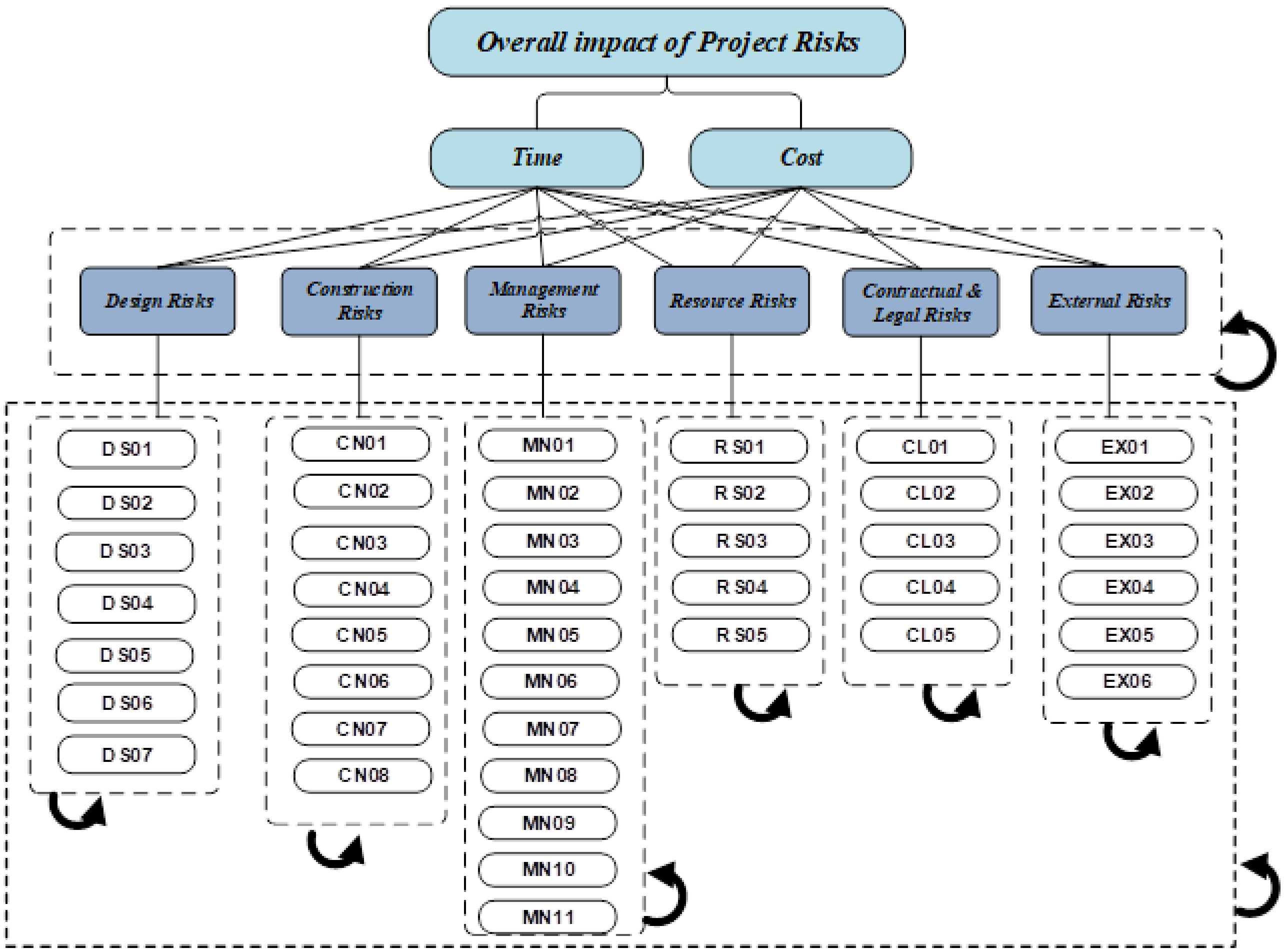

Figure 4.3. Overall ANP model of project risks and their impacts on time and Cost

4.4.2. Pairwise comparisons and priority vectors

The pairwise comparison technique is a well-established technique and is widely used in AHP/ANP (Saaty, 1996) to compare two attributes or alternatives with respect to a given criterion. The pairwise comparison matrix consists of elements that are expressed on a numerical scale, and the values of the elements are assigned by decision-makers based on their experiences to convert the qualitative attribute or criteria into measurable numbers. The relative importance values are determined with a scale of 1–9, where a value of 1 indicates that the two items are of equal importance, and a value of 9 indicates that one item is extremely important compared to the other. The inverse comparison is given a reciprocal value, aji = 1/aij, where aij denotes the importance of the ith element in comparison to the jth element (Asan et al., 2012).

i. Building pairwise comparison matrices with fuzzy scales

Data collected from the experts were transformed into TFNs and then aggregated using the geometric mean technique and assigned to the pairwise comparison matrices as shown below.

$$\tilde{A} = \begin{bmatrix} 1 & \tilde{a}_{12} & \dots & \tilde{a}_{1n} \\ \tilde{a}_{21} & 1 & \dots & \tilde{a}_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ \tilde{a}_{n1} & \tilde{a}_{n2} & \dots & 1 \end{bmatrix} = \begin{bmatrix} 1 & \tilde{a}_{12} & \dots & \tilde{a}_{1n} \\ 1/\tilde{a}_{12} & 1 & \dots & \tilde{a}_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ 1/\tilde{a}_{1n} & 1/\tilde{a}_{2n} & \dots & 1 \end{bmatrix}$$

To aggregate the group decision, this study adopted the geometric mean that has been commonly used in fuzzy MCDM. The following formula can be used to transfer expert opinions into triangular fuzzy numbers (Buckley, 1985).

$$\tilde{a}_{ij} = \left(\tilde{a}_{ij}^{1} \otimes \vec{a}_{ij}^{2} \otimes \cdots \otimes \tilde{a}_{ij}^{N}\right)^{\frac{1}{n}}$$

where,

$\tilde{a}_{ij}$ = the integrated triangle fuzzy umber by N experts;

$\tilde{a}_{ij}^{k}$ j = the ith to the jth factor pair comparison by expert k.

$\otimes$ = the symbol of matrix multiplication

In this study, the scale of linguistic variables depicted in Table 4.9 is used for fuzzy pairwise comparison.

Table 4.9. Linguistic variables for fuzzy pairwise scale

Linguistic scale	Triangular fuzzy scale	Triangular fuzzy reciprocal scale
Equally important	$\tilde{1} = (1,1,1)$	$\tilde{1}^{-1} = (1,1,1)$
Judgment values between equally and moderately	$\tilde{2} = (1,2,3)$	$\tilde{2}^{-1} = \left(\frac{1}{3}, \frac{1}{2}, 1\right)$
Moderately more important	$\tilde{3} = (2,3,4)$	$\tilde{3}^{-1} = \left(\frac{1}{4}, \frac{1}{3}, \frac{1}{2}\right)$
Judgment values between moderately and strongly	$\tilde{4} = (3,4,5)$	$\tilde{4}^{-1} = \left(\frac{1}{5}, \frac{1}{4}, \frac{1}{3}\right)$
Strongly more important	$\tilde{5} = (4,5,6)$	$\tilde{5}^{-1} = \left(\frac{1}{6}, \frac{1}{5}, \frac{1}{4}\right)$
Judgment values between strongly and very strongly	$\tilde{6} = (5,6,7)$	$\tilde{6}^{-1} = \left(\frac{1}{7}, \frac{1}{6}, \frac{1}{5}\right)$
Very strongly more important	$\tilde{7} = (6,7,8)$	$\tilde{7}^{-1} = \left(\frac{1}{8}, \frac{1}{7}, \frac{1}{6}\right)$
Judgment values between very strongly and extremely	$\tilde{8} = (7,8,9)$	$\tilde{8}^{-1} = \left(\frac{1}{9}, \frac{1}{8}, \frac{1}{7}\right)$
Extremely more important	$\tilde{9} = (8,9,9)$	$\tilde{9}^{-1} = \left(\frac{1}{9}, \frac{1}{9}, \frac{1}{8}\right)$

ii. Consistency ratio in fuzzy ANP

Since an inconsistent matrix can lead to wrong conclusions, it is of absolute importance that consistency is checked before solving a problem. If the consistency requirement is not met, the decision-maker is asked to modify her/his preferences. Saaty (1977) has developed a method for determining the degree of decision-maker consistency using the eigenvalues and eigenvectors of a pairwise comparison matrix. Saaty's approach for judgmental consistency of decision-makers has been extended and an improved approach was developed by Gogus & Boucher (1998) to incorporate more than one value for each comparison, checking for the consistency of the mean values and the consistency of the lower and upper bounds. They proposed that two matrices (middle number and fuzzy number limit) should be derived from each fuzzy matrix, and then the Consistency ratio of the matrix can be calculated using Saaty's method. The consistency rate for fuzzy pairwise comparison matrices would be determined as the following.

Step 1: Transform a triangular fuzzy matrix ($A_i = (l_i, m_i, u_i)$) into two independent matrices. The first matrix contained the middle numbers of a triangular fuzzy matrix (A_m)

$$A_m = [a_{ijm}]$$

while the second matrix consists of upper and lower geometrical limits of TFNs

$$A_g = [(a_{ijl}a_{iju})^{\frac{1}{2}}]$$

Step 2: Compute the maximum eigenvalue

Once the pairwise comparisons are completed, a local priority vector (eigenvector) is derived for all comparison matrices, as an estimate of relative dominance associated with the elements (or clusters) being compared. The eigenvector and the maximum eigenvalue of the comparison matrix are determined by solving the general problem of eigenvalues:

$$AW = \lambda_{max} W$$

$$\sum_{j=1}^{n} a_{ij} w_i = \lambda_{max} w_i$$

Where:

A- the pairwise comparison matrix,

w- the principal eigenvector (priority vector) and,

λ_{max} - the maximum eigenvalue of A.

Step 3: Calculate the consistency index (CI): for each matrix, the CI can be calculated using the following equation:

$$CI_m = \frac{\lambda_{max}^{m} - n}{n - 1}$$

$$CI_g = \frac{\lambda_{max}^{g} - n}{n - 1}$$

Step 4: Calculate the consistency ratio (CR) of the matrices. It is the ratio of the consistency index to the average random index for the same order matrix. CR values are calculated for the two matrices and are compared to the 0.1 thresholds.

$$CR_m = \frac{CI_m}{RI_m}$$

$$CR_g = \frac{CI_g}{RI_g}$$

The fuzzy matrix is consistent if the values of CR_m and CR_g are less than 0.1. If both values are greater than 0.1, the decision-makers would be asked to modify his/her preferences (Gogus & Boucher, 1998).

The values of the random indices (RI) obtained by the Gogus and Boucher method differ from those obtained by the Saaty method. Gogus and Boucher redeveloped the RI table for fuzzy pairwise comparison matrices. Table 4.10 presents the values of the RI for each matrix of the Gogus and Boucher method (Gogus & Boucher, 1998).

Table 4.10. Random Indices for fuzzy pairwise matrices

n	1	2	3	4	5	6	7	8	9	10	11	12
RI_m	0	0	0.4890	0.7937	1.0720	1.1996	1.2874	1.3410	1.3793	1.4095	1.4181	1.4462
RI_g	0	0	0.1796	0.2627	0.3597	0.3818	0.4090	0.4164	0.4348	0.4455	0.4536	0.4776

Pairwise comparisons were made based on the ANP model shown in Figure 4.3. Pairwise comparisons were conducted with respect to risk factors among the other factors within the risk category (cluster). The data from experts were transformed into a triangular fuzzy scale and their preferences were aggregated into triangular fuzzy matrices. The interdependence matrix of each risk factor had to be determined relative to other risk factors based on the used fuzzy scales based on Chang's fuzzy AHP method. These matrices were then converted into two independent matrices to determine the consistency of expert judgments. The triangular fuzzy matrix is consistent if the values of CR_m and CR_g are less than 0.1. The local weights of project risk factors were calculated based on the fuzzy extent analysis method.

iii. Computing the local weights of the factors and subfactors

The FANP has been widely employed for calculating priority weights from fuzzy comparison matrices. There are many fuzzy AHP/ANP methods proposed by various authors (Buckley, 1985; Chang, 1996; Leung & Cao, 2000; Mikhailov & Singh, 2003). These methods are systematic approaches to computing local weights by using the concepts of FST. Fuzzy extent analysis proposed by (Chang, 1996) has been widely used to calculate weights from fuzzy comparison matrices. Every criterion or alternative is evaluated by linguistic variables and then the extent analysis is performed. The algorithm of the extent analysis approach is summarized as follows:

Let X = $\{x_1,x_2, \cdots,x_n\}$ be an object set and U= $\{u_1,u_2, \cdots,u_m\}$ be a goal set, then for each object. According to the method of Chang's (1996) extent analysis, each object is taken and extent analysis for each goal is performed. Hence, *m* extent analysis values for each object, given as $M_{g_i}^1, M_{g_i}^2, \ldots, M_{g_i}^m, i = 1,2, \ldots m$, are obtained, where all the $M_{g_i}^j$ (*j*= 1, 2,…, *m*) are TFNs. The steps of Chang's extent analysis method are given below.

Step 1: The value of fuzzy synthetic extent, with respect to the *i*th object, is defined as:

$$S_i = \sum_{j=1}^{m} M_{gi}^j \otimes \left[\sum_{i=1}^{n} \sum_{j=1}^{m} M_{gi}^j\right]^{-1}$$

To obtain $\sum_{j=1}^{m} M_{\hat{g}_i}^j$ the fuzzy addition operation of *m extent* analysis values of a particular matrix is performed:

$$\sum_{j=1}^{m} M_{g_i}^j = \left(\sum_{j=1}^{m} l_j, \sum_{j=1}^{m} m_j, \sum_{j=1}^{m} u_j\right)$$

To obtain $\left[\sum_{i=1}^{n} \sum_{j=1}^{m} M_{gi}^j\right]^{-1}$ the fuzzy additional operation of $M_{g_i}^j$ (*j*= 1, 2,...,*m*) values are performed as:

$$\sum_{i=1}^{n} \sum_{j=1}^{m} M_{g_i}^j = \left(\sum_{i=1}^{n} l_i, \sum_{i=1}^{n} m_i, \sum_{i=1}^{n} u_i\right)$$

and then compute the inverse of the vector in equation xxx such that:

$$\left[\sum_{i=1}^{n}\sum_{j=1}^{m} M_{g_i}^{j}\right]^{-1} = \left(\frac{1}{\sum_{i=1}^{n} u_i}, \frac{1}{\sum_{i=1}^{n} m_i}, \frac{1}{\sum_{i=1}^{n} l_i}\right)$$

Step 2: The degree of possibility of $M_2 = (l_2, m_2, u_2) \geq M_1 = (l_1, m_1, u_1)$ is defined as:

$$V(M_2 \geq M_1) = \sup_{y \geq x}\left[min\left(\mu_{M_1}(x), \mu_{M_2}(y)\right)\right]$$

When a pair (x, y) exists such that x ≥y and $\mu_{M_1}(x) = \mu_{M_2}(y) = 1$, then we have $V(M_2 \geq M_1)$=1. Since M_1 and M_2 are convex fuzzy numbers:

$$V(M_2 \geq M_1) = hgt(M_1 \cap M_2) = \mu_{M_2}(d)$$

$$V(M_2 \geq M_1) = \begin{cases} 1 & \text{if } m_2 \geq m_1 \\ 0 & \text{if } l_1 \geq u_2 \\ \dfrac{l_1 - u_2}{(m_2 - u_2) - (m_1 - l_1)} & \text{otherwise} \end{cases}$$

where *d* is the ordinate of the highest intersection point *D* between μ_{m1} and μ_{m2}. To compare M_1 and M_2, we need both the values of $V(M_1 \geq M_2)$ and $V(M_2 \geq M_1)$.

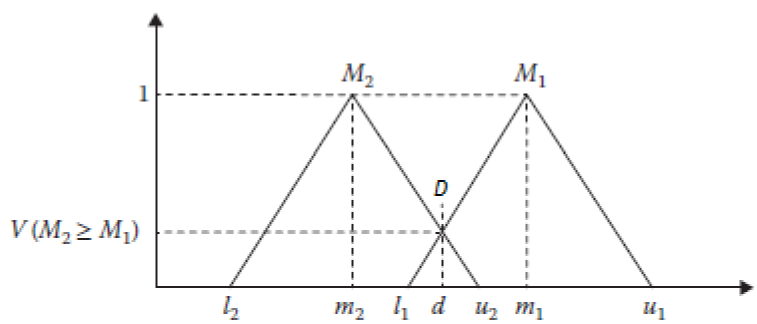

Figure 4.4. Intersection point "d" between two fuzzy numbers M_2 and M_2

Step 3: The degree of the possibility of a convex fuzzy number to be greater than *k* convex fuzzy numbers, M_i (i = 1, 2, …, k) can be defined by:

$$V(M \geq M_1, M_2, \cdots, M_k) = V[(M \geq M_1) \text{ and } (M \geq M_2) \text{ and } \ldots\ldots \text{ and } (M \geq M_k)]$$

$$= minV(M \geq M_i), i = 1,2, \cdots, k$$

Assume that $d'(A_i) = \min V(S_i \geq S_k)$, for $k = 1, 2, \ldots, n$; $k \neq i$.

Then, the weight vector is given by:

$W' = (d'(A_1), d'(A_2), \ldots, d'(A_n))^T$, where A_i *(i=1,2,…n)* are *n* elements.

Step 4: The normalized weight vectors are defined as:

$$d(A_i) = \frac{d'(A_i)}{\sum_{i=1}^{n} d'(A_i)};$$

$$W = (d(A_1), d(A_2), \ldots, d(A_n))^T,$$

where W is a non-fuzzy number.

Table 4.11 and Table 4.12 show the pairwise comparison matrix with respect to project objectives (time and cost) among the main categories of railway construction project risks and the resulting normalized eigenvectors. Moreover, Table 4.13 and Table 4.14 show the pairwise comparison matrix of design and construction risk factors with respect to time respectively.

4.4.3. Supermatrix formation

ANP uses the formation of a supermatrix to allow for the resolution of the effects of the interdependence that exists between the elements of the system. The supermatrix (Figure 4.5) is a partitioned matrix, where each submatrix is composed of a set of relationships between and within levels as represented by the graphical model (Meade & Sarkis, 1999). The priority vectors derived from pairwise comparison matrices are each entered as a part of some column of a supermatrix. The supermatrix represents the influence priority of an element on the left of the matrix on an element at the top of the matrix (Saaty, 2004). The supermatrix consisting of N clusters is presented as follows (Hosseini et al., 2013):

$$W = \begin{array}{cc} & \begin{array}{ccccc} C_1 & & C_k & & C_n \\ e_{11}\, e_{12} \cdots e_{1m1} & \cdots & e_{k1}\, e_{k2} \cdots e_{k\,mk} & \cdots & e_{n1}\, e_{n2} \cdots e_{n\,mn} \end{array} \\ \begin{array}{cc} C_1 & \begin{array}{c} e_{11} \\ e_{12} \\ \vdots \\ e_{1m1} \end{array} \\ \vdots & \vdots \\ C_k & \begin{array}{c} e_{k1} \\ e_{k2} \\ \vdots \\ e_{kmk} \end{array} \\ \vdots & \vdots \\ C_n & \begin{array}{c} e_{n1} \\ e_{n2} \\ \vdots \\ e_{nmn} \end{array} \end{array} & \begin{bmatrix} W_{11} & \cdots & W_{1k} & \cdots & W_{1n} \\ \vdots & & \vdots & \vdots & \vdots \\ W_{k1} & \cdots & W_{kk} & \cdots & W_{kn} \\ \vdots & & & & \vdots \\ & & & \vdots & \\ W_{n1} & \cdots & W_{nk} & \cdots & W_{nn} \end{bmatrix} \end{array}$$

Figure 4.5. The supermatrix of a network

where C_k is the kth cluster (k = 1, 2,..., n) and each cluster K consists of mK items displayed by e_{k1}, e_{k2},..., e_{kmk}. Each column of W_{ij} is the priority vector acquired from the identical pairwise comparison, indicating the significance of the elements in the ith cluster with respect to an element in the jth cluster. When there is no relationship between the components, the corresponding matrix segment is a null matrix. The supermatrix is then converted to a weighted supermatrix where the sum of the columns is 1. This `column stochastic' feature of the weighted supermatrix allows convergence to occur in the limit supermatrix. Finally, the weighted supermatrix is transformed into the limit supermatrix by raising it to powers. Raising the weighted supermatrix allows the convergence of the matrix, and the resulting matrix is called the limit supermatrix, which yields limit priorities capturing all of the direct and indirect influences of each element on every other element. All supermatrices are depicted in Appendix C.

4.4.4. Project risk impact weight

Based on the results of the limit matrix, the impact of project risks on project time and cost is calculated using fuzzy ANP. The overall impact of risks on the project objectives is depicted in Table 4.15. The table shows that contractors' lack of experience has corresponded to the highest risk rating, contributing to the overall project risk. Right-of-way and quality of construction have been found to have the second and third position based on the overall project risk impact on delays and cost overruns. Similarly, incomplete contract details, construction errors, and payment delays by the client have acquired the fourth, fifth, and sixth position as per the overall project risk ratings on the case railway construction project.

According to the study findings, contractor's lack of experience, right-of-way, incomplete contract details, poor quality of construction, payment delays, design changes, lack of coordination, and client's financial difficulties were identified as the significant risks that have a higher impact on delays and cost overruns of Addis-Djibouti railway construction project.

Prior studies on risk assessment and reports from the ERC confirm the findings of this study. According to the ERC report, one of the potential risks that affect project duration is the risk related to the right-of-way. Design changes were also identified as the main risk for the Addis-Djibouti railway project. In this project, the external power supply was changed from an independent double-line power supply to a loop circuit based on a proposal from the Ethiopian Electric Power

Agency (EEP). This change prompted the contractor to claim for the additional construction time, resulting in a delay in the construction period. Moreover, due to incomplete contract details and changes in some technical standards in the technical proposal, adjustments were made to the contract price and these changes increased the project cost.

In addition, construction errors were identified as the main reason that extremely affects the overall delay of construction projects in India (Doloi et al., 2012) and in Denmark (Larsen et al., 2016). Andrić et al. (2019) showed that the most critical risks in railway projects in China are changes in design and design errors. Inadequate and inappropriate designs can result in inaccurate construction. As a result, construction projects based on defective designs may result in delays and cost overruns (Beltrão & Carvalho, 2019). Design change has also been identified as one of the top four delay factors in Turkish construction projects (Murat et al., 2013). These design changes may result from variations, scope changes demanded by clients, and design shortcomings (Taylan et al., 2014). Poor site management and supervision, lack of coordination, and substandard contracts were also identified as the second, third, and seventh main risk factors that impact the delay of construction projects in India (Doloi et al., 2012). Shrivastava et al. (2019) also showed that lack of coordination among parties, improper construction methods, and poor site management were among the factors that had the greatest impact on delays and cost overruns of the Indian railway construction project.

Table 4.11. Pairwise comparison matrix of risk factors with respect to time

	DS	CN	MN	RS	CL	EX	Normalized eigenvector (NEV)
DS	(1,1,1)	(0.81,1.15,1.52)	(0.81,1.15,1.53)	(0.78,1.04,1.36)	(0.8,1.11,1.48)	(0.77,0.93,1.13)	*0.177*
CN	(0.66,0.87,1.23)	(1,1,1)	(0.81,1,1.23)	(0.72,0.92,1.2)	(0.71,0.97,1.37)	(0.6,0.8,1.17)	*0.152*
MN	(0.65,0.87,1.24)	(0.81,1,1.23)	(1,1,1)	(0.75,0.92,1.16)	(0.69,0.97,1.4)	(0.61,0.8,1.16)	*0.152*
RS	(0.74,0.96,1.28)	(0.84,1.09,1.38)	(0.86,1.09,1.34)	(1,1,1)	(0.76,1.07,1.5)	(0.68,0.87,1.19)	*0.168*
CL	(0.67,0.9,1.24)	(0.73,1.03,1.41)	(0.72,1.03,1.44)	(0.68,0.94,1.32)	(1,1,1)	(0.64,0.83,1.13)	*0.158*
EX	(0.89,1.07,1.3)	(0.86,1.25,1.67)	(0.86,1.24,1.65)	(0.84,1.15,1.47)	(0.89,1.2,1.55)	(1,1,1)	*0.193*
CR_m=0.0003 CR_g=0.0009 λ_{max}^m=6.0016 $\lambda_{max}^g = 6.0017$							

Table 4.12. Pairwise comparison matrix of risk factors with respect to cost

	DS	CN	MN	RS	CL	EX	NEV
DS	(1,1,1)	(0.86,0.95,1.06)	(0.97,1.18,1.35)	(0.94,1.16,1.35)	(0.72,0.81,1)	(0.67,0.78,0.98)	*0.157*
CN	(0.94,1.06,1.16)	(1,1,1)	(1,1.25,1.43)	(0.99,1.22,1.4)	(0.74,0.86,1.06)	(0.64,0.81,1.13)	*0.174*
MN	(0.74,0.84,1.03)	(0.7,0.8,1)	(1,1,1)	(0.89,0.98,1.09)	(0.56,0.69,0.98)	(0.56,0.68,0.91)	*0.110*
RS	(0.74,0.86,1.06)	(0.72,0.82,1.01)	(0.91,1.02,1.13)	(1,1,1)	(0.58,0.72,1.01)	(0.56,0.69,0.94)	*0.117*
CL	(1,1.23,1.39)	(0.94,1.16,1.35)	(1.02,1.44,1.77)	(1.01,1.41,1.73)	(1,1,1)	(0.77,0.95,1.2)	*0.220*
EX	(1.02,1.29,1.48)	(0.89,1.23,1.56)	(1.1,1.48,1.77)	(1.07,1.45,1.77)	(0.84,1.06,1.31)	(1,1,1)	*0.221*
CR_m=0.0004 CR_g=0.0013 λ_{max}^m=6.0023 $\lambda_{max}^g = 6.0025$							

Table 4.13. Pairwise comparison matrix of design risk factors with respect to time

	DS01	DS02	DS03	DS04	DS05	DS06	DS07	*NEV*
DS01	(1,1,1)	(1.06,1.39,1.65)	(0.86,1,1.16)	(0.42,0.56,0.88)	(0.72,0.84,1.06)	(0.38,0.51,0.81)	(0.74,0.95,1.21)	*0.083*
DS02	(0.61,0.72,0.95)	(1,1,1)	(0.28,0.39,0.68)	(0.34,0.45,0.68)	(0.66,0.76,0.95)	(0.32,0.45,0.76)	(0.53,0.68,1)	*0.017*
DS03	(0.86,1,1.16)	(1.48,2.53,3.56)	(1,1,1)	(0.31,0.43,0.7)	(0.86,0.96,1.09)	(0.41,0.52,0.76)	(0.78,0.94,1.14)	*0.132*
DS04	(1.14,1.79,2.35)	(1.48,2.2,2.95)	(1.43,2.34,3.2)	(1,1,1)	(0.85,1.17,1.48)	(0.34,0.43,0.63)	(0.87,1.22,1.61)	*0.220*
DS05	(0.94,1.18,1.39)	(1.06,1.32,1.51)	(0.91,1.04,1.16)	(0.67,0.85,1.17)	(1,1,1)	(0.23,0.31,0.46)	(0.3,0.41,0.66)	*0.070*
DS06	(1.23,1.98,2.65)	(1.32,2.23,3.08)	(1.32,1.93,2.45)	(1.6,2.32,2.98)	(2.18,3.28,4.32)	(1,1,1)	(0.85,1.13,1.48)	*0.301*
DS07	(0.83,1.05,1.35)	(1,1.46,1.9)	(0.88,1.07,1.28)	(0.62,0.82,1.15)	(1.51,2.43,3.29)	(0.68,0.88,1.18)	(1,1,1)	*0.177*
CR_m=0.0332 CR_g=0.0882 λ_{max}^{m}=7.2562 $\lambda_{max}^{g} = 7.2165$								

Table 4.14. Pairwise comparison matrix of construction risk factors with respect to time

	CN01	CN02	CN03	CN04	CN05	CN06	CN07	CN08	*NEV*
CN01	(1,1,1)	(0.83,1.01,1.21)	(1.07,1.3,1.51)	(1.23,1.6,1.88)	(1,1.53,2.03)	(0.45,0.6,0.93)	(1.04,1.76,2.5)	(1.1,1.66,2.12)	*0.171*
CN02	(0.83,0.99,1.2)	(1,1,1)	(0.54,0.67,0.92)	(0.77,0.83,0.95)	(0.8,0.98,1.19)	(0.39,0.5,0.76)	(0.8,1.09,1.42)	(0.67,0.8,1)	*0.073*
CN03	(0.66,0.77,0.93)	(1.09,1.48,1.85)	(1,1,1)	(0.81,1.08,1.39)	(0.68,1.08,1.66)	(0.38,0.51,0.81)	(1.16,1.78,2.3)	(1.14,1.76,2.29)	*0.152*
CN04	(0.53,0.63,0.81)	(1.06,1.2,1.3)	(0.72,0.93,1.23)	(1,1,1)	(0.81,0.88,1)	(0.46,0.59,0.88)	(0.89,1.16,1.53)	(0.9,1.21,1.5)	*0.095*
CN05	(0.49,0.65,1)	(0.84,1.02,1.25)	(0.6,0.93,1.47)	(1,1.14,1.23)	(1,1,1)	(0.51,0.65,0.95)	(1.16,1.78,2.3)	(1,1.57,2.12)	*0.135*
CN06	(1.07,1.66,2.22)	(1.32,1.99,2.58)	(1.23,1.98,2.65)	(1.14,1.69,2.15)	(1.06,1.54,1.95)	(1,1,1)	(1.68,2.65,3.57)	(1.45,2.32,3.22)	*0.250*
CN07	(0.4,0.57,0.96)	(0.71,0.91,1.25)	(0.43,0.56,0.86)	(0.65,0.86,1.13)	(0.43,0.56,0.86)	(0.28,0.38,0.6)	(1,1,1)	(0.76,0.94,1.15)	*0.054*
CN08	(0.47,0.6,0.91)	(1,1.25,1.48)	(0.44,0.57,0.88)	(0.67,0.83,1.11)	(0.47,0.64,1)	(0.31,0.43,0.69)	(0.87,1.06,1.31)	(1,1,1)	*0.070*
CR_m=0.0357 CR_g=0.0213 λ_{max}^{m}=8.3355 $\lambda_{max}^{g} = 8.0622$									

Table 4.15. Railway construction project risk impact

Risk Clusters	Risk factors	Impact Weight	Risk Clusters	Risk factors	Impact Weight
Design-related risks	DS01	0.0167	Resource-related risks	RS01	0.0253
	DS02	0.0058		RS02	0.0312
	DS03	0.0076		RS03	0.0266
	DS04	0.0345		RS04	0.0277
	DS05	0.0040		RS05	0.0265
	DS06	0.0140	Contractual and legal related risks	CL01	0.0041
	DS07	0.0150		CL02	0.0141
Construction-related risks	CN01	0.0330		CL03	0.0060
	CN02	0.0242		CL04	0.0483
	CN03	0.0504		CL05	0.0066
	CN04	0.0234	Management-related risks	MN01	0.0238
	CN05	0.0472		MN02	0.0326
	CN06	0.0782		MN03	0.0248
	CN07	0.0230		MN04	0.0324
	CN08	0.0321		MN05	0.0196
External risks	EX01	0.0250		MN06	0.0226
	EX02	0.0010		MN07	0.0103
	EX03	0.0009		MN08	0.0416
	EX04	0.0007		MN09	0.0427
	EX05	0.0004		MN10	0.0437
	EX06	0.0012		MN11	0.0513

4.5. Summary

In this chapter FSE, BBN, and FANP approaches are implemented for risk analysis. The FSE and BBN approaches are adopted to determine the likelihood of risk occurrences while the FANP is utilized for determining the structure of risks and their interdependency for analyzing the impact of project risks. The proposed hybrid approach has shown that project risks and their effect on project objectives mainly cost and time can be effectively structured and analyzed by taking into account data unavailability, subjective judgment, the likelihood of occurrence, interdependence as well as the impact on cost and time.

5. INTEGRATED SYSTEM DYNAMICS MODEL DEVELOPMENT FOR PROJECT RISK ASSESSMENT

5.1. Introduction

This chapter introduces the application of SD for risk analysis of railway construction projects. Based on the identified project risks, causal loop diagrams are developed to address the interdependencies of project risks. Qualitative causal loop diagrams are converted into quantitative models to evaluate the interactions of risk variables in the entire system. The risk severity values are incorporated into the stock and flow diagrams to simulate the dynamics of risk effects and impacts on project cost and time.

5.2. Problem articulation

The most important stage of system dynamic modeling is problem articulation. This process is performed to identify problems or issues that are the focus of decision-makers. This phase also identifies key variables, patterns of behavior, and time horizons for the key variables.

Due to the complexity and dynamic nature as well as the involvement of various stakeholders, railway construction projects are exposed to the effects of plentiful risk factors leading to delays and cost overruns. For these reasons, different approaches (probabilistic, fuzzy-based, MCDM, etc) have been implemented to analyze the impact of construction project risks on project objectives. However, these approaches considered the impact of risks on project objectives as static. However, project risks are dynamic: some risks disappear, while others lead to undesired events during the project lifespan. As a result, handling project risk dynamics necessitates a different approach based on a holistic and systemic perspective that is capable of capturing feedback and quantifying relevant subjective factors. Thus, the SD approach for risk assessment in railway construction projects has been suggested to evaluate the dynamic effect of project risks and their feedback consequences. Therefore, for the railway construction project, this research utilized the SD approach to develop appropriate and effective risk assessment models that address the interrelationships, and dynamic and feedback effects of project risks.

5.2.1. Variable identification

All variables or factors relevant to the study objectives are considered when selecting variables to include in the model. The variables used in the model are discussed further below. When a complex system employs dynamic equations, slack variables are employed to reduce the complexity of the equations. For the dynamic risk assessment, the identified key variables and their definition are depicted in Table 5.1.

Table 5.1. Key variables and definitions for SD modeling

Variables	Description
Incomplete contract details	Incomplete contracts have gaps, missing provisions, ambiguity, and need to be completed
Improper construction method	Inappropriate procedures and techniques utilized during construction
Ineffective site management	Inadequate supervision of construction projects to ensure professional and efficient implementation
Inadequate quality control and testing methods	The quality control and testing techniques employed do not meet the established standards
Errors during construction	Execution of work that deviates from the established criteria and requirements
Poor quality of construction materials	The quality of materials used for construction is below the standards established
Scope change	A deviation from the scope of the originally agreed project or the work contained in the contract
Incomplete design	Failure to include all required components of the designs
Design change	The change or modification of design by the client
Inadequate site investigation	Inadequate considerations of the technical issues
Design error	A design that includes mistakes that do not meet the design standards

Variables	Description
Misunderstanding client’s requirements	Failure to fully comprehend and define the client’s requirements
Change in government regulations	introduction of, or any change in any applicable law, rule, regulation, or guideline related to the construction project by governmental authorities
Inflation	The decline in purchasing power of certain currencies over time causing an increase in the prices of materials, machinery, and other inputs to construction projects
Force majeure	External factors including bad weather conditions, heavy floods, earthquakes, landslides, etc
Design delay	Failure to complete and submit the designs within the specified time
Schedule pressure	the shortness of working time that was originally allocated to a schedule to perform some work.
Management of materials resources and personnel	The effective management of resources used for the construction project
Client's lack of experience	Lack of experience of the client on similar projects
Client's financial difficulty	The financial inability of a client to make payments to contractors for the executed works
Delay in decision-making by client	Owner replies are delayed as a result of lengthy bureaucracy or management's lack of commitment
Payment delays	Delayed release of payment from the client to contractors
Right-of-way problems	Delays in gaining access to the site or land unavailability issues that may affect project commencement and construction activities
Low productivity of plant and equipment	The plant's and equipment's productivity are lower than anticipated
Equipment damage	any occurrence in which equipment fails to fulfill its intended purpose or task

Variables	Description
Poor equipment maintenance	Ineffective maintenance methods and procedures to keep the equipment in good working condition
Low labor productivity	Low output produced by laborers per labor hour
Inadequate skill of the workforce	Not having enough skilled workers available to complete a project

5.2.2. Model boundary

When delimiting model boundaries of the project risk assessment system, all important elements that affect other parts of the system and are also significantly influenced by the factors of the system are modeled as endogenous variables, while all factors that could seriously impact the system but are not sufficiently influenced by the system become exogenous variables, and all other elements are omitted. Since it is practically impossible to include all of the variables in the risk assessment model, the model boundary must be clearly defined in SD modeling. For each subsystem (design, construction, and management risk assessment), the variables in the model are classified as endogenous and exogenous. Endogenous components are dynamic variables involved in the feedback loops of the system and affect and are affected by other system variables whereas exogenous variables are outside variables that affect but are not directly affected by the system. Hence, the boundaries of the railway construction project risk assessment system models contain risk variables that are required to generate the problem behavior on project performance. The project risk factors and related variables are included within the system boundary to ensure the model's comprehensiveness and adequacy.

The bull's eye diagrams are used to provide a brief overview of the modeler's system boundary choices. Endogenous variables are placed in the center, exogenous variables in the outer ring, and excluded variables outside the outer ring. The bull’s eye diagrams for the design, construction, and management-related risk assessment models are depicted in Figures 5.1-5.3.

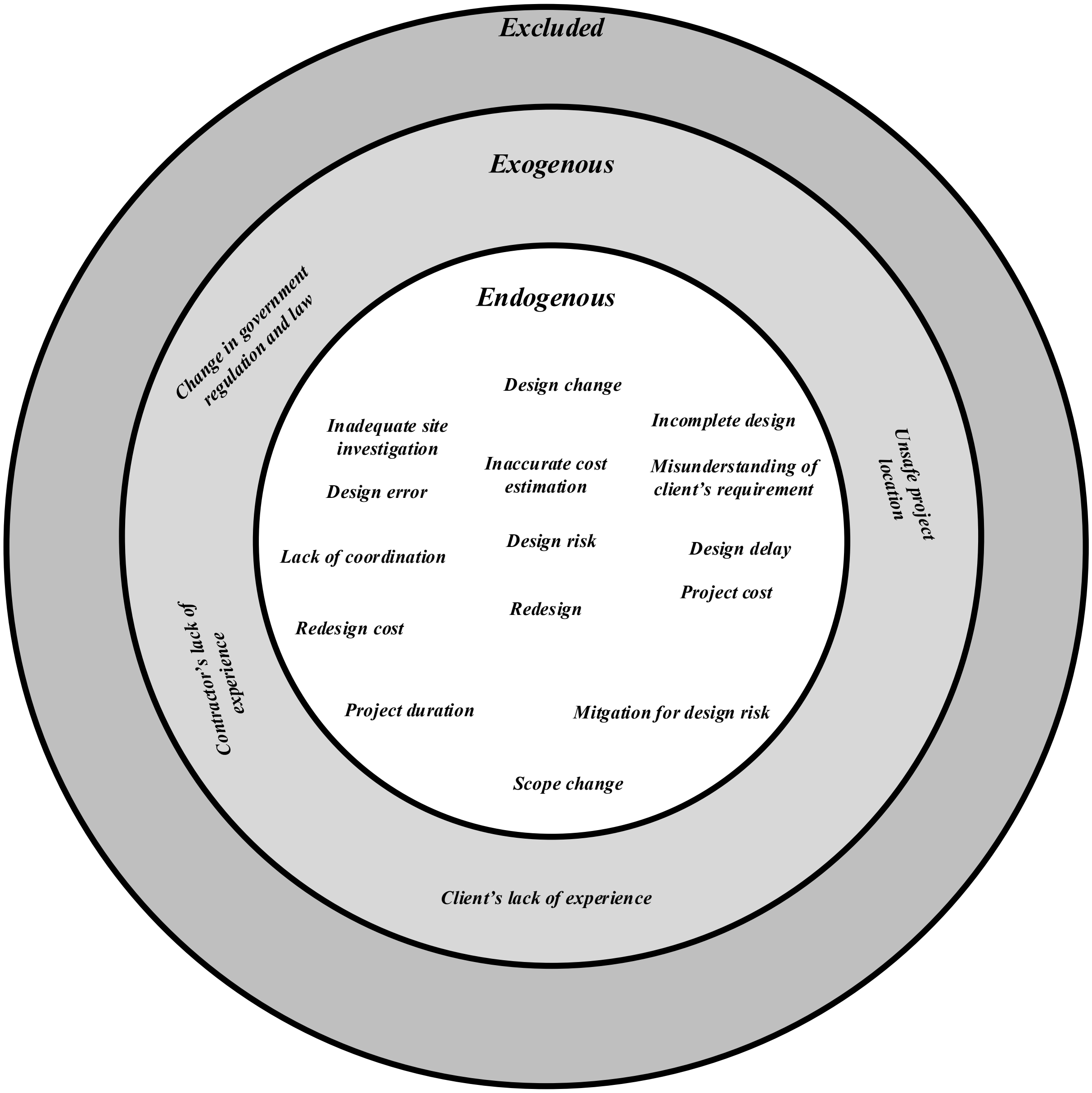

Figure 5.1. System boundary diagram of design risk assessment model

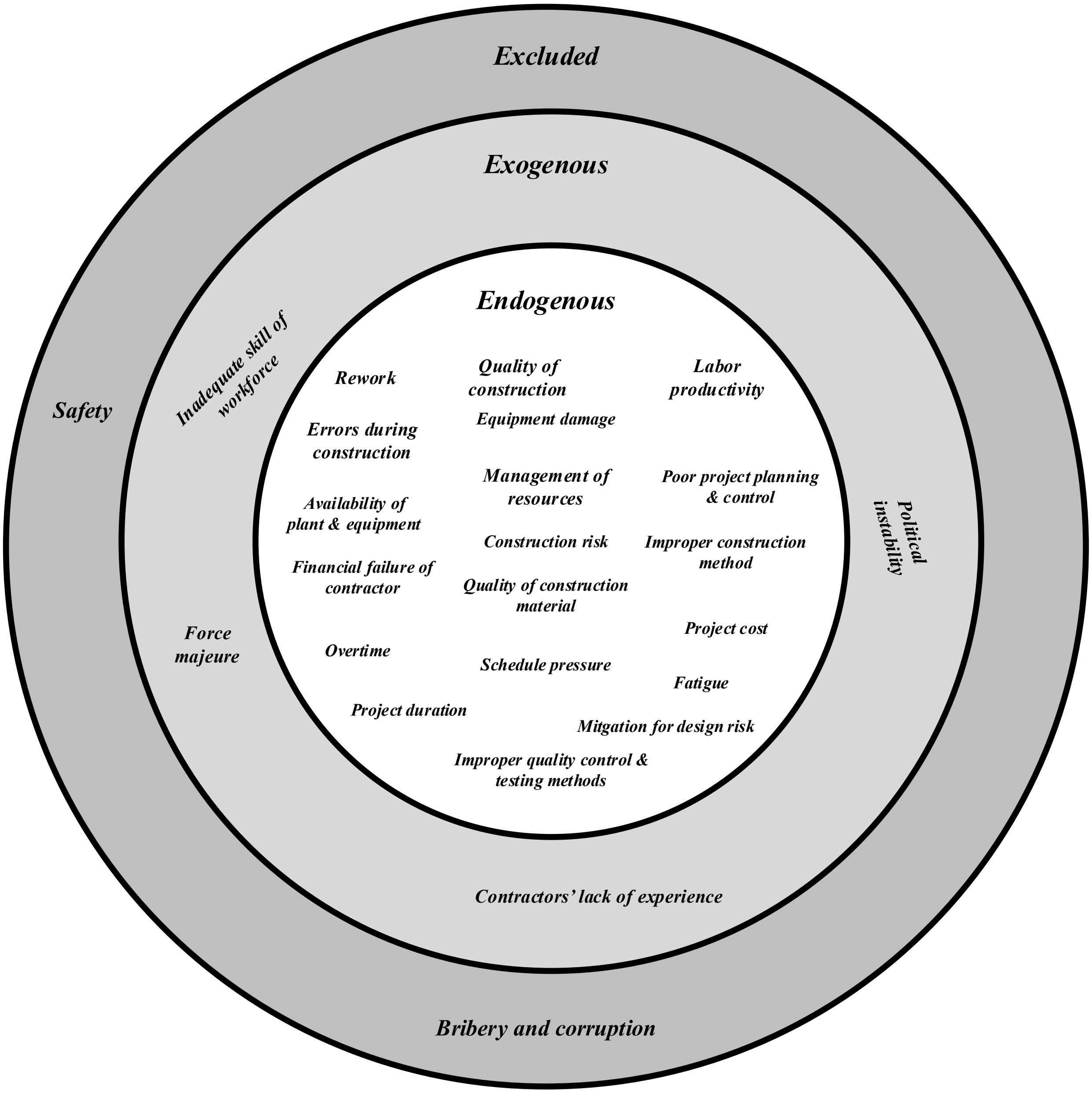

Figure 5.2. System boundary diagram of construction risk assessment model

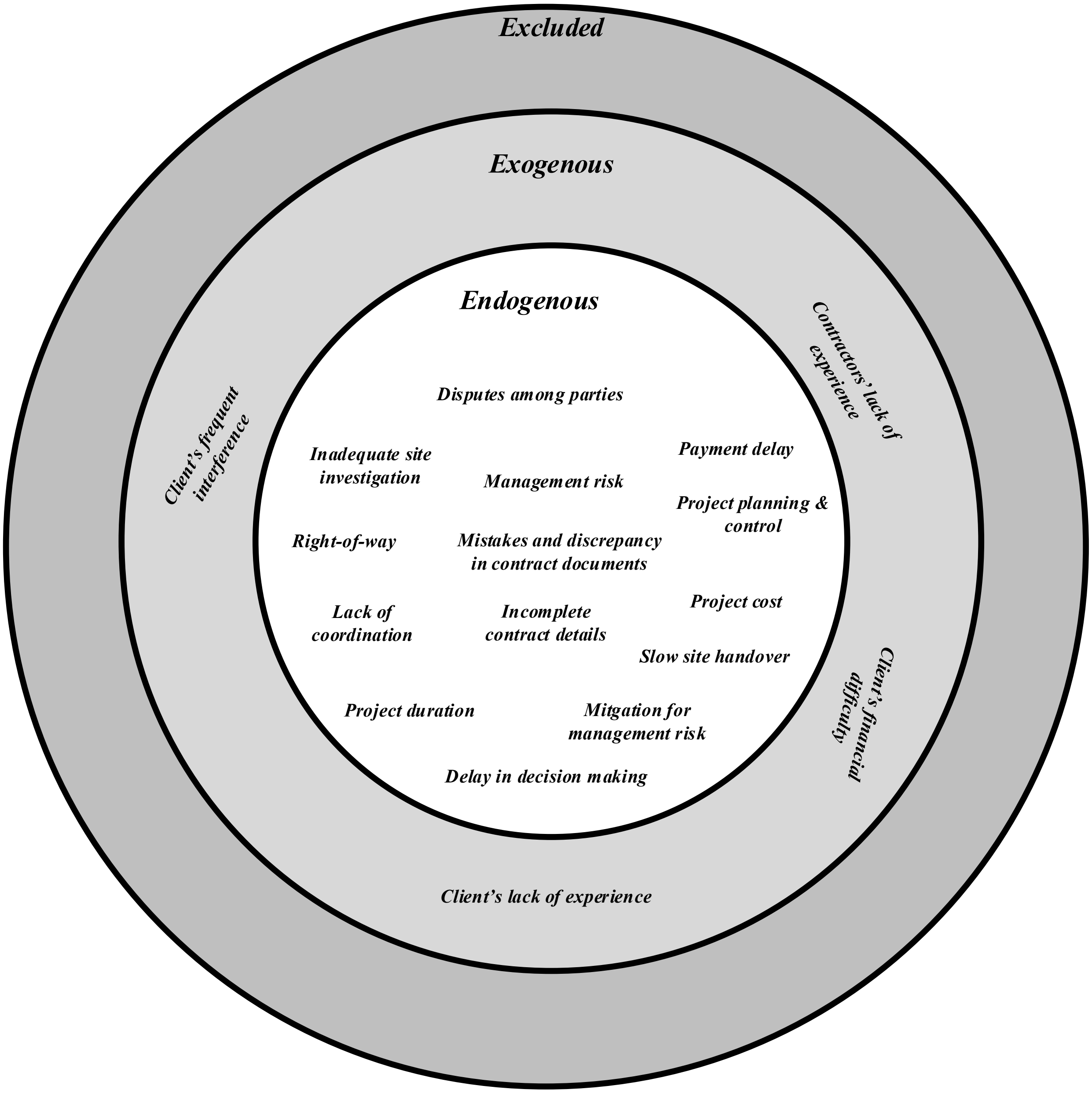

Figure 5.3. System boundary diagram of management risk assessment model

5.2.3. Reference modes and time horizon

To dynamically characterize a problem, a reference mode needs to be developed as a pattern of behavior over time that shows how the problems arise and how they will evolve in the future. A reference mode is a set of graphs and other descriptive data that depicts the development of a problem over time (Sterman, 2000). The reference mode is a qualitative and intuitive concept that represents the key variables' pattern of behavior over time (Saeed, 2003), provides hints for appropriate model structure, and can check plausibility after the model is built. During the modeling process, reference modes can be changed, and the modeler can reassess and redefine the model's purpose based on the initial reference mode (Albin, 1997).

Different reference modes can indicate the behavior of variables and their impact on project objectives. In this study, project risk factors negatively impact railway construction project delays and cost overruns. The extent of the dynamic impact of these project risks varies in the stages of the project. The reference modes for risks and their impact on delays and cost overruns are depicted in Figure 5.4.

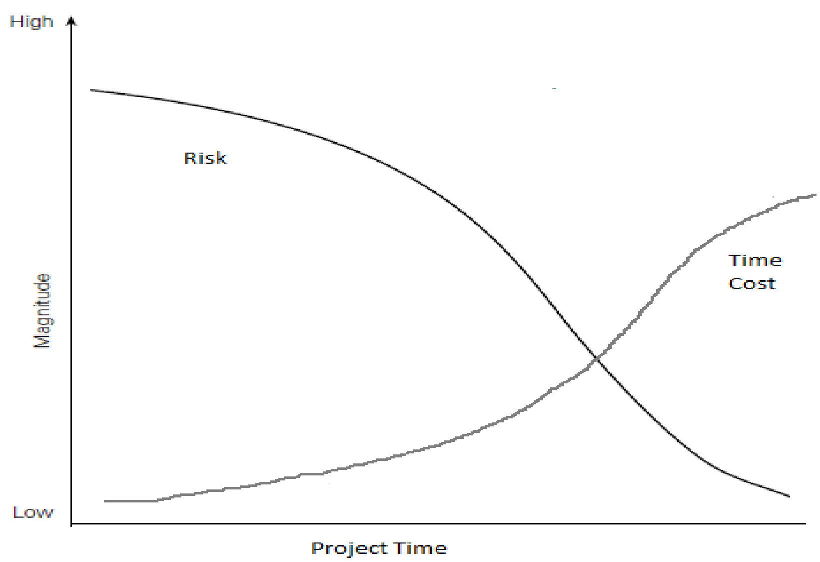

Figure 5.4. Degree of risks and their impact over time

As shown in Figure 5.4, the risk is assumed to be greatest at the start of the project. These factors decrease over the project life cycle as decisions are made and deliverables are accepted. The impact of these risks on delays and costs is small at first, increases as work progresses, and decreases rapidly as the project draws to a close.

The time horizon of the reference mode depends on the purpose of the model, but it is often longer than the historical information on which the model is based, as it also includes information about the inferred future (Saeed, 2003). In this research, the time horizon of the model is determined considering the average time taken to complete the railway construction project. Hence, a duration of seventy months is taken for this SD modeling.

5.3. Dynamic hypotheses

Dynamic hypothesis is a theory about the structure that generates the reference modes. It explains the dynamic behavior of a system based on feedback and interactions between different components. Dynamic hypotheses can be expressed by causal loop diagrams or stock and flow diagrams. Tools like causal loop diagrams and stock and flow diagrams can be used to map different assumptions about why a system's "reference mode" behaves in a particular way. This is an important phase for gathering information about the problem through brainstorming with groups, data, literature, and personal experience (Sterman, 2000).

The railway construction project risk assessment system is made up of three main subsystems, each of which is controlled by the identified project risk-related variables. The models of the subsystems are developed considering the nature and process of railway construction projects. These models are designed to analyze the interrelationship, feedback as well as dynamic effects of project risks on cost and time. The risk analysis modeling system is divided into three major subsystems in this research:

a. Design risk assessment model,
b. Construction risk assessment model and,
c. Management risk assessment model.

5.3.1. Causal loop diagrams

The causal loop diagrams (CLDs) of each subsystem of the risk analysis model of the railway construction project explain the system structure qualitatively. These show how different variables in the system affect each other. It also indicates whether the relationship is positive or negative. However, it does not provide information about the quantitative relationships between variables. The CLDs are developed in consultation with the domain experts in railway construction projects.

CLDs are a useful tool for representing the feedback structure of systems. A causal diagram is made up of risk factors that are connected by arrows that represent the causal influences between the variables. Variables (risk factors) are linked together by causal links, which are depicted by arrows. Each causal link is assigned either positive (+) or negative (-) polarity to show how the dependent variable changes when the independent variable changes. Positive polarity indicates that the two variables change in the same direction, i.e., if the independent variable increases (or decreases), the dependent variable also increases (or decreases). Negative polarity indicates that the linked variables change in opposite directions.

The causal loops are either positive (reinforcing) or negative (balancing). A negative (balancing) loop exists when a small increase (or decrease) of any variable in the loop results in a decrease (or increase) of the same variable. In a positive loop, a small increase (or decrease) in a variable in the loop causes the same variable to increase (or decrease).

The CLDs for the aforementioned subsystems of the project risk assessment models are developed based on the literature review and opinions of domain experts. These CLDs are:

i. Design risk assessment causal loop diagram
ii. Construction risk assessment causal loop diagram
iii. Management risk assessment causal loop diagram

5.3.1.1. Design risk assessment causal loop diagram

The design risk assessment subsystem is one of the submodels in the railway construction project risk analysis model. The submodel describes the interrelationships among potential design-related risk factors that have an impact on project cost and duration.

The causal loop diagram of the design risk assessment subsystem is depicted in Figure 5.5. The causal loop diagram of the design risk analysis model illustrates the interaction of the potential project risks that are encountered during the design process. The interrelationships of these factors are shown using the polarity of the links.

The diagram was used to examine the relationship between risk factors to determine the root causes of the project delay and cost overrun. The main elements that are considered in the design risk analysis system are scope changes, design changes, design errors and omissions, schedule pressure, rework (redesign), and delayed design.

Changes in scope are caused by additions, deletions, omissions, or changes in the nature of the work to be done. The majority of change orders are at the client's request and are typically in the form of design changes (Love et al., 2010). The client's change in scope of work has an impact on the design change. Changes in design necessitate rework, which increases the risk of design-related risks impacting cost and time. Design errors are also major factors that have a significant impact on project success. These factors can occur as a result of a misunderstanding of the client's requirements, a tight project schedule, inadequate site information, or poor coordination among relevant parties.

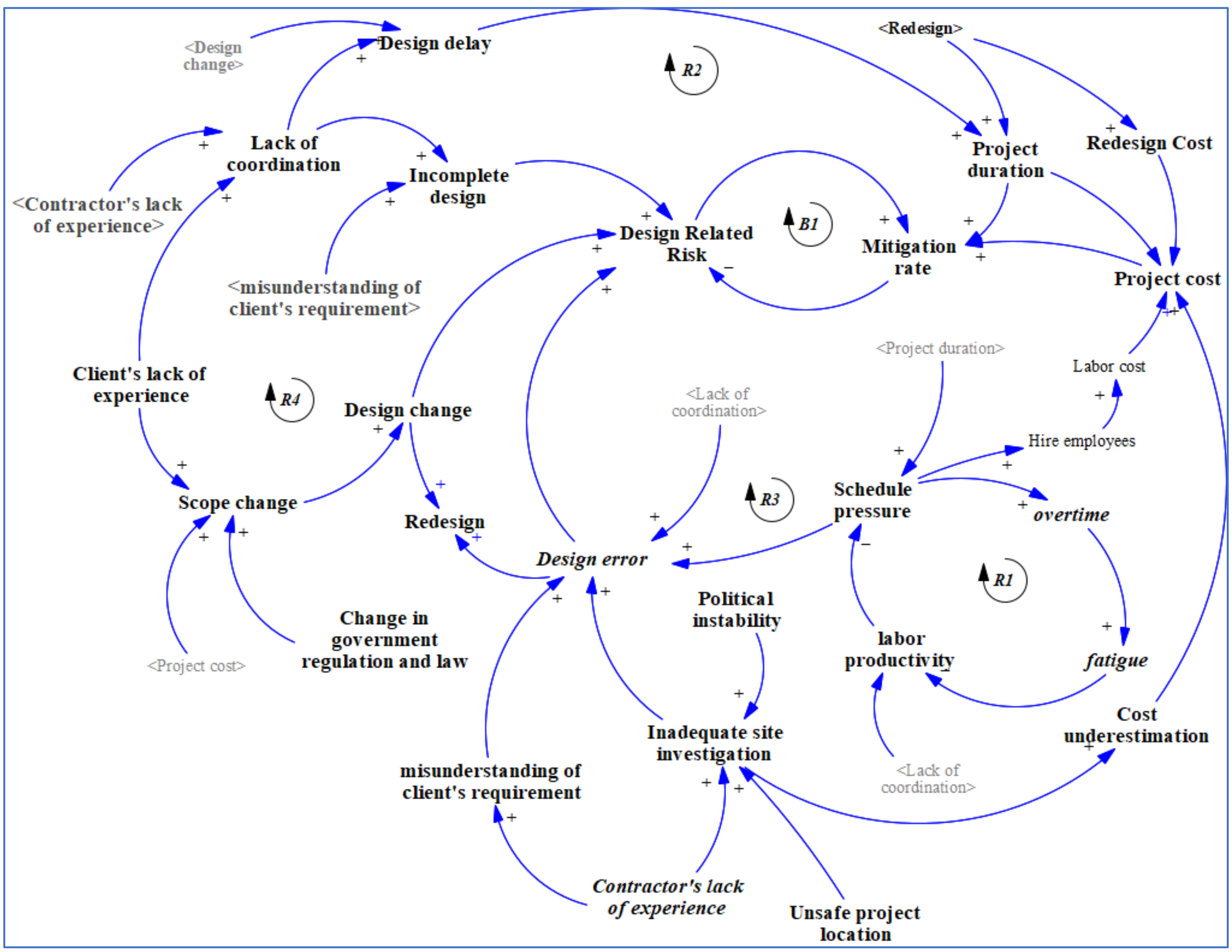

Figure 5.5. Causal loop diagram for design-related risk assessment model

The CLD of the design risk assessment model consists of a balancing loop (B1) and three main reinforcing feedback loops (R1, R2, and R3).

- Loop B1: Design risk; mitigation rate
- Loop R1: Schedule pressure; overtime; fatigue; labor productivity
- Loop R2: Scope change; design change; design delay; project duration; project cost
- Loop R3: Project cost; scope change; design change; design delay; project duration; schedule pressure; design error; redesign; redesign cost

Loop B1 portrays the degree of the risk mitigation rate depends on the level of risk and its impact on cost and time. The control system reduces the impact of design-related risks on project objectives, thereby creating a negative loop to balance the adversely enhanced impact of design-related risks on project success (Figure 5.6). The remaining factors demonstrate the causal interdependence of design-related risk factors.

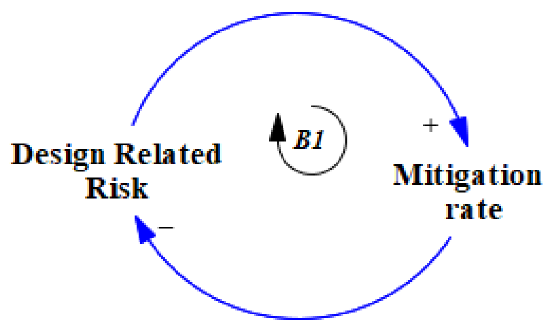

Figure 5.6. Causal links between design risks and mitigation

Loop R1 presents that increased project duration risks put pressure on schedule. This pressure also triggers the need to complete the design on time (Figure 5.7). As a result, designers can work longer; however, it causes fatigue and decreased productivity, which in turn increases the risk of schedule pressure. Han et al.,(2013) demonstrated that schedule pressure can propagate the negative impact of design errors on a wide range of construction activities, including those that are not directly related to the errors.

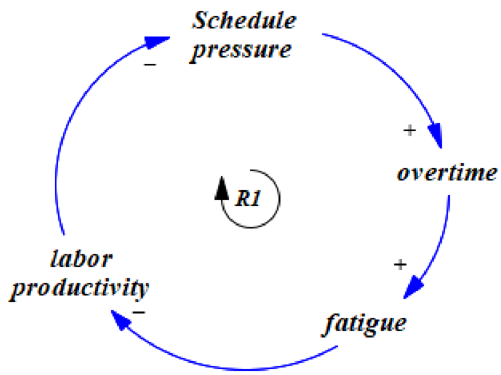

Figure 5.7. Causal loop of the effect of schedule pressure

Loop R2 shows the positive effect of changing the scope of work on project delays and cost overruns. When the client changes the scope of work, the risk of design changes and design delays increases, which has a positive impact on delays and cost overruns.

Design changes, errors, and omissions in contract documentation have all contributed significantly to rework (Love, 2002; Love & Edwards, 2004). Loop R3 depicts the impact of schedule pressure, design errors on delays, and cost overruns. The positive loop considers scope change, design change, design delay, schedule pressure, design error, and redesign as interrelated factors that influence project objectives.

5.3.1.2. Construction risk assessment causal loop diagram

Construction-related risk assessment system submodel describes the interrelations among potential construction risk factors that have an impact on project cost and duration. The variables of the model are identified to define the boundary of the risk system and are classified as endogenous and exogenous variables as shown in Figure 5.2. The causal loop diagram of the construction-related risk assessment system is depicted in Figure 5.8. The diagram shows the interrelations between different causes which lead to the occurrence of risks and their impact on the project objectives.

The construction risk assessment model comprises one balancing loop and three reinforcing loops. Loop B1 is the negative balancing loop that shows the relationship between construction risk and mitigation measures. Loop R1 presents the effect of schedule pressure and labor productivity on project duration. This reinforcing loop comprises schedule pressure, overtime, fatigue, and labor productivity. When there is schedule pressure, project managers deploy resources to complete the project on time. The workers are then required to work extra hours to complete the tasks. However, overtime leads to fatigue, increased construction errors, and reduced labor productivity.

The reinforcing loop R2 depicts the causal relationships between project duration, schedule pressure, overtime, fatigue, errors during construction, poor quality of construction, and rework. The loop represents the effect of schedule pressure on construction quality and rework. Due to the occurrence of schedule pressure, worker fatigue increases construction errors and decreases construction quality.

To achieve high-quality construction that meets requirements, construction errors have to be rectified. This leads to an increase in rework and project delays.

Loop R3 represents the impact of equipment productivity, construction methods, and construction quality on project delays and cost overruns. This reinforcing loop considers the impact of rework on project objectives. Rework has been identified in the construction industry as a key factor leading to increased project costs and schedule delays.

The reinforcing loop considers plant & equipment productivity, schedule pressure, improper construction methods, errors during construction, poor quality of construction, and rework as factors that influence project objectives. As rework is one of the factors that affect cost and time, it is considered in this loop.

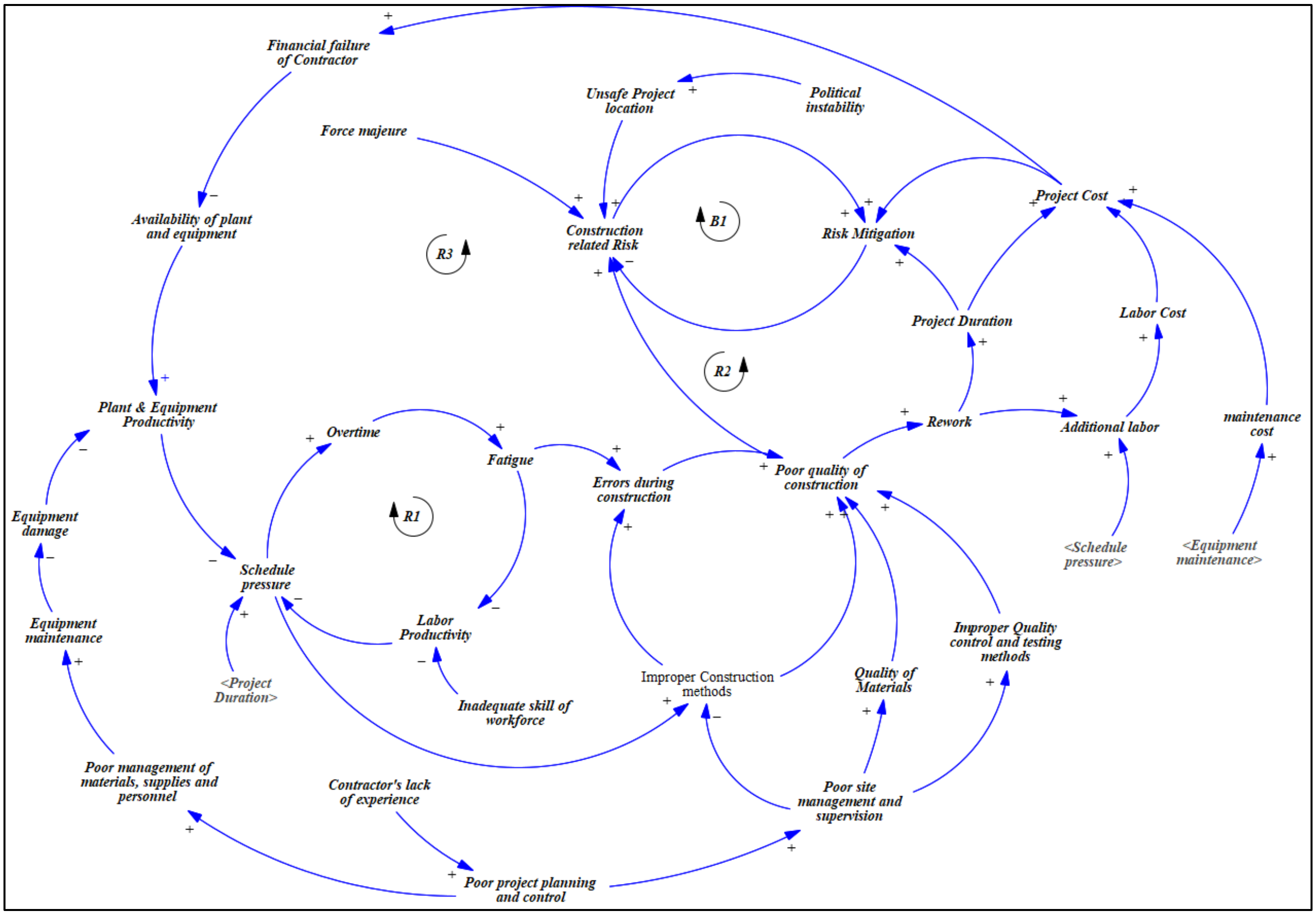

Figure 5.8. Construction-related risk subsystem causal loop diagram

5.3.1.3. Management risk assessment causal loop diagram

Like other models, the management risk assessment model is developed to assess the impact of management-related risks on delays and cost overruns. This model describes the interrelationships between potential management-related risk factors that affect the project objectives.

The causal loop diagram of the management risk assessment model is shown in Figure 5.9. The diagram depicts the interrelationships between the various causes that lead to the occurrence of management-related risks and their impact on time and cost.

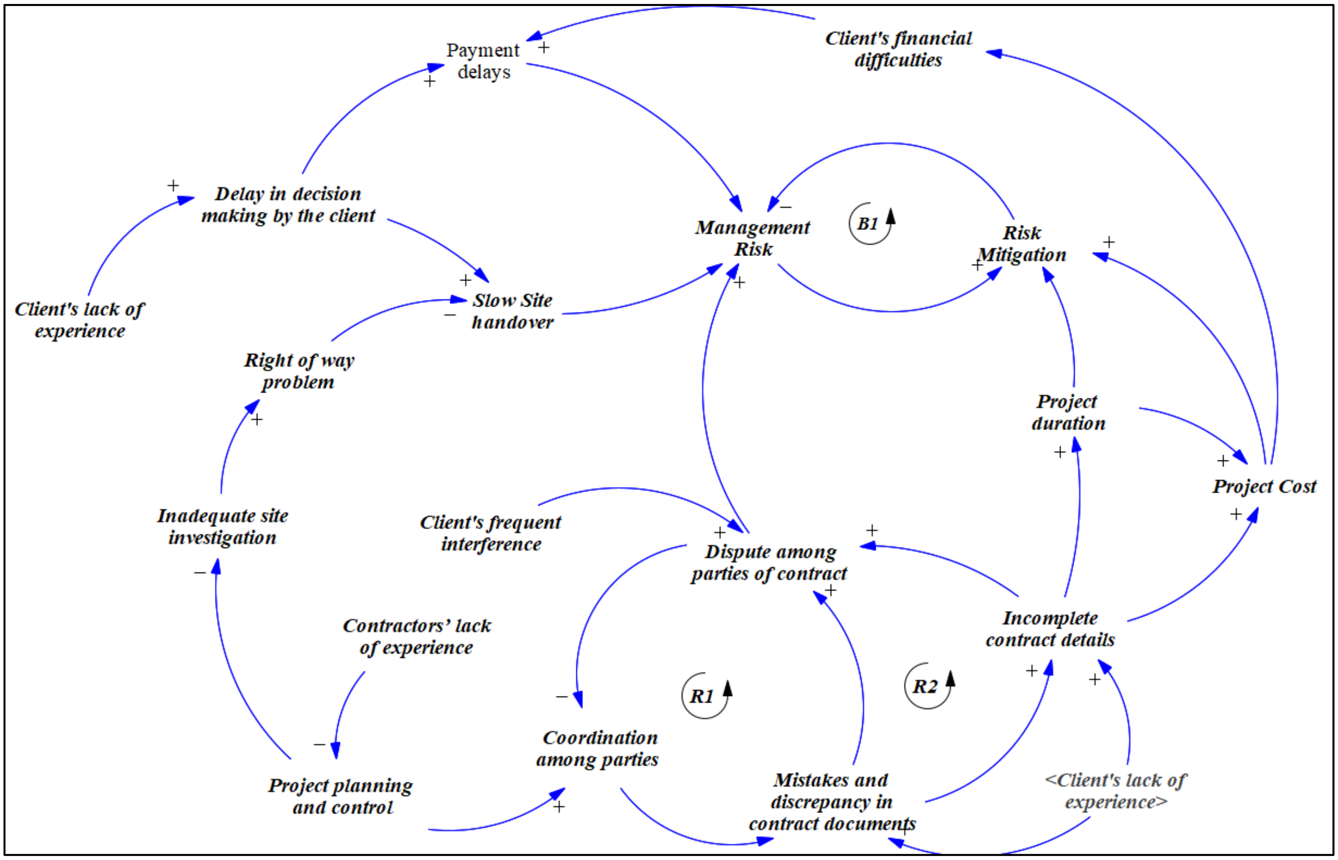

Figure 5.9. Management-related risk subsystem causal loop diagram

Determining how different factors relate to each other plays a central role in understanding the performance of a project (Love et al., 2010). To establish the underlying causes of management risks, it is necessary to examine the relationship between variables. Coordination among contract parties, mistakes and discrepancies in contract documents, incomplete contract details, resource management, and payment delays are the major variables that are considered within the management risk assessment system.

The causal loop diagram of the management risk assessment model consists of a balancing loop (B1) and two reinforcing feedback loops (R1 and R2). Loop B1 describes the negative relationship between management risks and mitigation effects.

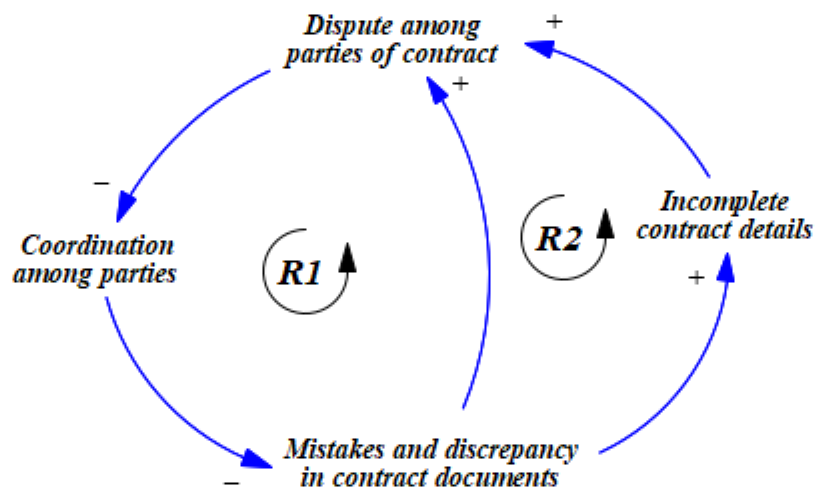

Figure 5.10. Factors affecting disputes in the management risk assessment system

The factors affecting disputes are depicted in Figure 5.10. The Figure shows the reinforcing loops that affect disputes and contains four management risk factors in the loops. Loop R1 shows the reinforcing (positive) effect of coordination among parties of the contract on disputes among parties. Moreover, loop R2 portrays the effect of coordination on incomplete contract details and disputes. The main causes of disputes are changes in scope, poor contract documentation (e.g., inadequate/incomplete design information, ambiguities in contract documents), and individual behaviors (e.g., poor communication) (Love et al., 2010).

5.4. Formulating simulation model

Following the development of CLDs that represent feedback loops, interdependence, and the effect of project risk factors on project objectives, a model with socks and flows is created to assess their dynamic effect over time. The model entails creating a formal model of the system that includes equations, parameters, and initial conditions.

5.4.1. Stock-flow diagrams

The qualitative structure of the system is described by CLDs of each subsystem of the construction project risk analysis model. They show how various system variables interact with one another. They also show whether the relationships are positive or negative. However, they do not reveal any quantitative relationships between the variables. The quantitative aspects of the railway construction project risk analysis system are captured by stock and flow structures. SFDs are created by combining level and rate variables from CLDs. They provide information about the values of various variables as well as the rate at which those values are associated with them.

The SFD is a quantitative model that introduces the time dimension by accounting for the rate of change in the level of variables over time. Stocks (or levels), flows, auxiliary variables, and constants are the types of elements in this risk assessment model.

The simulation models are formulated following the creation of the SFDs. The variables in the model take into account the values of the variables that influence it and from which it receives information. The dynamic behavior of the system is generated by equations that simulate the system's behavior over time using initial values for stock variables. SD model can thus be used to investigate the long-term behavior of complex systems (Bouloiz et al., 2013).

The SFD of the design, construction and management-related risks are developed based on the CLDs of the respective subsystems. The SFDs of these subsystems are depicted in Figures 5.11-5.13. These diagrams clearly show the relationships between the stocks, flows, and auxiliary variables. The variables used to model the effect of risks on the project objectives are defined in Table 5.1.

Simulations are in continuous time. The corresponding integral equation is:

$$\text{Stock}\ (t) = \int_{t_0}^{t} [\text{Inflow}\ (s) - \text{Outflow}\ (s)]ds + \text{Stock}\ (t_0)$$

5.4.1.1. Stock and flow diagram of the design-related risk assessment model

Stock and flow diagrams are created by adding levels and flow variables to CLDs. They provide information about the values of various variables as well as the rate at which those values are associated with them. The design-related risk subsystem stock-flow diagram depicts the interdependence of stocks (design risk, project duration, and project cost), rates (change in design risks, mitigation rate, rate of change in project duration, and change in project cost), auxiliary and exogenous variables (Table 5.2). Figure 5.11 depicts the design-related risk subsystem stock and flow diagram. It is built on the validated causal loop diagram shown in Figure 5.5. Within the model, mathematical equations are formulated for each of the endogenous system variables.

Table 5.2. Stock and flow variables of design risk assessment model

Subsystem	Variable	Variable Type
Design risk assessment model	Design risk	Stock
	Project duration (design)	Stock
	Project cost (design)	Stock
	Change in design risk	Flow
	Change in duration	Flow
	Change in cost	Flow
	Mitigation rate	Flow

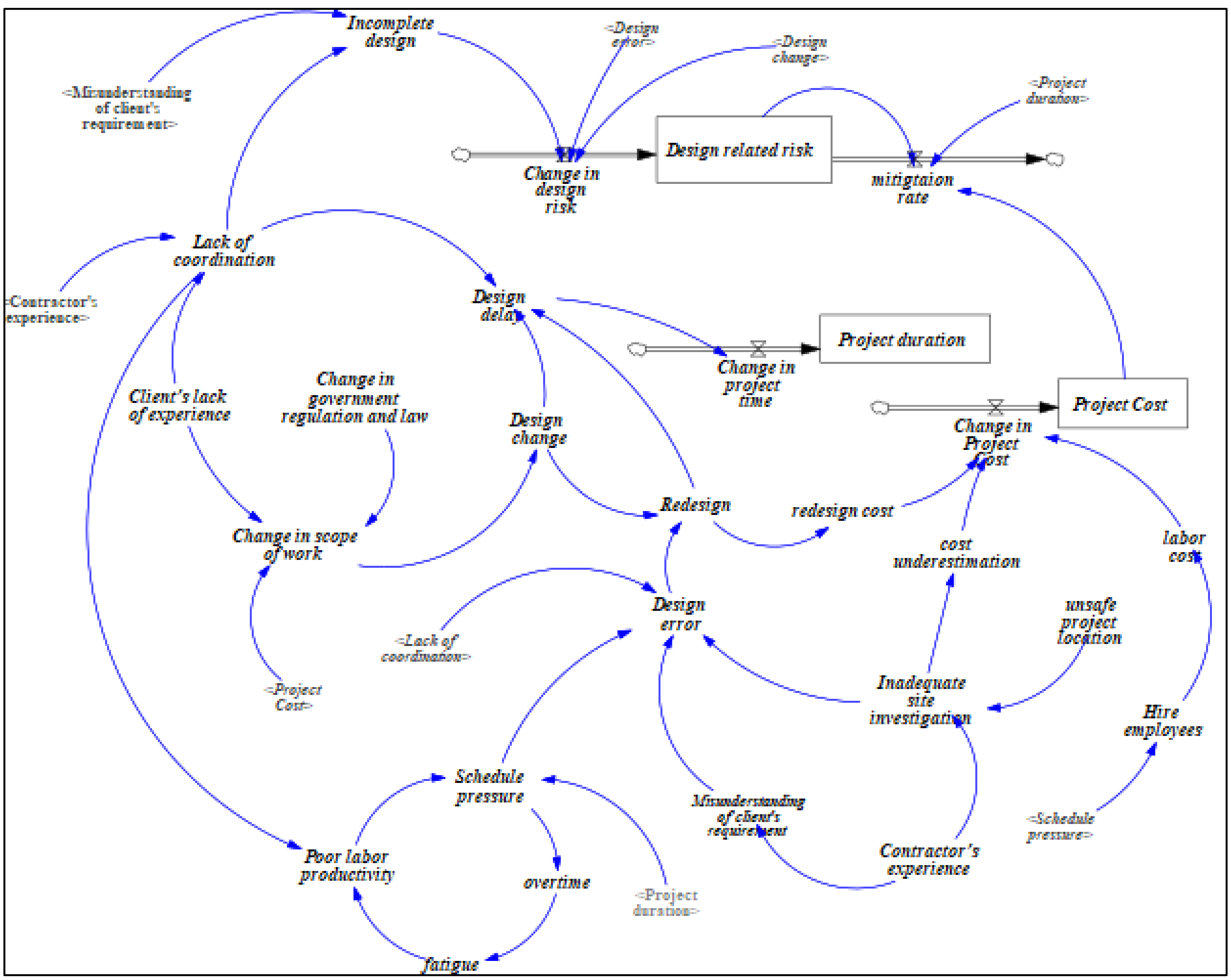

Figure 5.11. Stock and flow diagram for design-related risk subsystem

5.4.1.2. Stock and flow diagram of the construction-related risk assessment model

Stock and flow diagrams are created by adding levels and flow variables to CLDs. They provide information about the values of various variables as well as the rate at which those values are associated with them. The construction-related risk subsystem stock-flow diagram (Figure 5.12) depicts the interdependence of stocks (construction-related risk, project duration, and project cost), rates (change in construction risk, change in project duration, and change in project cost), auxiliary and exogenous variables (Table 5.3).

Table 5.3. Stock and flow variables of construction risk assessment model

Subsystem	Variable	Variable Type
Construction risk assessment model	Construction risk	Stock
	Project duration (construction)	Stock
	Project cost (construction)	Stock
	Change in construction risk	Flow
	Change in duration	Flow
	Change in cost	Flow
	Mitigation rate	Flow

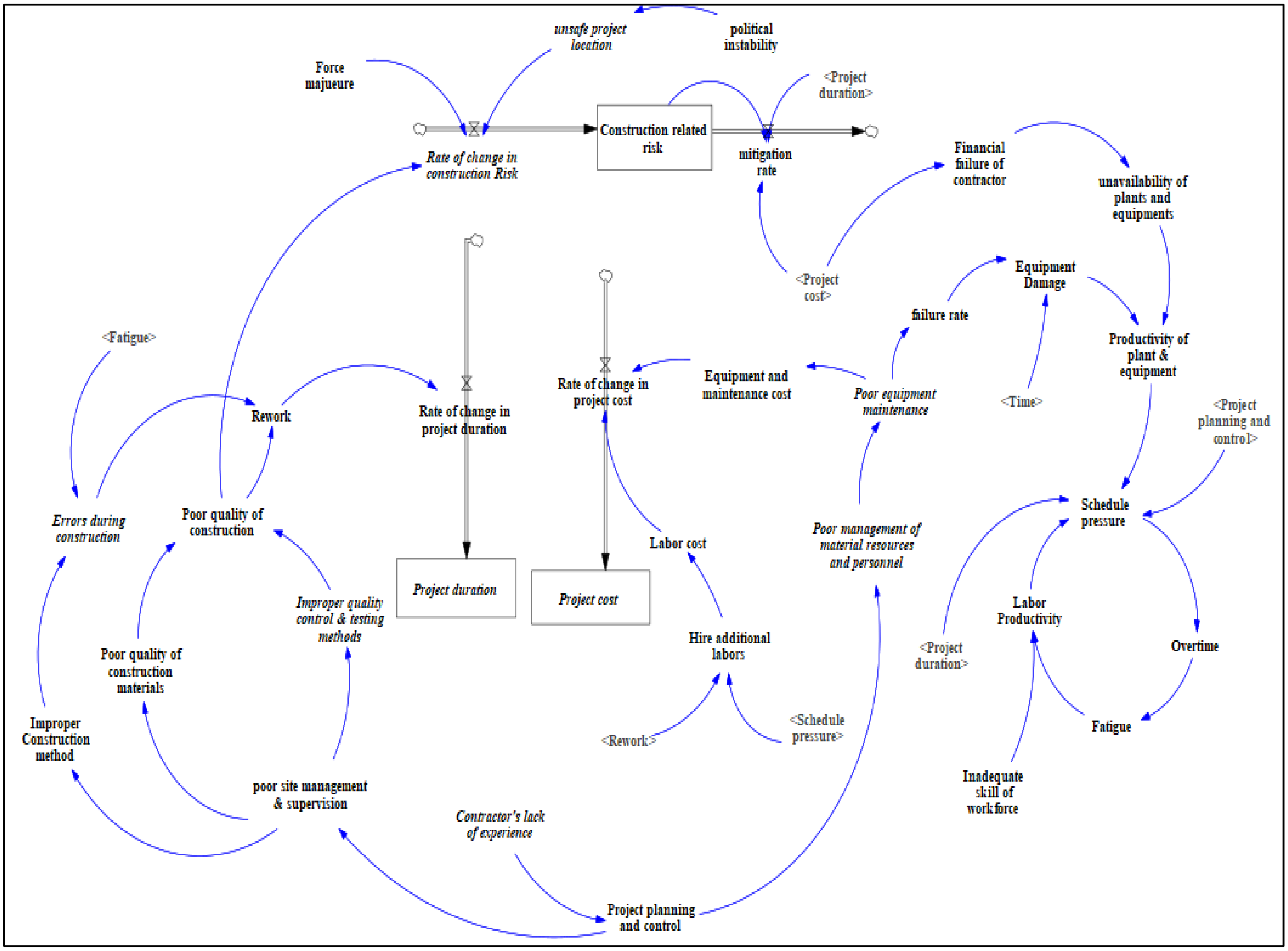

Figure 5.12. Stock and flow diagram for construction-related risk subsystem

5.4.1.3. Stock and flow diagram of project management-related risk assessment model

Similar to the aforementioned models, the management risk assessment model was developed from the causal loop diagram of the management model, and the stock-flow diagram of this model is depicted in Figure 5.13. It shows the quantitative relationship between variables comprising stocks, flows, auxiliary and exogenous variables. Within the model, mathematical equations are developed for each of the endogenous system variables. The stock and flow variables of the management risk assessment model are shown in Table 5.4.

Table 5.4. Stock and flow variables of management risk assessment model

Subsystem	Variable	Variable Type
Management risk assessment model	Management risk	Stock
	Project duration (management)	Stock
	Project cost (management)	Stock
	Change in management risk	Flow
	Change in duration	Flow
	Change in cost	Flow
	Mitigation rate	Flow

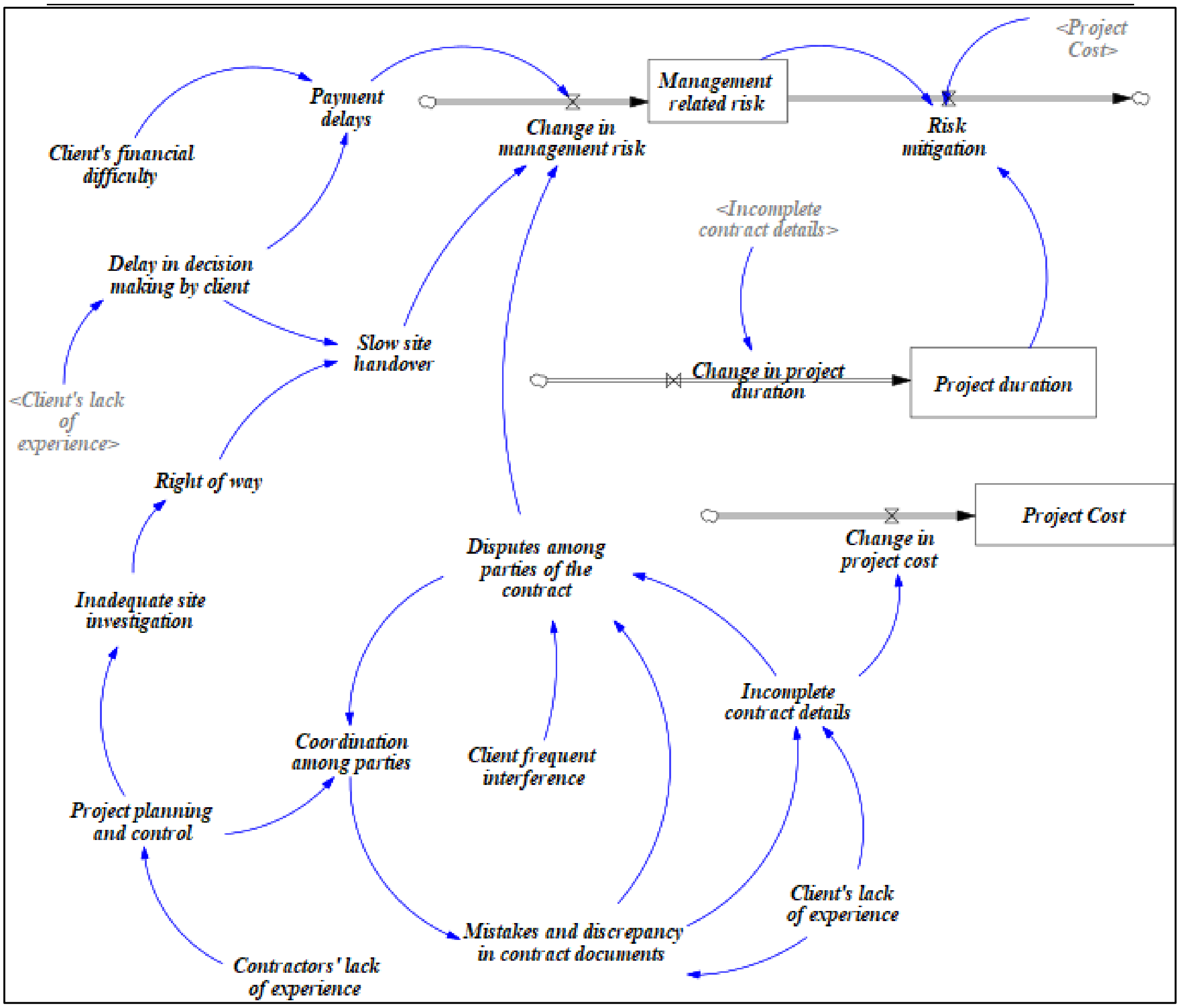

Figure 5.13. Stock and flow diagram for project management-related risk subsystem

5.5. Simulation results and analysis

Simulation is the generation of the behavior of a system with a formal computer model (Ford, 2019). SD modeling offers unique advantages for developing simulation models for large and complex systems. These include the use of graphical descriptions to facilitate inspection and peer interactions, declarative languages with automatic renaming, separation of model structure from data and output, productive debugging from the visibility of full model state and causal tracing, good testing habits, and automated testing tools (Yeager et al., 2014).

Vensim® is a visual modeling tool for conceptualizing, documenting, simulating, analyzing, and optimizing models of dynamic systems. It offers a simple and flexible way of building simulation models from a causal loop or stock and flow diagram (Ventana Systems, 2007). It is used for building high-quality simulation models in business, scientific, environmental, and social systems. It features cause and effect diagramming, graphical and textual model construction, easy reproduction of model structure using subscripts, Monte Carlo sensitivity analysis, and optimization. Vensim was thus chosen as the simulation software for this research. All of the simulation results for the models were obtained through numerical integration with Euler's method.

SD simulation models can quantify the interaction of project risks. The most notable feature of the model is its ability to simulate scenarios in which multiple risks interact. The feedback nature of the SD simulation model ensures that the cross-impacts of different risks are captured and that the direct and indirect risks are quantified.

The following assumptions are made for the project risk assessment models:

- A time horizon of seventy months was used for simulation in this railway construction project risk assessment model.
- The initial time for the model simulation is assumed to start at zero month.
- To produce smooth time profiles for the model's various variables, a time step of 0.0625 months was used.
- The risk mitigation process was assumed to be initiated after the impact of project risks on delays and cost overruns.

- The nonlinearity of the dynamic risk assessment models was assumed to be due to the linear dependence between project risks.

5.5.1. Design risk assessment model

The interaction of project risks can be quantified using SD simulation models. The ability of the SD simulation model to simulate scenarios in which multiple risks interact is its most notable feature.

The design risk analysis model is simulated to evaluate the impact of each risk factor on the project delays and cost overruns. The risk analysis model is run for a total of 70 months, which corresponds to the construction duration of the Addis-Djibouti railway construction project. The simulation results of the impact of risk factors on project duration and cost are shown in Figures 5.14 -5.15 and Table 5.5.

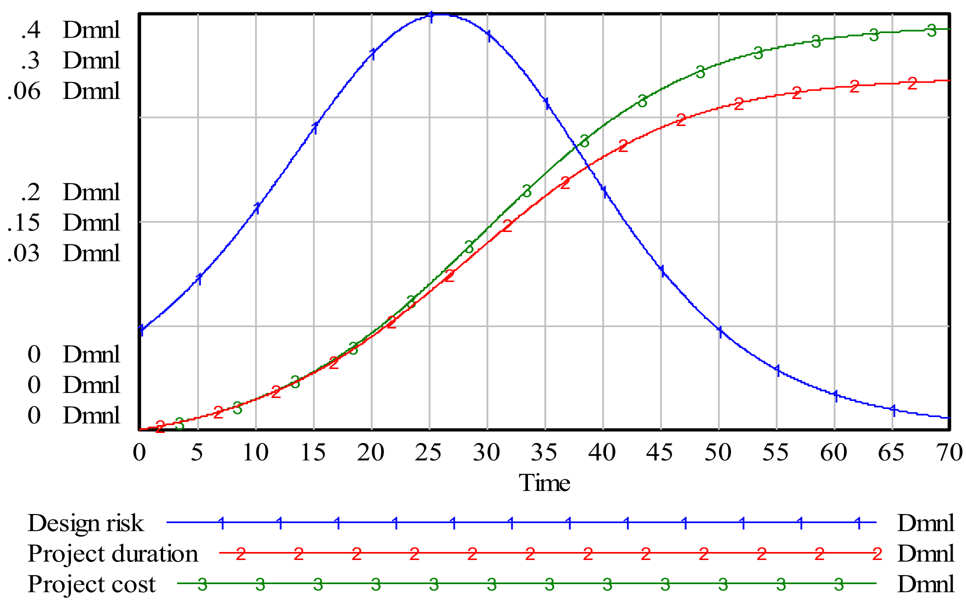

Figure 5.14. Simulation patterns for design risk, project duration and cost

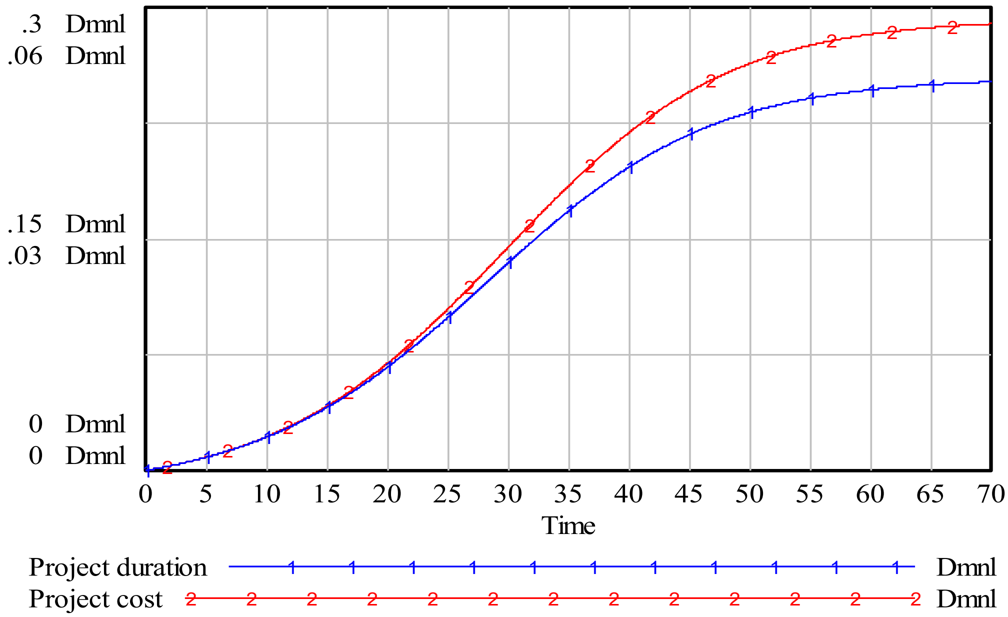

Figure 5.15. Simulation patterns of design risk impacts on project duration and cost

Figure 5.14 shows the dynamic simulation patterns of the stock variables, indicating the behavior trends for design risk, project cost, and project duration, whereas Figure 5.15 displays the impact of design risks on project delay and cost overrun.

According to Figure 5.15, the impact level of design risks on project duration ranges from 0 to 0.2517, while the impact on cost ranges from 0 to 0.0579 over a 70-month simulation period. The Figure shows S-shaped growth which can be generated by a shift in dominance from a positive to a negative feedback loop. The positive loops (reinforcing loops) dominate the system and the graph increases exponentially up to the 24th month, after the 24th month, the negative feedback loops (balancing loops) take control of the system and shift the graph to approach the value of 0.2517 for delays and 0.0579 for cost overruns. These values indicate that the percentages of project delay and cost overruns at the end of the simulation period are 25.17 and 5.79 respectively.

Table 5.5 provides detailed dynamic results of risk variables within the design risk analysis model generated by Vensim's built-in function. The maximum and minimum values of the simulation results of the design risk analysis model are also shown in the Table. These values also represent the mean and standard deviation for each variable. A variable with zero standard deviation indicates that the value of the factor is assumed to be constant over the simulation period or the factor is identified as an exogenous variable.

Table 5.5. Summary of simulation results for design-related risk assessment model

Design risk factors	Minimum	Maximum	Average	Standard deviation
Change in design risk	0.0014	0.0387	0.0195	0.0125
Change in government regulation	0.0166	0.0166	0.0166	0.0000
Change in project cost	0.0001	0.0016	0.0008	0.0005
Change in project time	0.0003	0.0071	0.0036	0.0023
Change in schedule pressure	0.0000	0.0008	0.0004	0.0003
Change in scope of work	0.0413	0.0992	0.0740	0.0210
Client's lack of experience	0.0247	0.0247	0.0247	0.0000
Contractor's lack of experience	0.0705	0.0705	0.0705	0.0000
Cost underestimation	0.0812	0.0812	0.0812	0.0000
Design change	0.0508	0.0740	0.0639	0.0084
Design delay	0.0789	0.0889	0.0845	0.0037
Design error	0.0354	0.0451	0.0409	0.0035
Design-related risk	0.0113	0.3991	0.1966	0.1305
Fatigue	0.0325	0.0624	0.0494	0.0109
Hire employees	0.0325	0.0624	0.0494	0.0109
Inadequate site investigation	0.0748	0.0748	0.0748	0.0000
Incomplete design	0.0015	0.0015	0.0015	0.0000
labor cost	0.0325	0.0624	0.0494	0.0109
Lack of coordination	0.0719	0.0719	0.0719	0.0000
Mitigation rate	0.0000	0.0492	0.0206	0.0166
overtime	0.0325	0.0624	0.0494	0.0109
Poor labor productivity	0.1044	0.1343	0.1214	0.0109
Project cost	0.0000	0.0579	0.0327	0.0210
Project duration	0.0000	0.2517	0.1463	0.0909
Redesign	0.0861	0.1190	0.1048	0.0120
Schedule pressure	0.0325	0.0624	0.0494	0.0109
Unsafe project location	0.0007	0.0007	0.0007	0.0000

5.5.1.1. Scenario analysis for design risk assessment model

Scenario analysis is performed to analyze the impact of future events on system performance by considering some alternative outcomes, i.e., scenarios, and to present different options for future development paths that lead to different outcomes and corresponding impacts. Scenario analysis is the process of predicting the expected value of key performance indicators over a specific period, the occurrence of various situations, and the relevant changes in the values of system parameters in an uncertain environment. Scenario analysis can be used to estimate system behavior in response to unexpected events, and to explore changes in system performance in theoretical best-case (optimistic) or worst-case (pessimistic) scenarios.

Three different scenarios on the effect of design-related risk factors were conducted to understand the impact of the variables on project delays and cost overruns:

- Scenario A: Effect of exogenous variables on project delay and cost overrun: This scenario considers whether a change in the impact of exogenous risk factors (government regulations and laws, unsafe location, client and contractor experience on similar projects) would affect project delay and cost overruns.
- Scenario B: Influence of design change: the scenario investigates the effect of design changes on the project objectives.
- Scenario C: Effect of design errors: this scenario also aims to figure out the impact of design errors on railway project delays and cost overruns.

The effects of design change, design errors, and exogenous factors are simulated with a 20% increase and a 20% decrease of the factors in question. The conditions for each scenario are shown in Table 5.6.

Table 5.6. Scenario conditions for design risk assessment model

Scenarios	Dataset	Description
Scenario A: Effect of exogenous risks	Current situation	
	High risk	Degree of increase: +20% of the current situation
	Low risk	Degree of decrease: -20% of the current situation
Scenario B: Effect of design change	Current situation	
	High risk	Degree of increase: +20% of the current situation
	Low risk	Degree of decrease: -20% of the current situation
Scenario C: Effect of design errors	Current situation	
	High risk	Degree of increase: +20% of the current situation
	Low risk	Degree of decrease: -20% of the current situation
Time bounds for model		Initial time: 0 Final time: 70 months
Timestep		0.0625

a) Effect of exogenous variables on project delay and cost overrun

Exogenous variables refer to variables whose causes are outside the model and whose role is to explain other variables or results in the model. These variables are identified in the modeling process and boundary determination. The dynamic simulation was carried out to investigate the effects of exogenous parameters on duration and cost. The exogenous variables for this design risk analysis model are changes in government regulations and laws, unsafe project location, and client's and contractors' experience on similar projects. Figures 5.16 and 5.17 show that the rise of the initial values of these exogenous risks by 20% leads to an increase in project duration and project cost by 10.01% and 23.49% from their base runs respectively, while the 20% decrease results in 10.45% and 21.42% decrease in time and cost respectively.

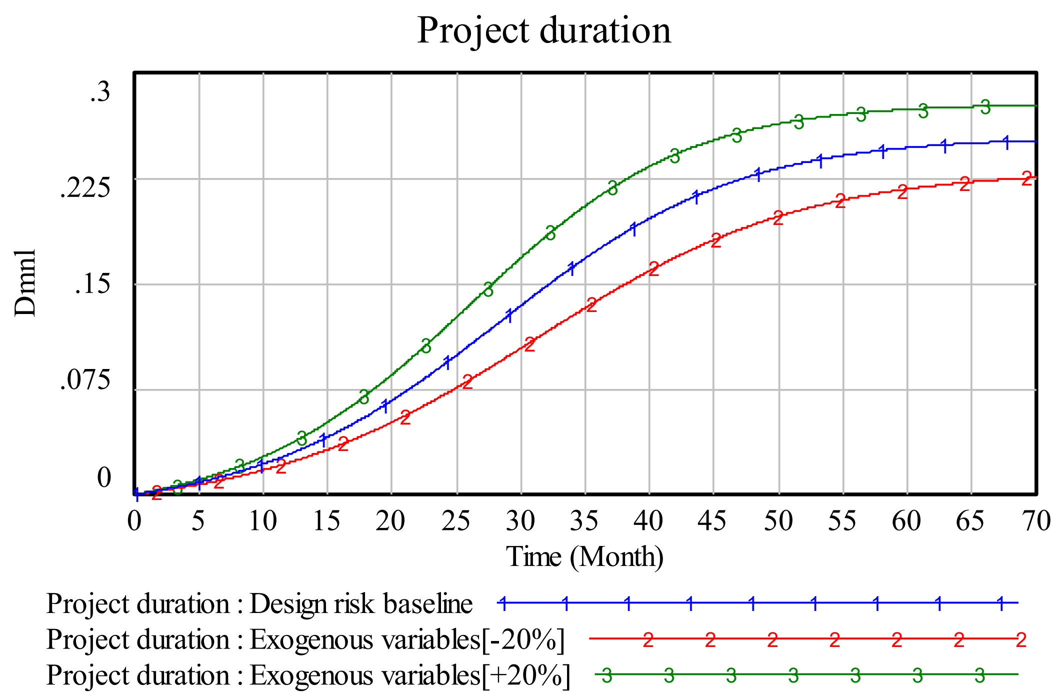

Figure 5.16. Effect of exogenous risks on project duration

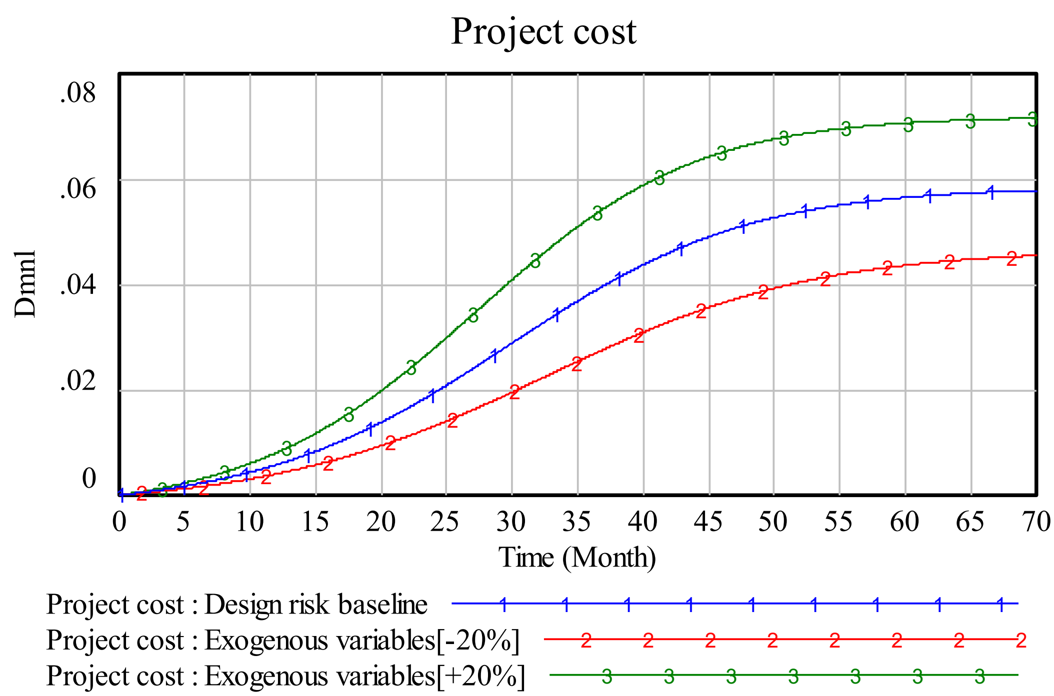

Figure 5.17. Effect of exogenous risks on project cost

b) Effect of design change

Design change in construction projects is one of the main risks that occur frequently. These risks mainly arise from changes in the scope of work by the clients. The majority of change orders are at the client's request and are typically in the form of design changes (Love et al., 2010). Changes in design necessitate rework, which increases the risk of design-related risks impacting cost and time. Figures 5.18 and 5.19 depict the effect of design changes on railway construction project duration and cost. The simulation results show that changing the design has a significant impact on the project objectives. Within the 20 percent risk range of design change, the risk of delay ranges from 0.2132 to 0.2924, while the risk of cost overrun ranges from 0.0453 to 0.0728 within the project timeline. This indicated a 20% increase in design change increased project duration and cost by 16.17% and 25.73%, and a 20% decrease in the risk decreases the duration and cost by 15.30% and 21.76 % respectively.

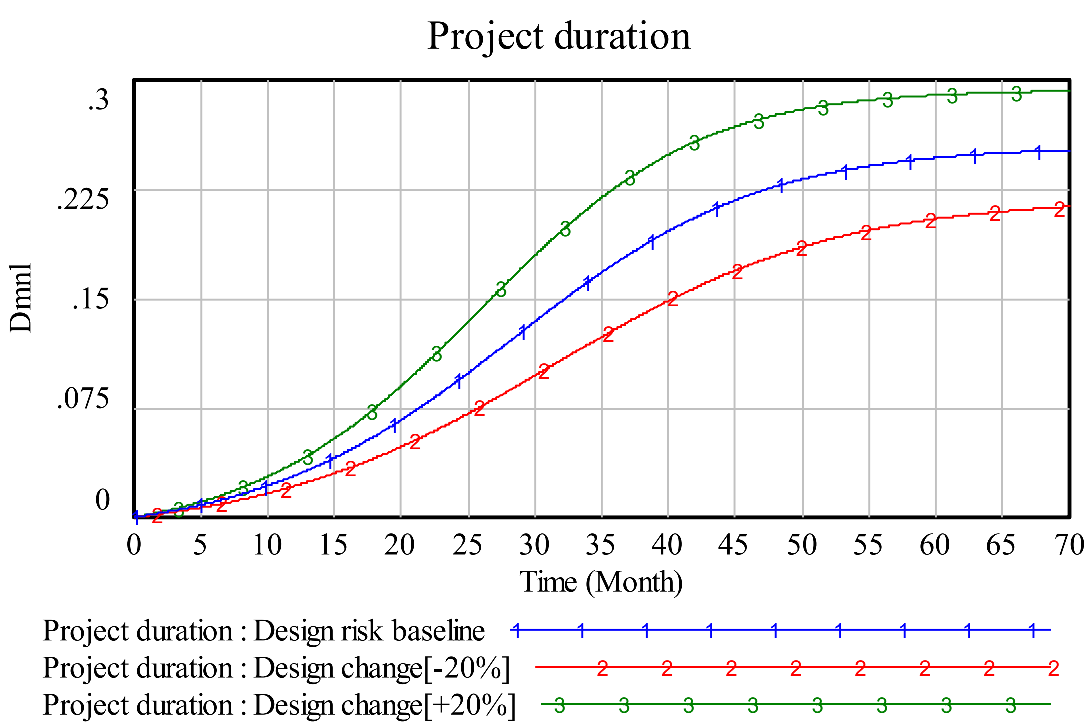

Figure 5.18. Effect of design change on project duration

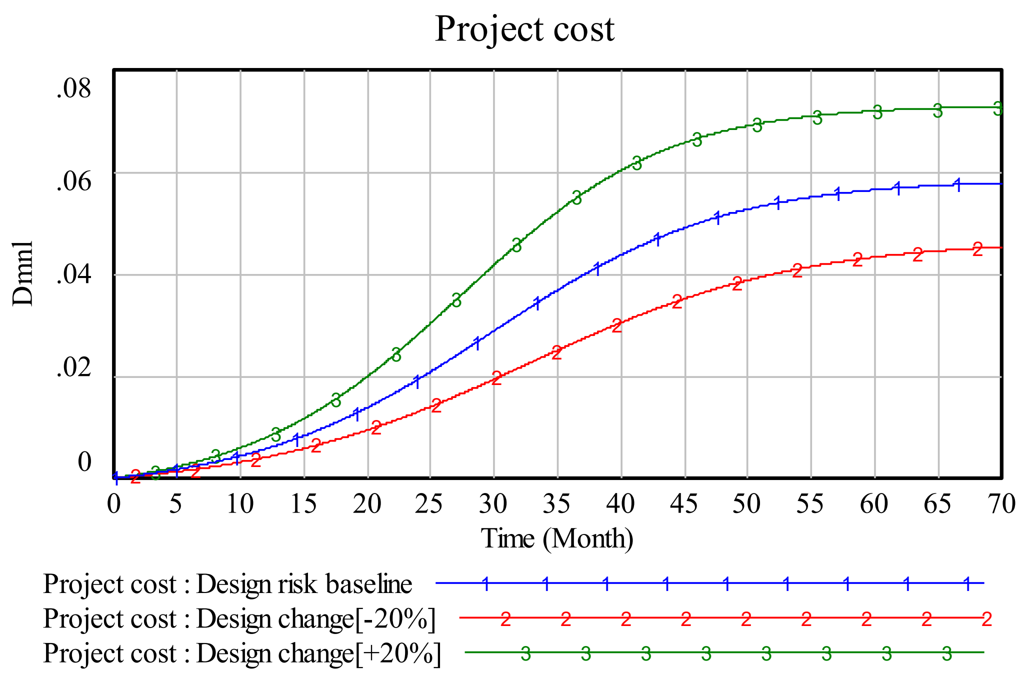

Figure 5.19. Effect of design change on project cost

c) Effect of design errors

Errors have become an inextricable part of the design process in construction and engineering projects (Love et al., 2012). In the construction industry, design errors are unavoidable, and they have a negative impact on project management efficiency and effectiveness and can adversely affect cost, schedule, and safety (Love et al., 2012; Peansupap & Ly, 2015). According to the simulation results of the model, design errors have a significant impact on the project objectives. Within the 20% design error risk range, the delay risk ranges from 0.2982 to 0.3538, while the project cost overrun risk ranges from 0.0617 to 0.083 within the project timeline. The 20% rise in design error risk leads to an increase in delays and cost overruns by 9.61% and 15.03%, respectively, whereas the 20% reduction in design errors leads to a 9.61% and 14.66% drop in delay and cost overrun. Figures 5.20 and 5.21 show how varying the risk level of design errors affects the duration and cost of the project.

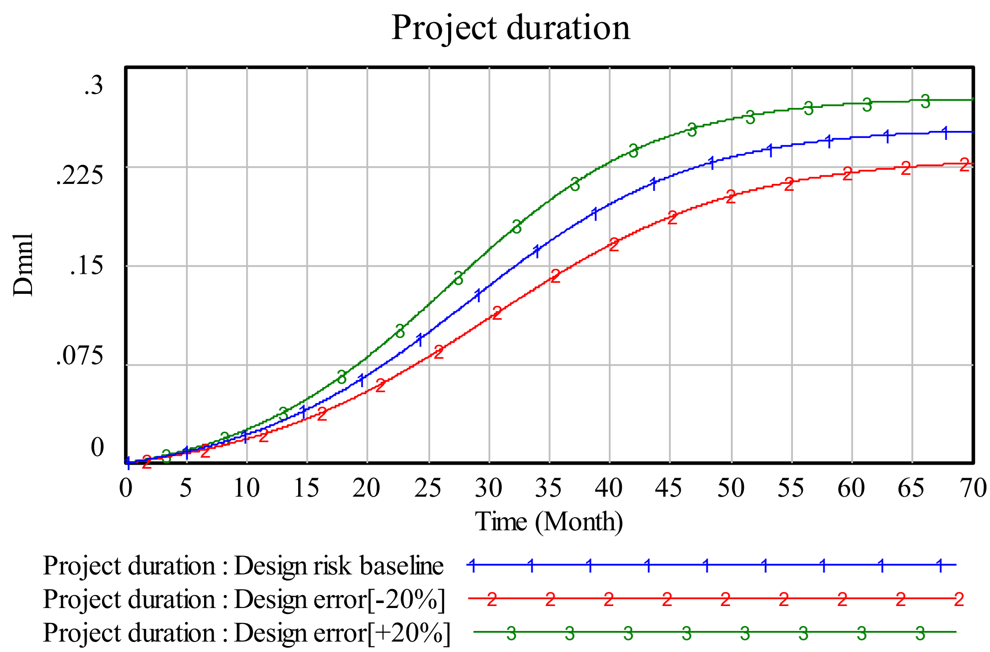

Figure 5.20. Effect of design errors on project duration

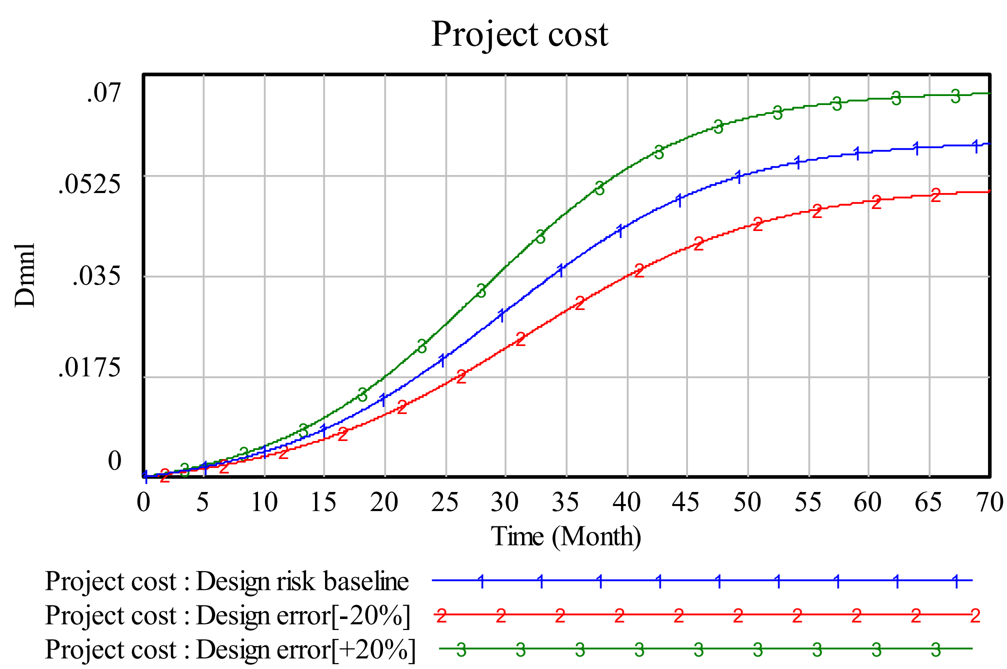

Figure 5.21. Effect of design errors on project cost

In summary, design change and exogenous variables (unsafe project location, change in government regulations, client's and contractors' lack of experience) have a significant impact on project delays and cost overruns. According to the simulation results, increasing the design change and exogenous risks by 20% increases the risk of project delays by 16.17% and 10.01%, and cost overruns by 25.73% and 23.49% respectively. Moreover, design errors contribute a significant effect on the project objectives of the case project. As a result, of the three scenarios, Scenarios A and B are the most influential cases, having the greatest impact on the objectives of the railway construction project.

5.5.2. Construction risk assessment model

The construction-related risk assessment model is simulated to assess the impact of each risk factor on the project objectives (project duration and project cost). The risk analysis model is run for a total of 70 months, which corresponds to the length of construction of the Addis-Djibouti railway project. The results of the impact of risk factors on project duration and project cost are shown in Figures 5.22 and 5.23.

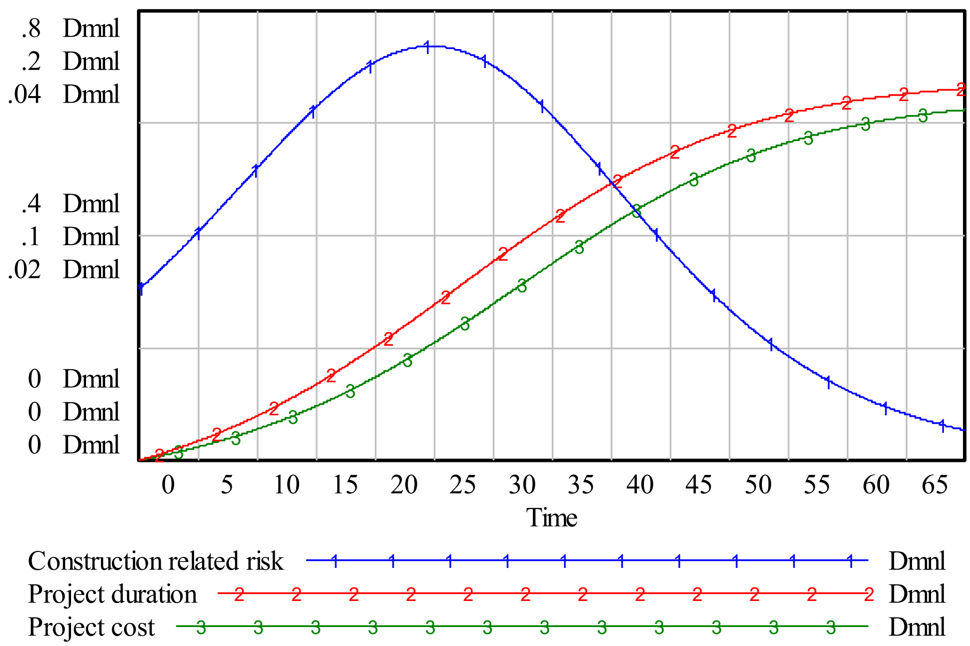

Figure 5.22. Simulation patterns of construction risk and their impact on duration and cost

According to Figures 5.22 and 5.23, the impact of construction risks on project duration ranges from 0 to 0.1654, and the impact on cost ranges from 0 to 0.0312 over a 70-month simulation period. These graphs depict S-shaped growth, which can be caused by a dominance shift from a positive to a negative feedback loop. The positive loops (reinforcing loops) dominate the system and the graph increases exponentially until the 16th month, after which a negative feedback loop (balanced loop) controls the system and shifts the graph to near the value of 0.1654 for delays and

0.0312 for cost overruns. These values indicate that the percentages of project delay and cost overruns at the end of the simulation period are 16.54 and 3.12, respectively.

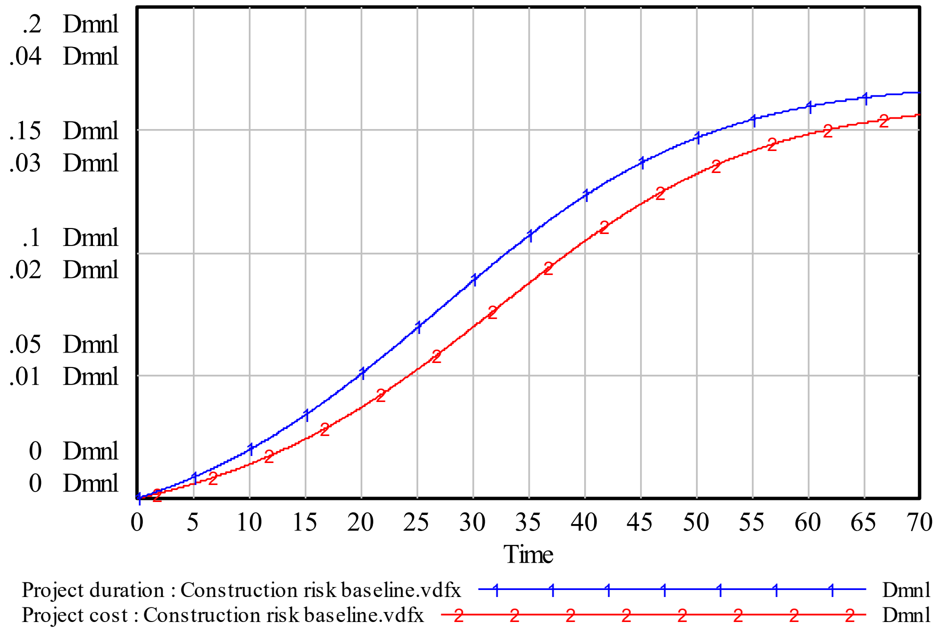

Figure 5.23. Simulation patterns of project duration and cost of construction risk assessment model

The dynamic simulation results of the system variables within the risk assessment model are also shown in Table 5.7. This table contains detailed dynamic results for all risk variables in the construction-related risk assessment system generated by Vensim's built-in functions. These values represent the minimum, maximum, mean, and standard deviation for each variable. A variable with zero standard deviation indicates that the value of the factor is assumed to be constant over the simulation period or the factor is identified as an exogenous variable.

Table 5.7. Summary of simulation results for construction risk analysis model

Construction risk factors	Minimum	Maximum	Average	Standard deviation
Construction-related risk	0.0538	0.7371	0.4311	0.2252
Contractor's lack of experience	0.0705	0.0705	0.0705	0.0000
Equipment damage	0.0000	0.8519	0.5538	0.2393
Equipment maintenance	0.0273	0.0273	0.0273	0.0000
Errors during construction	0.0186	0.0574	0.0379	0.0140
Force majeure	0.0010	0.0010	0.0010	0.0000
Inadequate skill of the workforce	0.0306	0.0306	0.0306	0.0000
Labor productivity	0.0631	0.1533	0.1078	0.0326
Management of material and personnel	0.0273	0.0273	0.0273	0.0000
Mitigation rate	0.0000	0.0572	0.0292	0.0185
Poor site management & supervision	0.0109	0.0109	0.0109	0.0000
Productivity of plant & equipment	0.0211	0.9042	0.5916	0.2498
Political instability	0.0007	0.0007	0.0007	0.0000
Project cost	0.0000	0.0312	0.0167	0.0107
Project duration	0.0000	0.1654	0.0959	0.0561
Project planning and control	0.0273	0.0273	0.0273	0.0000
Rework	0.0784	0.1172	0.0977	0.0140
Schedule pressure	0.0325	0.1227	0.0772	0.0326
Shortage of equipment	0.0000	0.0312	0.0167	0.0107
Unsafe project location	0.0007	0.0007	0.0007	0.0000

5.5.2.1. Scenario analysis for construction risk assessment model

Two scenarios on the effect of construction-related risk factors were conducted to understand the impact of the variables on delays and cost overruns (Table 5.8):

- Scenario A: Effect of exogenous variables on project delay and cost overrun: This scenario considers whether a change in the level of exogenous risks (force majeure, inadequate skill of workforce, political instability, and contractors' experience on similar projects) would affect project delay and cost overruns.

- Scenario B: Effect of quality of construction: the impact of construction quality on the objectives is assessed in this scenario.

Table 5.8. Case study conditions for construction risk assessment model

Case study	Data set	Description
Case A: Effect of exogenous risks	Current situation	
	High risk	Degree of increase: +20% of the current situation
	Low risk	Degree of decrease: -20% of the current situation
Case B: Effect of construction quality	Current situation	
	High risk	Degree of increase: +20% of the current situation
	Low risk	Degree of decrease: -20% of the current situation
Time bounds for model		Initial time: 0 Final time: 70 months
Timestep		0.0625

a) Effect of exogenous variables

The dynamic simulation was carried out to investigate the effects of exogenous parameters on construction risks, project cost risks, and project duration risks. The exogenous variables for this construction-related risk analysis model are force majeure, unsafe project location, and contractors' experience on similar projects.

The effect of a 20% increase in exogenous risks on project duration ranges from 0.1588 to 0.1716, while the effect on cost ranges from 0.0274 to 0.0350. This means that a 20% increase in the risk of exogenous variables results in a 3.75 percent increase in project duration and a 12.18 percent increase in project cost. Moreover, the 20% decrease in the risks decreases the impact on delays and cost overruns by 4 percent and 12.18 percent respectively. Figures 5.24 and 5.25 show the simulation results of the impact of change in magnitude of exogenous risks on delays and cost overruns of the construction risk assessment model.

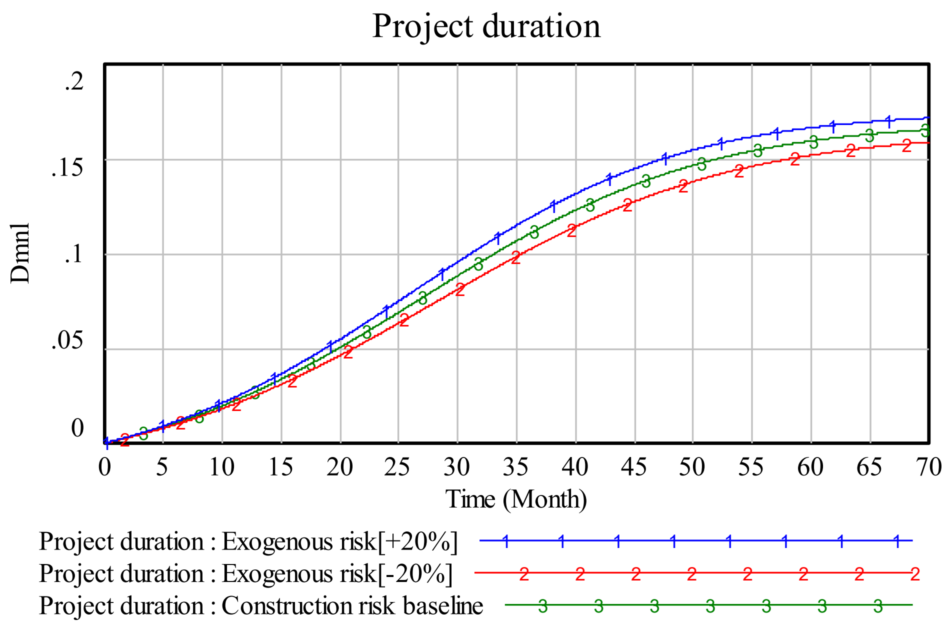

Figure 5.24. Effect of construction exogenous risks on project duration

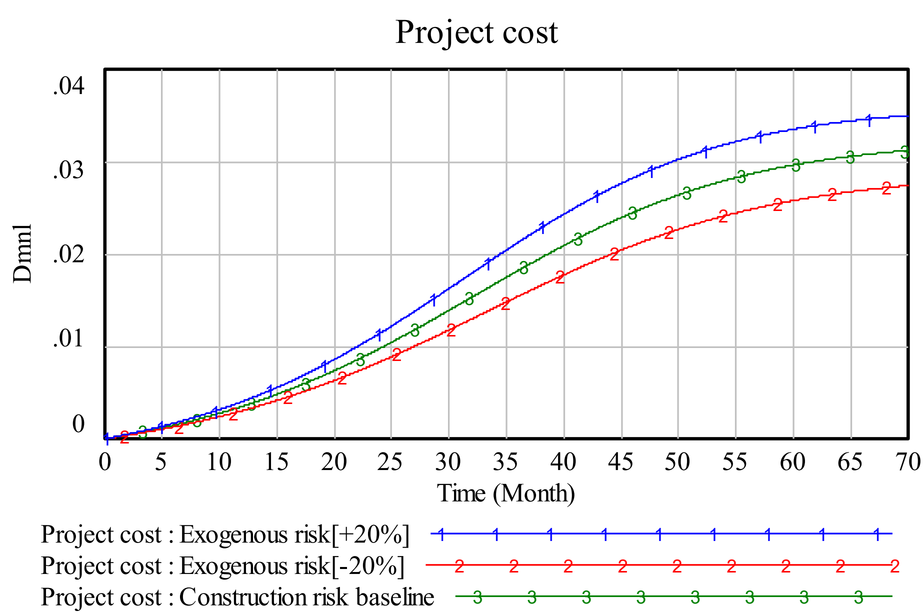

Figure 5.25. Effect of construction exogenous risks on project cost

b) Effect of quality of construction

The quality of railway construction is mainly determined by the quality of construction materials, the errors of construction, and the effective quality testing procedures. These contributing risk factors have a greater impact on the quality of the construction.

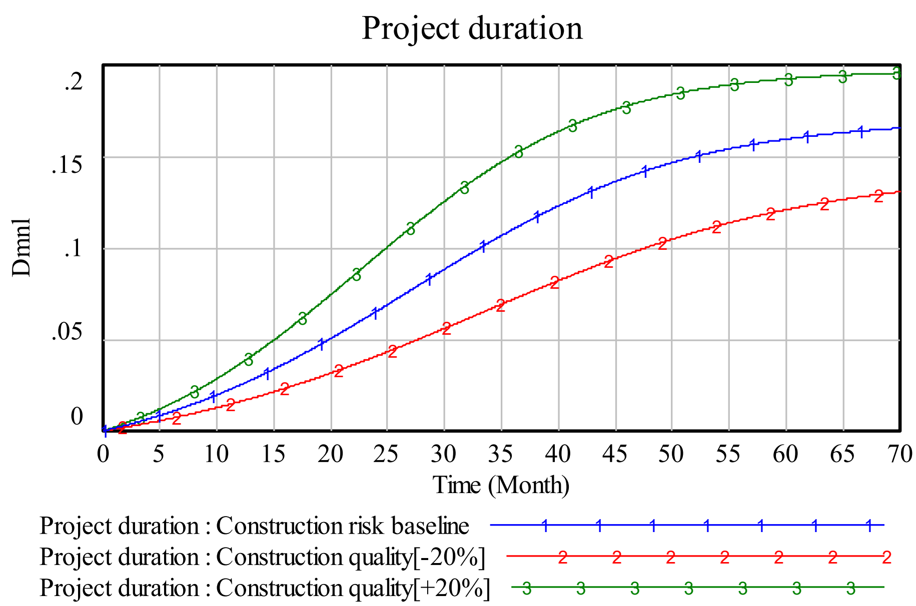

Figure 5.26. Effect of quality of construction duration

The model was simulated with a 20% increase and a 20% decrease in the risk of construction quality and the impacts of the risk on delays and cost overrun were analyzed. The result revealed that a 20% increase in the risk increases the risk of delay from 0.1654 to 0.1956, and increases the risk of cost overruns from 0.0312 to 0.04. Similarly, a 20% decrease in risk resulted in a decrease in delays to 0.1306 and a decrease in cost overruns to 0.0222. This means a 20% increase in the risk leads to an 18.26% increase in project duration and a 28.21% increase in project cost. Likewise, a 20% risk reduction reduces the baseline project duration and cost by 21.04% and 28.85%, respectively. Hence, the result of the simulation of the construction-related risk analysis model shows that the change in risk of construction quality affects delays and cost overruns (Figures 5.26 and 5.27).

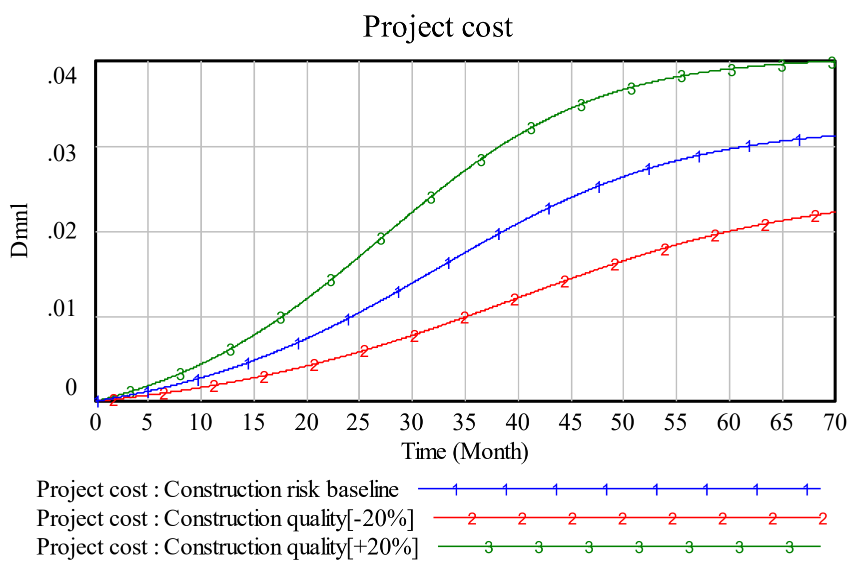

Figure 5.27. Effect of quality of construction on cost

5.5.3. Project management risk assessment model

Simulation of the management-related risk analysis model is carried out to analyze the impact of each risk factor on the project objectives (project duration and project cost). The results of the impact of risk factors on project duration and project cost are illustrated in Figures 5.28 and 5.29.

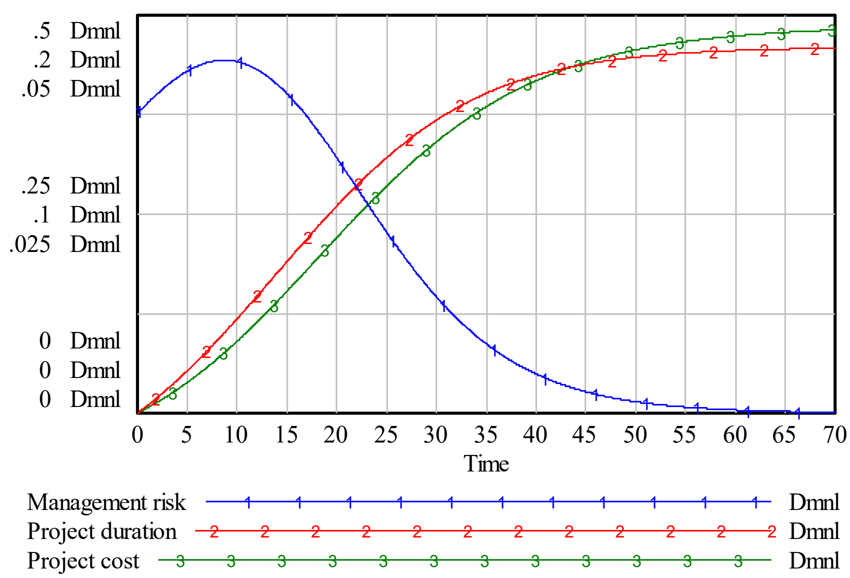

Figure 5.28. Simulation patterns for management-related risk, cost and duration

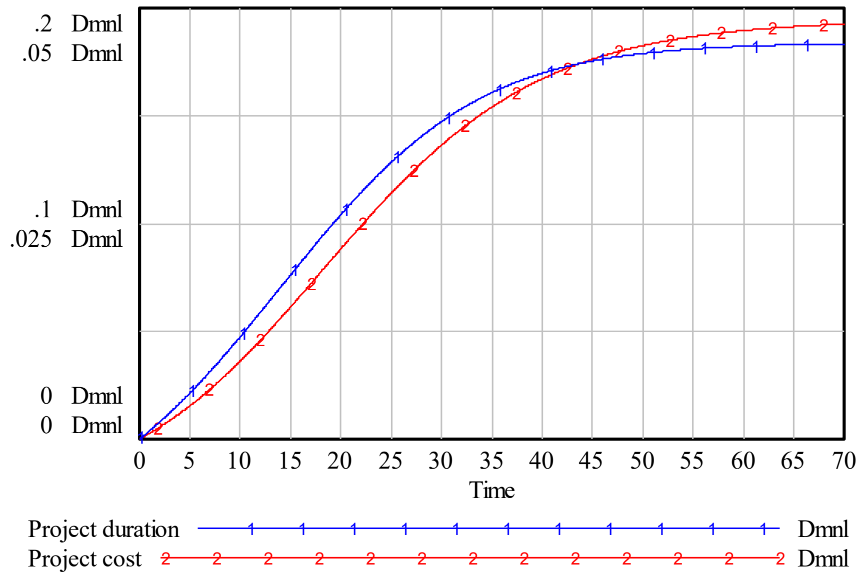

Figure 5.29. Simulation patterns of duration and cost of management risk assessment model

The dynamic simulation outputs for all system variables within the risk assessment model are also shown in Table 5.9. The Table displays detailed dynamic results of risk variables within the project management risk assessment system generated by Vensim's built-in function.

Table 5.9. Summary of simulation results of the management-related risk assessment model

Management-related variables	Minimum	Maximum	Average	Standard deviation
Client frequent interference	0.0115	0.0115	0.0115	0.0000
Client's financial difficulty	0.0000	0.0159	0.0106	0.0052
Client's lack of experience	0.0247	0.0247	0.0247	0.0000
Contractors' lack of experience	0.0705	0.0705	0.0705	0.0000
Coordination among parties	0.0880	0.6630	0.2989	0.1626
Delay in decision-making by client	0.0817	0.0817	0.0817	0.0000
Dispute occurrence rate	0.0032	0.0169	0.0082	0.0039
Disputes among parties of the contract	0.0039	0.5789	0.2148	0.1626
Incomplete contract details	0.1723	0.7473	0.3832	0.1626
Management-related risk	0.0011	0.4435	0.1681	0.1707
Mistakes and discrepancies in contract documents	0.0934	0.6684	0.3043	0.1626
Payment delays	0.0353	0.0421	0.0399	0.0023
Project cost	0.0000	0.0481	0.0321	0.0159
Project duration	0.0000	0.1834	0.1320	0.0580
Project planning and control	0.0511	0.0511	0.0511	0.0000

5.5.3.1. Scenario analysis for management risk assessment model

In this risk assessment model, three scenarios on the effect of construction-related risk factors were conducted to understand the impact of the variables on delays and cost overruns

- Scenario A: Effect of exogenous variables on project delay and cost overrun: This scenario considers whether a change in the level of exogenous risks (client frequent interference, client's and contractors' experience on similar projects) would affect project delay and cost overruns.
- Scenario B: Effect of contract details: the impact of incomplete contract details on the objectives is assessed in this scenario.
- Scenario C: Effect of project planning and control: the impact of ineffective project planning on the objectives is assessed in this scenario.

The effects of incomplete contract details, project planning, and exogenous factors are simulated with a 20% increase and a 20% decrease of the factors in question. The conditions for each scenario are shown in Table 5.10.

Table 5.10. Case study conditions for management risk assessment model

Case study	Data set	Description
Case A: Effect of exogenous risks	Current situation	
	High risk	Degree of increase: +20% of the current situation
	Low risk	Degree of decrease: -20% of the current situation
Case B: Effect of incomplete contract details	Current situation	
	High risk	Degree of increase: +20% of the current situation
	Low risk	Degree of decrease: -20% of the current situation
Case C: Effect of project planning and control	Current situation	
	High risk	Degree of increase: +20% of the current situation
	Low risk	Degree of decrease: -20% of the current situation
Time bounds for model		Initial time: 0 Final time: 70 months
Time step		0.0625

a) Effect of exogenous risks of management-related risk model

The dynamic simulation was carried out to investigate the effects of exogenous risks on project duration and cost. The values of the management exogenous risk factors were varied by ±20% to examine their impact on project delay and cost overrun. The exogenous variables for this management-related risk assessment model are the client's frequent interference, the client's and contractors' lack of experience on similar projects.

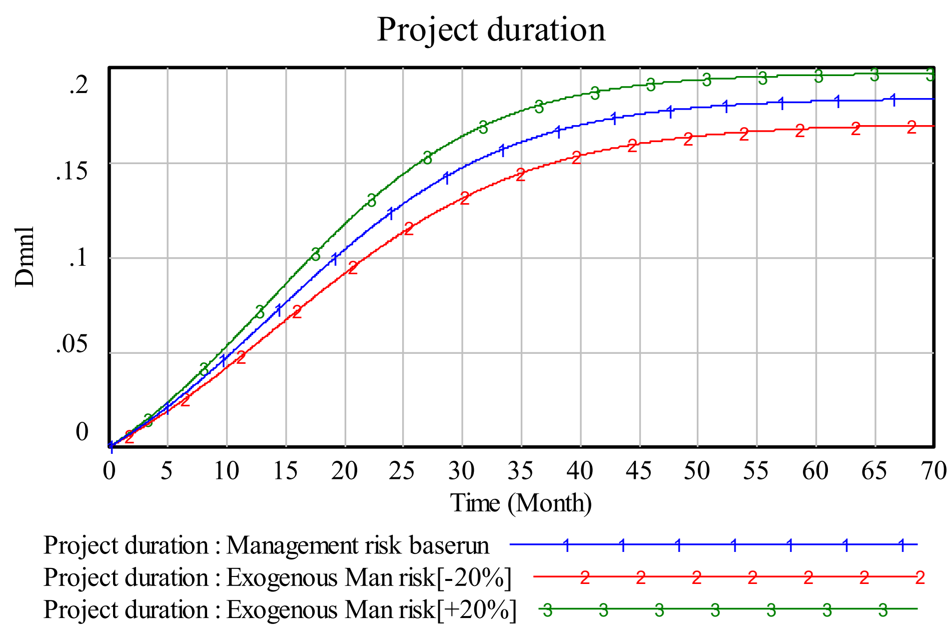

Figure 5.30. Effect of exogenous risks on the duration of management risk assessment model

The simulation results (Figures 5.30 and 5.31) indicate that the increase in exogenous risk factors increases project duration and cost. A 20% increase in exogenous risks increased the risk of project delay and cost overrun to 0.1969 and 0.0587, whereas a 20% decrease in exogenous factors reduced delay and cost overrun to 0.1696 and 0.0388, respectively. In other words, a 20% increase in the risk of exogenous variables increases project duration by 7.36% and project cost by 22.04 %. Likewise, a 20% decrease in the risks reduces project duration and cost by 7.52% and 19.33%, respectively.

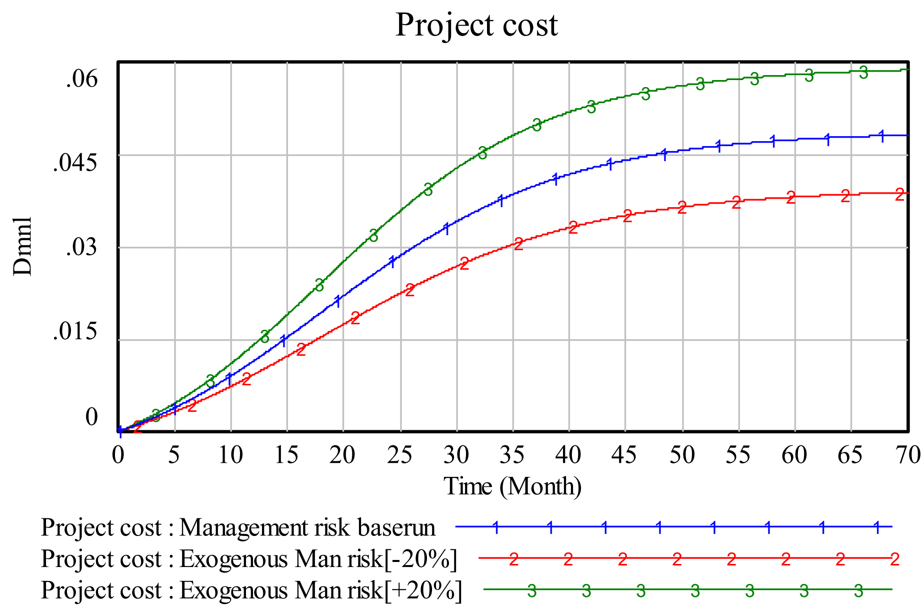

Figure 5.31. Effect of exogenous risks on the cost of management risk assessment model

b) Effect of incomplete contract details

The effects of risk factor incomplete contract details are also evaluated by changing the magnitude of the factor by ±20 percent and the simulation of the effect of the risk was analyzed based on its impact on project duration and cost.

Simulation results of the scenario analysis showed that a ± 20% change in the risk of incomplete contract details affects delays and cost overruns (Figures 5.32 and 5.33). When the risk level is increased by 20%, the project delay and cost overrun increase to 0.1897 and 0.061 respectively. Similarly, decreasing the risk factor by 20% reduces delay and cost overrun to 0.1765 and 0.0361, respectively. In other words, a 20% increase in the risk of incomplete contract details in the project management risk assessment model increases the baseline risk of project delays and cost overruns by 3.44% and 26.82%, respectively, whereas a 20 % decrease in the risk decreases the baseline risk of delay and cost overrun by 3.76% and 24.95%, respectively.

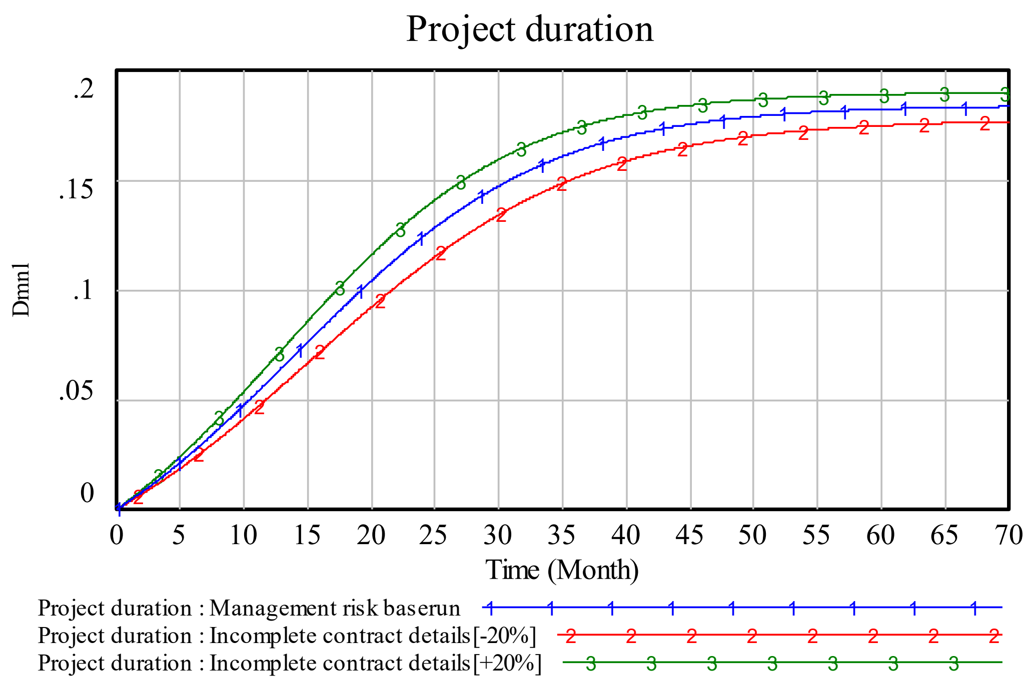

Figure 5.32. Effect of incomplete contract details on project duration

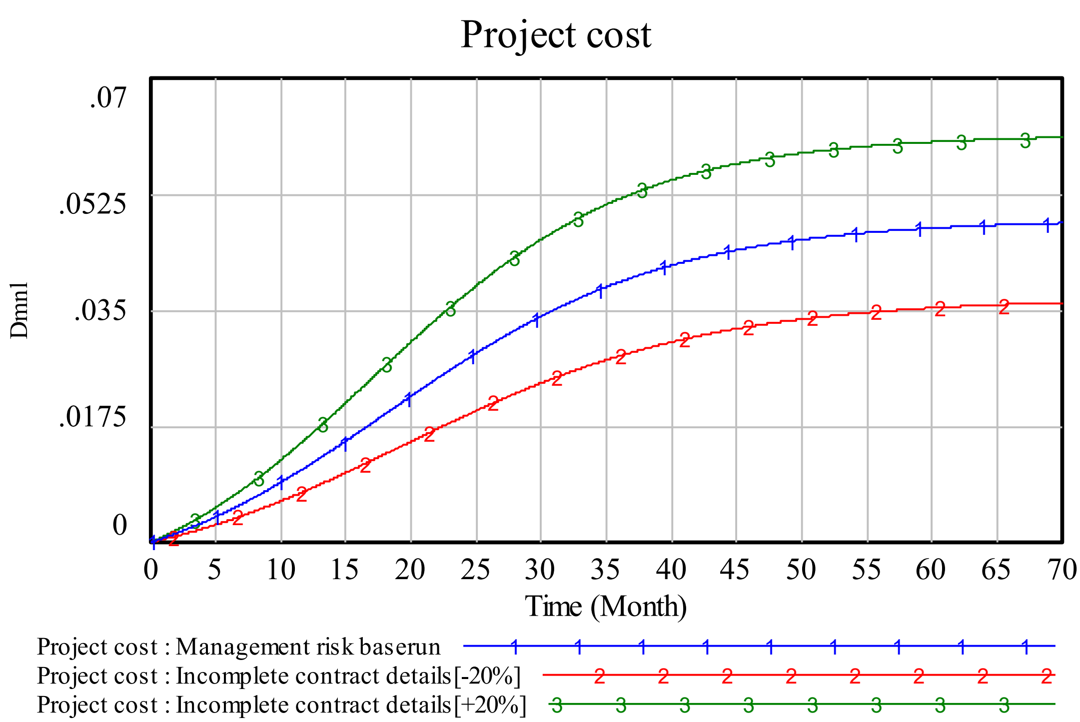

Figure 5.33. Effect of incomplete contract details on project cost

c) Effect of project planning and control

In this scenario, the risk of project planning and control is varied by 20% to investigate the impact on project progress and, ultimately, project time and cost. The relationship between the risk factor “project planning and control” with project duration and cost is depicted in Figures 5.34 and 5.35.

The simulation result (Figure 5.34) indicates that the increase/decrease in the risk factor increases/ decreases in project duration. The Figure revealed that the increase in the risk of project planning and control by 20% results in an increase in base run project duration to 0.1854, whereas a decrease in the risk level of project planning and control by 20% decreases the risk of project duration to 0.1812.

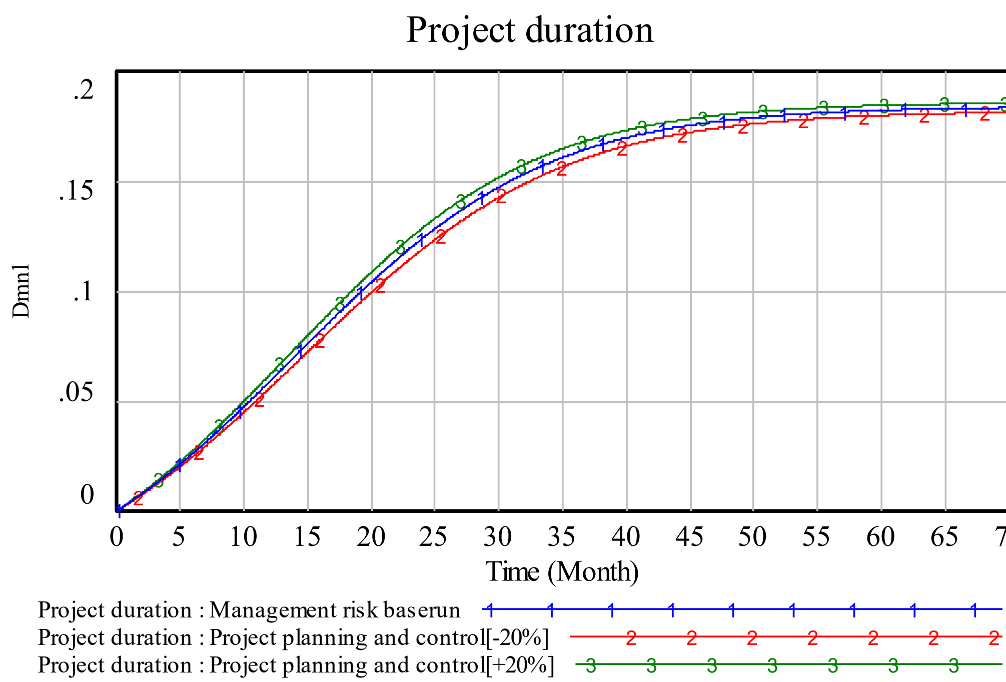

Figure 5.34. Effect of project planning and control on project duration

The project cost is also affected by the percentage change in the magnitude of project planning and control risk (Figure 5.35). An increase in the magnitude of the risk factor by 20% increases the risk of cost overrun to 0.0511 and a decrease in the magnitude of the risk decreases the cost overrun to 0.0451.

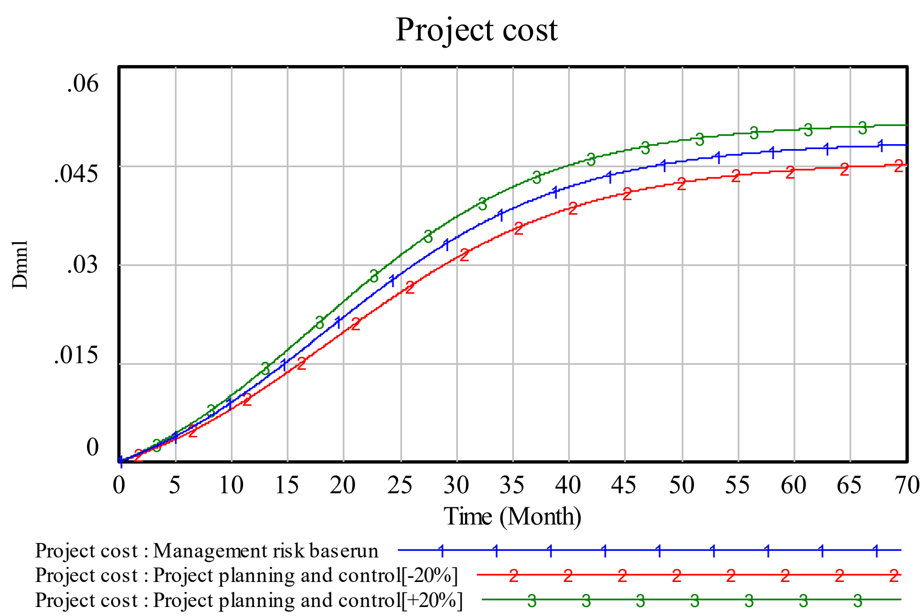

Figure 5.35. Effect of project planning and control on project cost

5.6. Model testing

In this research, the design, construction, and management risk assessment models are tested using different techniques. These verification and validation tests are performed on these models to check the appropriateness of the risk assessment models for railway construction projects. Several standard validation tests were performed to build confidence in the model, including structural and behavioral tests. The types of tests used in this project risk assessment model as part of the verification and validation process are described below.

a) Boundary adequacy

Boundary adequacy tests assess the appropriateness of the model boundary for the purpose at hand. It is done at the first stage of railway construction project risk assessment model development (Sterman, 2000). It is used to test whether the significant risk factors are endogenous to the risk analysis model. It is found that the significant risk factors are included in the model as shown in the boundary diagrams (Figures 5.1-5.3).

b) Structure assessment

Structure assessment tests ask whether the model is consistent with knowledge of the real system relevant to the purpose (Sterman, 2000). It is the process of directly comparing the structure of a model to the structure of the real system that the model represents (Forrester & Senge, 1980). The causal relationships between risk factors in each model were developed from the available knowledge and literature review of risk management of railway construction projects. The risk analysis model was examined and analyzed by professionals in railway construction projects to validate its structure as well as the logical interconnection of project risks to the real system.

c) Dimensional consistency

This modeling test uses Vensim software to verify the dimensional consistency between each equation and the actual system. The software has a built-in feature to notify the user if there is a dimensional inconsistency. In addition, each mathematical equation used to formulate the stock-flow diagram is tested by the researcher to ensure that the variables and constants used are dimensionally consistent. The risk assessment model for the railway construction project is validated for dimensional consistency.

d) Extreme condition

Models should be robust in extreme conditions. Robustness under extreme conditions refers to the model's ability to behave realistically no matter how extreme the inputs are (Sterman, 2000). A model is tested to determine whether it behaves plausibly under a wide range of conditions to enhance the utility of the model for studying policies that take the system beyond historical ranges of behavior (Forrester & Senge, 1980). The behavior of the project risk assessment models was tested under extreme conditions, and the generated behavior is compared to the expected real system behavior. The models were simulated with extreme values of variables to test their robustness under the extreme conditions and structure of the model. The outputs were plausible for the extreme and unlikely combinations of levels of variables in the system. For these models, exogenous variables for each model were set to 0 and 100% to test robustness to extreme conditions. The output of each model showed realistic trends, so there were no significant changes in behavior beyond the normal trend.

e) Integration error tests

SD models are usually formulated in continuous time and solved by numerical integration (Sterman, 2000). Integration error tests refer to selecting an appropriate method of integration and time step that the outcome of the simulation model should not be sensitive to the choice. The time step should ensure that the simulation results do not change significantly when the time step is halved. The risk assessment models were tested for different time steps of 0.5, 0.25, 0.125, and 0.0625 and the results exhibited insensitivity to the final time step or integration method. Euler's integration method and a time step of 0.0625 were selected as this yields a better result during the simulation of the risk analysis models.

f) **Sensitivity analysis**

Sensitivity analysis is a technique for determining how the influence of uncertainty in one or more input variables might lead to uncertainties in the output variables (Pichery, 2014). It is used to evaluate the model's robustness by ensuring that uncertainties and estimating errors do not have a substantial impact on the model's overall behavior (Sterman, 2000).

Parameter sensitivity is often evaluated as a series of tests performed to examine how a change in parameter values causes a change in the dynamic behavior of stocks (Breierova & Choudhari, 2001). Typically, the sensitivity of a model should be tested for a parameter range that is larger than the expected uncertainty around the baseline parameter value. A probability distribution that characterizes the likely values of each parameter is determined to perform a Monte Carlo analysis. For this research, the random uniform distribution, with any number between the minimum and maximum values being equally likely to occur, is used for the sensitivity analysis. Monte Carlo multivariate sensitivity is carried out by randomly selecting a set of numbers from bounded domains. The distribution for each specified parameter is sampled and the resulting values are used in a simulation to perform a multivariate analysis (Ventana Systems, 2007).

Vensim system dynamics software is used to investigate the impact of risk analysis model variables on project delays and cost overruns. The software runs the model with the provided values of each parameter, either one at a time (univariate testing) or all at once (multivariate testing). The software selects a value at random from the distributions for each parameter before simulating the model. The trajectories obtained from a large number of simulations provide dynamic confidence bounds for each variable (Sterman, 2000).

This research is concerned with numerical and behavior mode sensitivity analysis. Numerical sensitivity occurs when a change in assumptions changes the numerical values of the results, and behavior mode sensitivity occurs when a change in assumptions changes the patterns of behavior generated by the model (Sterman, 2000). By varying the impact level of the risk factors, the results are examined for changes in numerical values and the pattern of their effect on delays and cost overruns in the railway construction project. The results of the sensitivity analysis show confidence bounds of 50%, 75%, 95%, and 100% for each risk assessment model.

5.6.1. Sensitivity analysis for design risk assessment model

In this study, sensitivity analysis was conducted on the design risk assessment model to achieve optimal system control and determine which factors have a large impact on the system's behavior. The design risk assessment model for the railway construction project was evaluated using multivariate sensitivity analysis, and the results were validated over a wide variety of inputs to ensure that the numerical values did not vary considerably. The model's generated modes of behavior were also examined for notable differences.

In multivariate sensitivity analysis, all parameters are taken into account and their overall effect on project delays and cost overruns is evaluated. Changes in government regulations and laws, contractors' lack of experience, unsafe project location, and client's lack of experience are all assumed to have random uniform distributions between the minimum and maximum values of each input parameter.

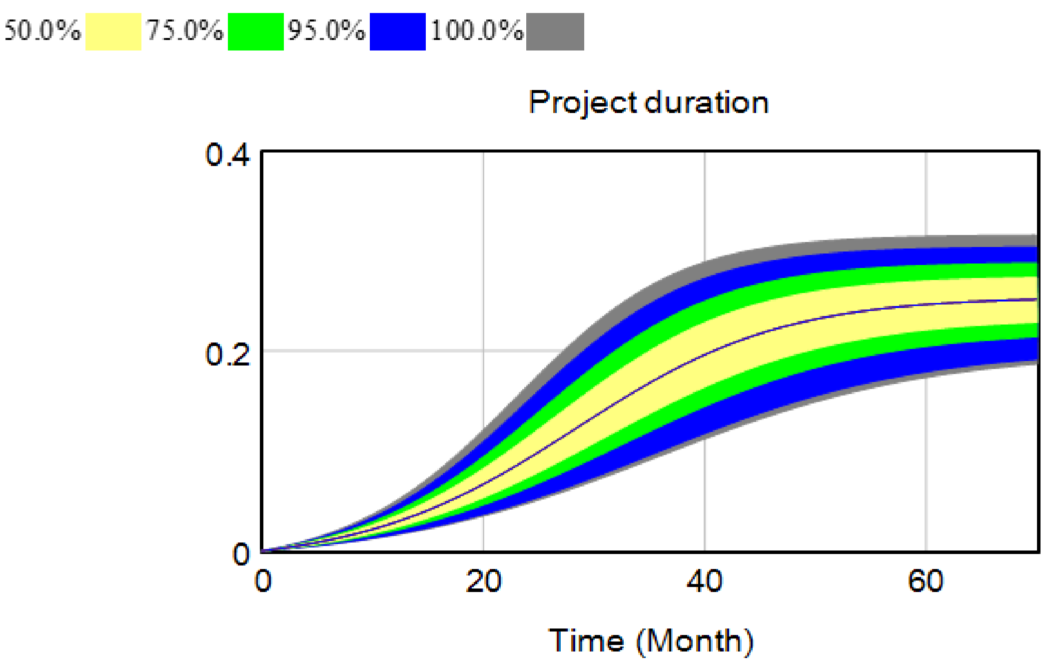

Figure 5.36. Sensitivity analysis of the effect of design parameters on project duration

The results of a Monte Carlo simulation of the design risk analysis model are shown in Figures 6.25 and 6.26. The Figures depict the 50%, 75%, 95%, and 100% confidence limits for project delays and cost overruns in a sample of 200 simulations. There is a 50% probability that the project delays will be between 0.229 and 0.273 and a 95% probability that the delays will be between 0.192 and 0.304 (Figure 5.36). Likewise, the probability of the impact of the design-related risk factors on project cost overruns is 50% in the range of 0.045 to 0.071, 75% between 0.039 and 0.082, and 95% between 0.032 and 0.089 (Figure 5.37).

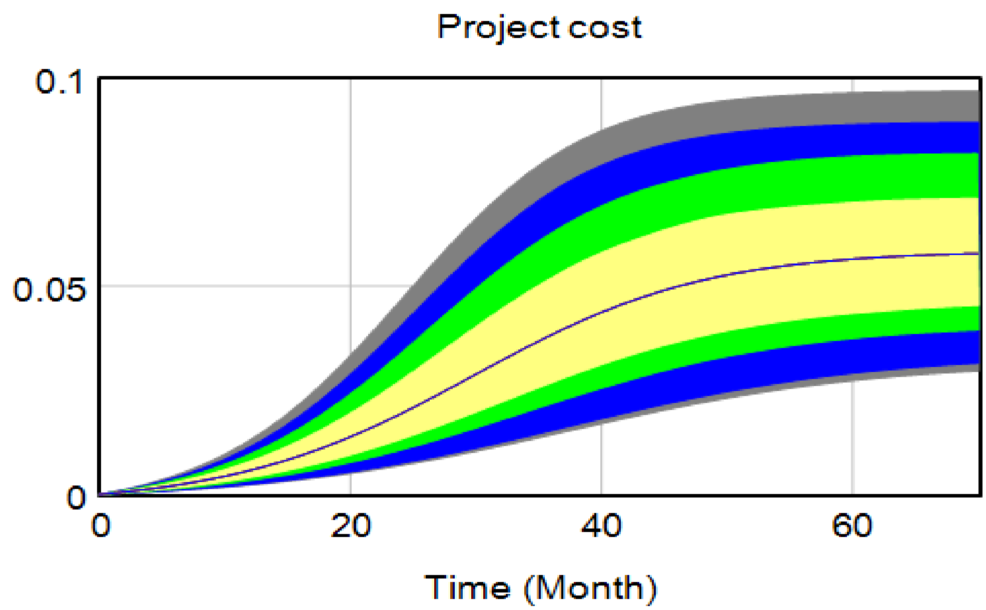

Figure 5.37. Sensitivity analysis of the effect of design parameters on project cost

5.6.2. Sensitivity analysis for construction risk assessment model

In this risk assessment model, force majeure, political instability, inadequate skill of workforces, and contractors' lack of experience in similar projects are considered for sensitivity analysis. The ranges of the values of these parameters are assumed to have random uniform distributions between the minimum and maximum values of each input parameter.

The effects of construction risk factors on project cost and time are simulated, and the results of the sensitivity analysis are depicted in Figures 5.38 and 5.39. The construction risk assessment model was evaluated using multivariate sensitivity analysis, and the results were validated over a wide range of inputs to ensure that the numerical values and behavior modes did not vary significantly.

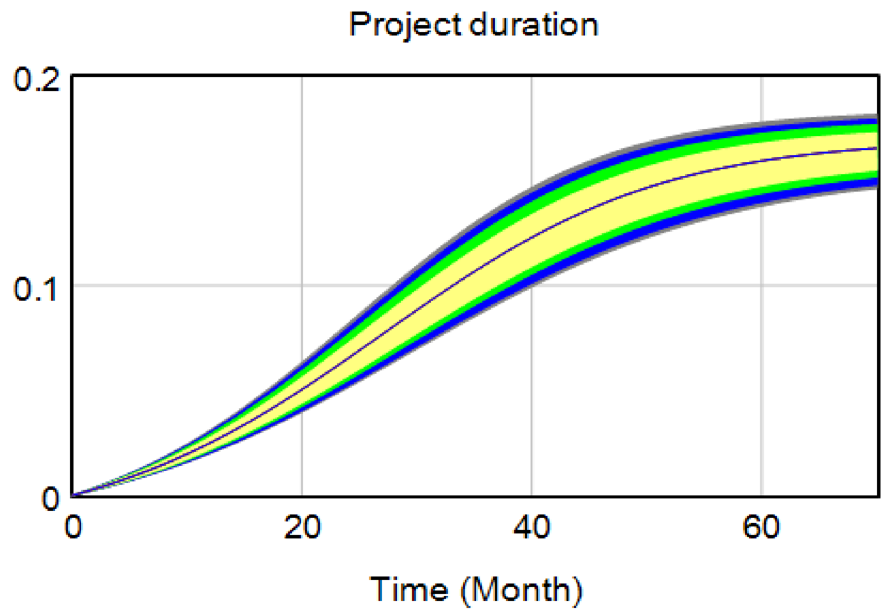

Figure 5.38. Sensitivity analysis of the effect of construction parameters on project duration

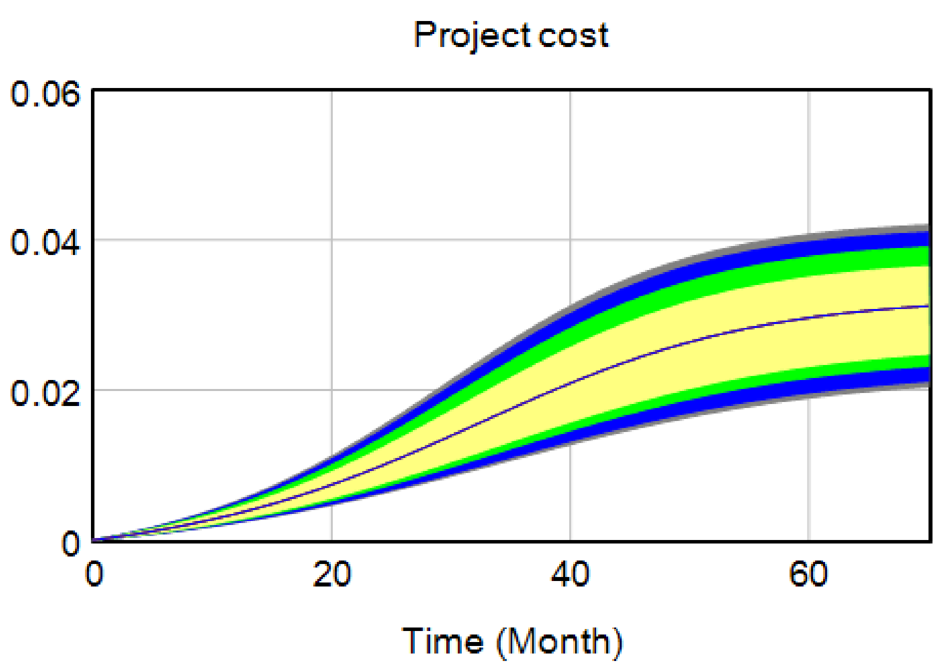

Figure 5.39. Sensitivity analysis of the effect of construction parameters on project cost

Figure 5.38 shows the 50%, 75%, 95%, and 100% confidence limits for project delays in a sample of 200 simulations. There is a 50% probability that the construction risk factors cause project delays between 0.155 and 0.173 and a 95% probability that the delays will be between 0.148 and 0.179. The sensitivity analysis for project cost is shown in Figure 5.39 with different confidence intervals. The effect of construction risk factors on project cost lies between 0.025 and 0.036 within a 50% confidence interval, between 0.023 and0.039 within 75% confidence interval, and between 0.021 and 0.041 within 95% confidence interval.

5.6.3. Sensitivity analysis for management risk assessment model

For the management risk assessment model, the client's frequent interference, the client's lack of experience, and contractors' lack of experience in similar projects were selected as parameters for sensitivity analysis.

The change in the risk of project delay was analyzed by changing the magnitude of management risk assessment model parameters within their ranges and the result of the sensitivity analysis is depicted in Figure 5.40. The result of the analysis showed that the risk of project delays lies between 0.168 and 0.195 within 50% confidence interval, between 0.161 and 0.202 within 75% confidence interval, and between 0.156 and 0.211 within 95% confidence interval.

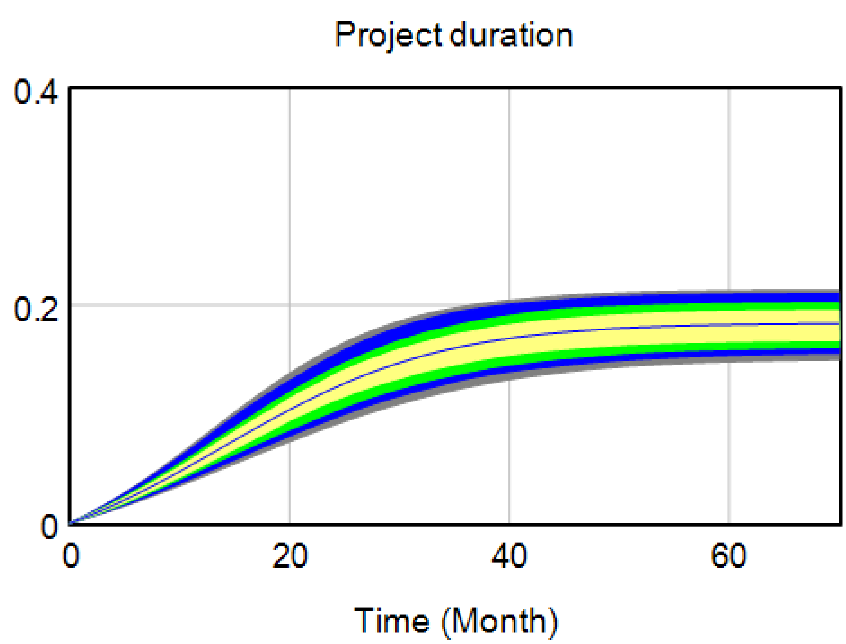

Figure 5.40. Sensitivity analysis of the effect of management parameters on project duration

Likewise, the effect of the parameters on cost overrun was assessed and the result of the sensitivity analysis is shown in Figure 5.41. The confidence intervals of the effect of risks on cost overruns showed that there was 50% confidence that the project experience cost overrun within the range of 0.038and 0.059, 75% confidence between 0.034 and 0.066, and 95% confidence between 0.031 and 0.073.

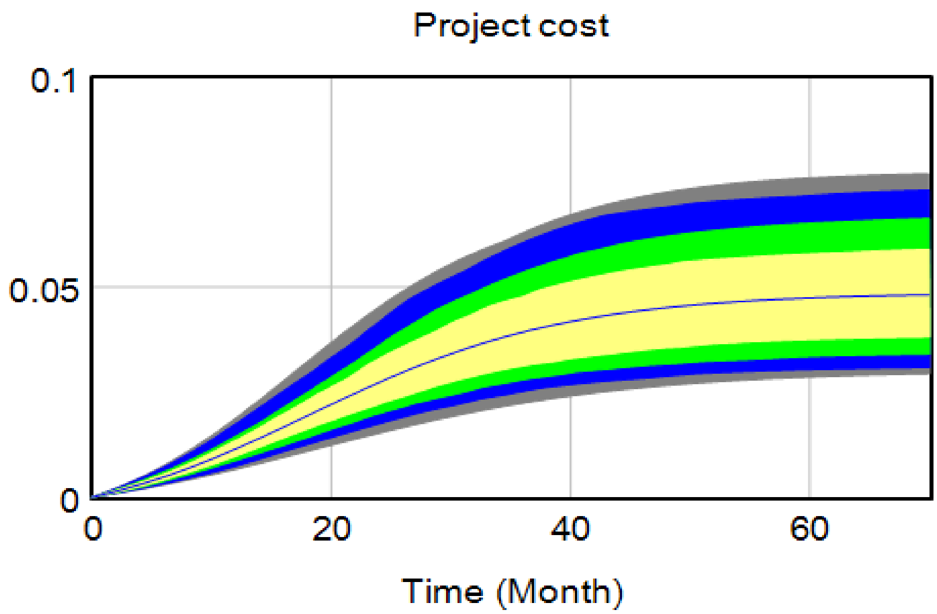

Figure 5.41. Sensitivity analysis of the effect of management parameters on project cost

From the results of the sensitivity analysis, it can be concluded that the effect of the parameters on a change in the project delay differs from the effect on a change in the project cost overrun. Changing parameter values can alter the appearance of graphs showing system behavior. However, there were no significant changes in the behavior of the system in all parameters. Therefore, the risk assessment models are generally insensitive to parameter changes.

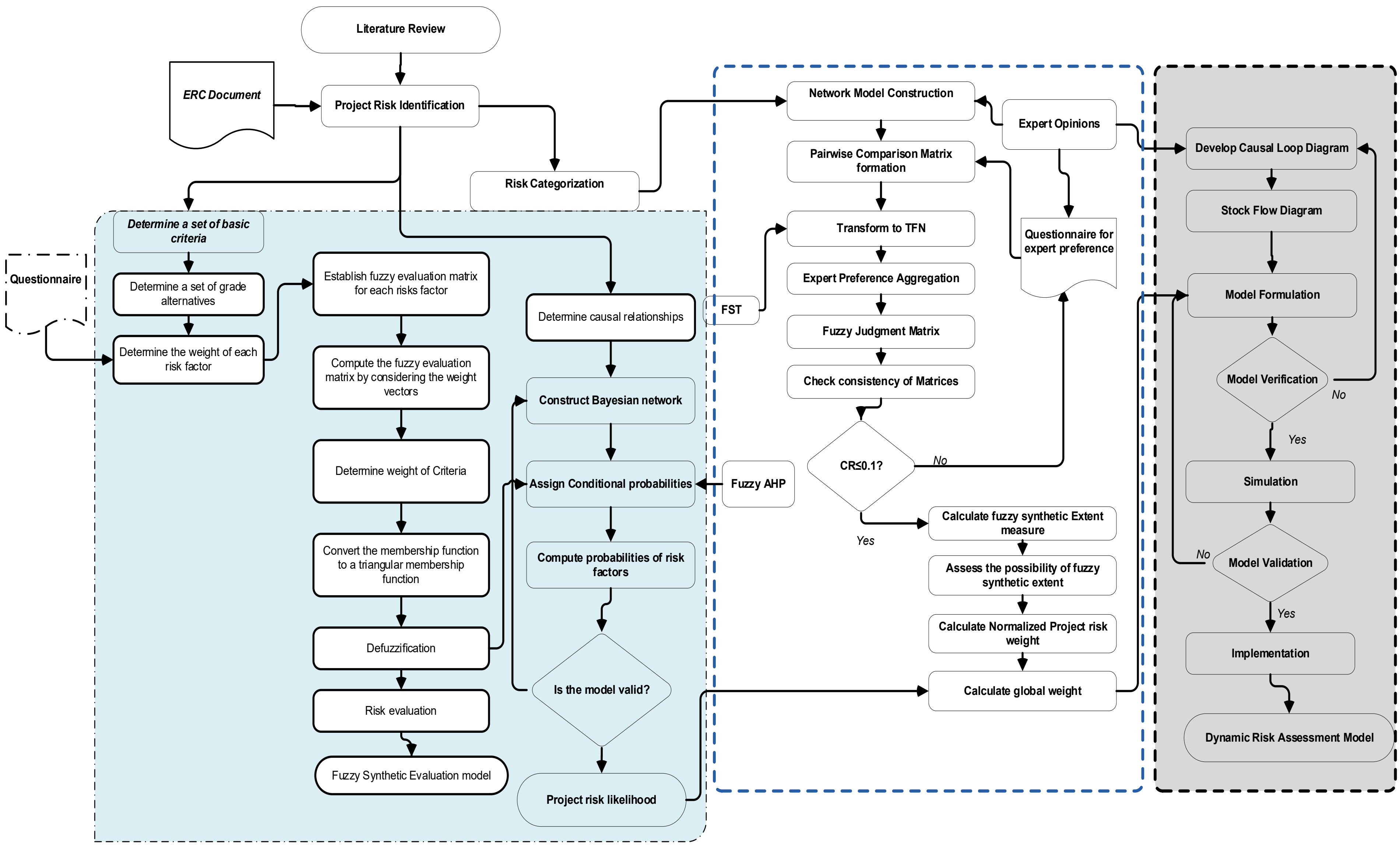

Figure 5.42. Integrated approach for railway construction project risk assessment

Based on the aforementioned approaches, a hybrid risk assessment approach that comprises fuzzy synthetic evaluation, Bayesian belief network, fuzzy ANP, and system dynamics was developed to analyze the impacts of risks on delays and cost overruns of railway construction projects. The hybrid risk assessment approach can address uncertainty due to subjective judgment, unavailability and scarcity of data, interrelationships between risks and dynamics, and feedback effects of risks of railway construction projects. Figure 5.42 depicts the overall flowchart of the proposed approach. The framework demonstrated the flow of methods and their relationships in determining the impact of project risks on delays and cost overruns while taking into account uncertainty, interdependence, and the dynamic and feedback effects of risks.

5.7. Summary

This chapter describes the development of a risk assessment model using system dynamics which provides a novel risk assessment tool for railway construction projects. The outputs from the previous chapter (i.e., FSE, BBN, and fuzzy ANP results of risk likelihood and impact on time and cost) were used as inputs for the project risk analysis model development using system dynamics. The integrated dynamic risk assessment model was verified and implemented on the case project. The proposed risk analysis model can solve the problems faced in conventional project risk analysis approaches.

6. CONCLUSIONS AND RECOMMENDATIONS

This chapter summarizes the key research findings related to the risk assessment approach for the railway construction project. It demonstrates that the proposed project risk assessment approach provides decision-makers and project managers with insight into the significant risk factors that affect project delays and cost overruns, as well as a technique for dealing with dynamic and interrelated project risks. It also discusses the limitations of the research and potential future research directions.

6.1. Conclusion

Railway construction projects are risk-prone endeavors that experience project delays and cost overruns. The delays and cost overruns are caused by a variety of risk factors that impede the success of railway construction projects. Since project risk factors affect project objectives, it is essential to assess the risks to enhance the overall performance of the construction project. Thus, an effective risk management approach is needed to alleviate the impact of risks on project time, cost, and related objectives. Despite the various studies on delays and cost overruns, there is a lack of comprehensive risk assessment for Ethiopian railway construction projects. Therefore, to ensure the success of the project, appropriate and effective risk assessment methods for railway construction projects are needed.

Although there is a lot of literature on risk assessment of railway construction projects, attention to dynamic and feedback effects and the interdependence of project risk is quite limited. To bridge this gap, the researcher conducted a literature review to identify potential risk factors that have a significant impact on railway construction project delays and cost overruns. Forty-two risk factors were identified through existing literature review, reports of ERC, and expert opinions. These potential risk factors were classified into six main categories: design, construction, management, resource, contractual and legal, and external factors.

Based on the identified risks, questionnaires were developed to rate the likelihood of occurrence of risks and their impact on project time and cost. In order to determine the likelihood of risks, an integrated approach of FSE and BBN was developed based on expert opinions. An FSE approach was employed to determine the likelihood of risks and handle the uncertainty, data unavailability, and vagueness in subjective judgments, while the BBN approach was implemented to develop a network that helps to determine the probability of occurrence of risks taking interrelationships among project risks into account. Expert judgments on probabilities (prior and conditional probabilities) and causality relationships among the identified project risk factors were used to develop the BN for risk assessment of the railway construction project. The result of the analysis revealed that risk factors related to design, construction, and management have a significant impact on the occurrence of delays and cost overruns in railway construction projects.

To determine the impact of risks on project time and cost, a network structure was established to create a mutual influence between risk factors using ANP. The network comprises the mutual dependency among main categories (design, construction, management, resource, contractual and external risks) and individual risk factors of the railway construction project. Fuzzy logic was integrated with ANP to address the uncertainty, unavailable data, and vagueness of expert opinions during rating interdependencies of risk factors and categories. Fuzzy logic was used to convert linguistic data into fuzzy numbers to account for the impact of risks on time and cost. The application of FST to the subjective judgment process has successfully addressed the uncertainty and ambiguity that arise from expert opinion. It has been discovered that calculating risk ratings has greatly aided in determining the degree of severity of risk that must be controlled for the construction project to be completed successfully.

The results of fuzzy ANP showed that contractors' lack of experience corresponded to the highest risk rating that contribue to the overall project risk. Right-of-way and quality of construction have been found to have the second and third position based on the overall project risk impact on delays and cost overruns. Similarly, incomplete contract details, construction errors, and payment delays by the client have acquired the fourth, fifth, and sixth position as per the overall project risk ratings on the case railway construction project.

Conventional risk management tools are ineffective in analyzing systemic interrelationships and dynamic and feedback effects of risks of railway construction projects. The SD approach fills in the gaps and provides a unique analysis in which project risks and their impact on project objectives are explicitly considered and quantified. Thus, to deal with the dynamic and feedback impact of construction project risks on project cost and duration, this research presented an SD approach for railway construction project risk assessment.

Following the identification and categorization of risks, CLDs were used to develop the interrelationships between these project risks. The quantitative dynamic risk assessment models have been developed from the CLDs by incorporating the mathematical relationships between the risk factors into each model. The project risk assessment models were simulated to analyze the impact of various risks on project time and cost. During the simulation period, the extent of risks associated with design, construction, and management and their impact on project objectives were determined. The dynamic simulation patterns and results showed that design-related risks tend to dominate and cause project cost and time overruns, followed by construction and management-related risks.

The performance and validity of the proposed integrated SD model were evaluated using various verification and validation tests. The results of these tests demonstrated the effectiveness of the proposed project risk assessment approach in determining the impact of risks on project time and cost.

Applying this integrated approach as part of a railway construction project risk assessment system allows dynamic analysis of risks and their impact on project objectives. This model can be generalized and modified to apply to other construction projects to analyze the impact of risk on project cost and time.

6.2. Contributions of the research

The main contribution of the proposed research is the introduction of a novel approach for project risk assessment based on combining four techniques in a novel way to support risk analysis while considering the subjective characteristics of the risk-related data. In this research, fuzzy synthetic evaluation is integrated with the Bayesian belief network to provide a practical and thorough approach for determining the likelihood of risk occurrences and offers risk experts the ability to express the probability of the occurrence of risks linguistically. Moreover, fuzzy logic is combined with analytic network process to determine the impact of identified risks on project time and cost. These approaches help to determine inputs for the dynamic risk assessment model to analyze the dynamic and the feedback effects of project risks using system dynamics.

The expected contribution of this research can be summarized as follows:

- The proposed risk assessment model provides a novel risk assessment model for the body of knowledge by integrating fuzzy synthetic evaluation, Bayesian belief network, fuzzy analytic network process, and system dynamics approach.
- The application of fuzzy logic enables experts to convey information about the likelihood of occurrence and the impact of risks in linguistic terms, which is more convenient for professionals.
- The proposed approach facilitates the identification of critical risks and assists decision-makers in taking appropriate proactive measures.
- The dynamic risk assessment model helps experts consider the interrelationships between project risks and the dynamic as well as the feedback effects for effective project risk management.

6.3. Limitations and recommendations for future research

This research achieved the aim of providing an integrated risk assessment approach for railway construction projects. However, in certain circumstances, the complexity of the SD models as well as the application of the proposed methods are limited and require further study. The limitations of this research have been identified as follows:

- The data used in this study was obtained from expert opinions and literature reviews. However, further risk assessment using real-world data is needed to analyze the impact of risk on project objectives.
- Due to the incomplete data, a questionnaire survey was conducted to gather expert opinions and assess the impact of risk on the project time and cost of the Addis-Djibouti railway construction project. However, it is recognized that both the size of the sample and the subjective nature of the response can contribute to the bias. It would be useful to be able to test the proposed SD model in further case studies to demonstrate various risk aspects and applicability to different construction projects. Future comparative studies are needed to demonstrate the proposed method and validate the risk data obtained.

Based on the purpose and limitations of the study, the current study can be extended to the following aspects:

- This study seeks to analyze the impact of risk on delays and cost overruns in the Addis Ababa-Djibouti railway construction project. However, future research should consider the impact of risk on the project quality of railway construction projects.
- In addition, the proposed risk assessment method focuses primarily on identifying and analyzing risks associated with the Addis-Djibouti railway construction project. Furthermore, most techniques ignore the impact of implementing a response strategy. As a result, future research is needed to develop an integrated SD model capable of incorporating response strategies to determine the severity of critical risks on construction project objectives and evaluate the effectiveness of response strategies before implementation.
- Moreover, this research does not consider the impact of risk dynamics and feedback loops in determining the probability of project risk. Therefore, future studies need to consider both project risk dynamics and feedback effects when determining risk probabilities.

REFERENCES

Abd El-Karim, M. S. B. A., Mosa El Nawawy, O. A., & Abdel-Alim, A. M. (2017). Identification and assessment of risk factors affecting construction projects. *HBRC Journal*, *13*(2), 202–216. https://doi.org/10.1016/j.hbrcj.2015.05.001

Abdelgawad, M., & Fayek, A. R. (2010). Risk management in the construction industry using combined fuzzy FMEA and fuzzy AHP. *Journal of Construction Engineering and Management*, *136*(9), 1028–1036. https://doi.org/10.1061/(ASCE)CO.1943-7862.0000210

Abdelgawad, M., & Fayek, A. R. (2011). Fuzzy reliability analyzer: Quantitative assessment of risk events in the construction industry using fuzzy fault-tree analysis. *Journal of Construction Engineering and Management*, *137*(4), 294–302. https://doi.org/10.1061/(ASCE)CO.1943-7862.0000285

Abdollahzadeh, G., & Rastgoo, S. (2015). Risk Assessment in Bridge Construction Projects Using Fault Tree and Event Tree Analysis Methods Based on Fuzzy Logic. *ASCE-ASME Journal of Risk and Uncertainty in Engineering Systems Part B: Mechanical Engineering*, *1*(3), 1–12. https://doi.org/10.1115/1.4030779

Abdullah, A., & Nashwan, D. (2015). Development of a client-based risk management methodology for the early design stage of construction processes: Applied to the KSA. *Engineering, Construction and Architectural Management*, *22*(5), 493–515. https://doi.org/10.1108/ECAM-07-2014-0096

African Development Bank. (2015). Rail Infrastructure in Africa Financing Policy Options. In *African Development Bank group, Abidjan*.

Al-Bahar, J. F., & Crandall, K. C. (1990). Systematic Risk Management Approach for Construction Projects. *Journal of Construction Engineering and Management*, *116*(3), 533–546. https://doi.org/10.1061/(ASCE)0733-9364(1990)116:3(533)

Albin, S. (1997). *Building a System Dynamics Model Part 1: Conceptualization*. Massachusetts Institute of Technology.

Aliabadi, M. M., Pourhasan, A., & Mohammadfam, I. (2020). Risk modelling of a hydrogen gasholder using Fuzzy Bayesian Network (FBN). *International Journal of Hydrogen Energy*, *45*(1), 1177–1186. https://doi.org/https://doi.org/10.1016/j.ijhydene.2019.10.198

Amoatey, C. T., & Ankrah, A. N. O. (2017). Exploring critical road project delay factors in Ghana. *Journal of Facilities Management*, *15*(2), 110–127. https://doi.org/10.1108/JFM-09-2016-0036

Andrić, J. M., Wang, J., & Zhong, R. (2019). Identifying the critical risks in railway projects based on fuzzy and sensitivity analysis: A case study of Belt and Road Projects. *Sustainability*, *11*(5), 1–18. https://doi.org/10.3390/su11051302

APM. (2004). *Project risk analysis and management (PRAM) guide* (Second Ed.). Association for Project Management.

Asan, U., Soyer, A., & Serdarasan, S. (2012). A Fuzzy Analytic Network Process Approach. In C.

Kahraman (Ed.), *Computational Intelligence Systems in Industrial Engineering: With Recent Theory and Applications* (pp. 155–179). Atlantis Press. https://doi.org/10.2991/978-94-91216-77-0_8

Assaf, S. A., & Al-Hejji, S. (2006). Causes of delay in large construction projects. *International Journal of Project Management*, *24*(4), 349–357. https://doi.org/10.1016/j.ijproman.2005.11.010

Attarzadeh, M., Chua, D., Beer, M., & Abbott, E. (2017). Fuzzy Randomness Simulation of Long-Term Infrastructure Projects. *ASCE-ASME Journal of Risk and Uncertainty in Engineering Systems, Part A: Civil Engineering*, *3*(3), 1–15. https://doi.org/10.1061/AJRUA6.0000902

Ayyub, B. M. (2014). *Risk Analysis in Engineering and Economics* (second). CRC Press.

Badri, M. A., Davis, D., & Davis, D. (1995). A study of measuring the critical factors of quality management. *International Journal of Quality & Reliability Management*, *12*(2), 36–53. https://doi.org/10.1108/02656719510080604

Baloi, D., & Price, A. D. F. (2003). Modelling global risk factors affecting construction cost performance. *International Journal of Project Management*, *21*(4), 261–269. https://doi.org/https://doi.org/10.1016/S0263-7863(02)00017-0

Banaitiene, & Banaitis, A. (2012). *Risk Management in Construction Projects* (A. B. E.-N. Banaitiene (ed.); p. Ch. 19). IntechOpen. https://doi.org/10.5772/51460

Bekele, W. (2015). *Risks and Risk Management of Addis Ababa Light Rail Transit System Project*. Addis Ababa University.

Beltrão, L. M. P., & Carvalho, M. T. M. (2019). Prioritizing Construction Risks Using Fuzzy AHP in Brazilian Public Enterprises. *Journal of Construction Engineering and Management*, *145*(2), 1–11. https://doi.org/10.1061/(ASCE)CO.1943-7862.0001606

Boateng, Chen, Z., Ogunlana, S., & Ikediashi, D. (2012). A system dynamics approach to risks description in megaprojects development. *Organization, Technology & Management in Construction: An International Journal*, *4*(3), 593–603.

Bottani, E., & Rizzi, A. (2006). A fuzzy TOPSIS methodology to support outsourcing of logistics services. *Supply Chain Management*, *11*(4), 294–308. https://doi.org/10.1108/13598540610671743

Bouloiz, H., Garbolino, E., Tkiouat, M., & Guarnieri, F. (2013). A system dynamics model for behavioral analysis of safety conditions in a chemical storage unit. *Safety Science*, *58*(1), 32–40. https://doi.org/https://doi.org/10.1016/j.ssci.2013.02.013

Breierova, L., & Choudhari, M. (2001). *An Introduction to Sensitivity Analysis*. Massachusetts Institute of Technology.

British Standards. (2014). *BS EN 62198 Managing risk in projects- Application guidelines*. The British Standards Institution.

Buckley, J. J. (1985). Fuzzy hierarchical analysis. *Fuzzy Sets and Systems*, *17*(3), 233–247. https://doi.org/https://doi.org/10.1016/0165-0114(85)90090-9

Cantarelli, C. C., Molin, E. J. E., van Wee, B., & Flyvbjerg, B. (2012). Characteristics of cost overruns for Dutch transport infrastructure projects and the importance of the decision to build and project phases. *Transport Policy*, *22*, 49–56. https://doi.org/https://doi.org/10.1016/j.tranpol.2012.04.001

Cárdenas, I. C., Al-Jibouri, S. S. H., Halman, J. I. M., & Van Tol, F. A. (2014). Modeling risk-related knowledge in tunneling projects. *Risk Analysis*, *34*(2), 323–339. https://doi.org/10.1111/risa.12094

Carr, V., & Tah, J. H. M. (2001). A fuzzy approach to construction project risk assessment and analysis: Construction project risk management system. *Advances in Engineering Software*, *32*(10–11), 847–857. https://doi.org/10.1016/S0965-9978(01)00036-9

Cebi, S. (2011). Developing a fuzzy based decision making model for risk analysis in construction project. *Journal of Multiple-Valued Logic and Soft Computing*, *17*(4), 387–405.

Chan, H. K., & Wang, X. (2013). *Fuzzy Hierarchical Model for Risk Assessment*. Springer-Verlag.

Chang, D.-Y. (1996). Applications of the extent analysis method on fuzzy AHP. *European Journal of Operational Research*, *95*(3), 649–655. https://doi.org/https://doi.org/10.1016/0377-2217(95)00300-2

Chapman, C., & Ward, S. (2003). *Project Risk Management: Processes, Techniques and Insights* (Second Ed.). John Wiley & Sons Ltd.

Cheng, & Li, H. (2005). Analytic network process applied to project selection. *Journal of Construction Engineering and Management*, *131*(4), 459–466. https://doi.org/10.1061/(ASCE)0733-9364(2005)131:4(459)

Choudhry, R. M., Aslam, M. A., & Arain, F. M. (2014). Cost and schedule risk analysis of bridge construction in Pakistan: Establishing risk guidelines. *Journal of Construction Engineering and Management*, *140*(7), 1–9. https://doi.org/10.1061/(ASCE)CO.1943-7862.0000857

Cooper, D. R., & Schindler, P. S. (2014). *Business Research Methods* (Twelfth). McGraw-Hill/Irwin.

Coyle, R. G. (1996). *System Dynamics Modelling: A Practical Approach*. Chapman & Hall.

Cronbach, L. J. (1951). Coefficient alpha and the internal structure of tests. *Psychometrika*, *16*(3), 297–334. https://doi.org/10.1007/BF02310555

Dağdeviren, M., & Yüksel, I. (2010). A fuzzy analytic network process (ANP) model for measurement of the sectoral competititon level (SCL). *Expert Systems with Applications*, *37*(2), 1005–1014. https://doi.org/10.1016/j.eswa.2009.05.074

Dey, P. K. (2001). Decision support system for risk management: A case study. *Management Decision*, *39*(8), 634–649. https://doi.org/10.1108/00251740110399558

Dey, P. K. (2010). Managing project risk using combined analytic hierarchy process and risk map. *Applied Soft Computing*, *10*(4), 990–1000. https://doi.org/10.1016/j.asoc.2010.03.010

Dey, P. K. (2012). Project risk management using multiple criteria decision-making technique and decision tree analysis: A case study of Indian oil refinery. *Production Planning and Control*, *23*(12), 903–921. https://doi.org/10.1080/09537287.2011.586379

Dikmen, I., Birgonul, M. T., & Han, S. (2007). Using fuzzy risk assessment to rate cost overrun risk in international construction projects. *International Journal of Project Management*, *25*(5), 494–505. https://doi.org/10.1016/j.ijproman.2006.12.002

Doloi, H., Sawhney, A., Iyer, K. C., & Rentala, S. (2012). Analysing factors affecting delays in Indian construction projects. *International Journal of Project Management*, *30*(4), 479–489. https://doi.org/10.1016/j.ijproman.2011.10.004

El-Razek, M. E. A., Bassioni, H. A., & Mobarak, A. M. (2008). Causes of Delay in Building Construction Projects in Egypt. *Journal of Construction Engineering and Management*, *134*(11), 831–841. https://doi.org/10.1061/(ASCE)0733-9364(2008)134:11(831)

El-Sayegh, S. M., & Mansour, M. H. (2015). Risk assessment and allocation in highway construction projects in the UAE. *Journal of Management in Engineering*. https://doi.org/10.1061/(ASCE)ME.1943-5479.0000365

Elbarkouky, M. M. G., Fayek, A. R., Siraj, N. B., & Sadeghi, N. (2016). Fuzzy arithmetic risk analysis approach to determine construction project contingency. *Journal of Construction Engineering and Management*, *142*(12), 1–11. https://doi.org/10.1061/(ASCE)CO.1943-7862.0001191

Emrouznejad, A., & Ho, W. (2017). *Fuzzy analytic hierarchy process*. Chapman and Hall/CRC.

Ertuğrul, I., & Karakaşoğlu, N. (2008). Comparison of fuzzy AHP and fuzzy TOPSIS methods for facility location selection. *International Journal of Advanced Manufacturing Technology*, *39*(7), 783–795. https://doi.org/10.1007/s00170-007-1249-8

Etemadinia, H., & Tavakolan, M. (2021). Using a hybrid system dynamics and interpretive structural modeling for risk analysis of design phase of the construction projects. *International Journal of Construction Management*, *21*(1), 93–112. https://doi.org/10.1080/15623599.2018.1511235

Ewenetu, W. (2015). *Cost overrun and impact assessment of Addis Ababa's Light Rail Transit Construction*. Addis Ababa University.

Fateminia, S. H., Nguyen, P. H., & Fayek, A. R. (2021). An Adaptive Hybrid Model for Determining Subjective Causal Relationships in Fuzzy System Dynamics Models for Analyzing Construction Risks. In *CivilEng* (Vol. 2, Issue 3, pp. 747–764). https://doi.org/10.3390/civileng2030041

Fayek, A. R. (2020). Fuzzy Logic and Fuzzy Hybrid Techniques for Construction Engineering and Management. *Journal of Construction Engineering and Management*, *146*(7), 1–12. https://doi.org/10.1061/(ASCE)CO.1943-7862.0001854

Fera, M., Macchiaroli, R., Fruggiero, F., & Lambiase, A. (2017). Risks prioritization in decision making for wind energy investments using analytic network process (ANP). *International Journal of Applied Engineering Research*, *12*(10), 2567–2573.

Flyvbjerg, B. (2007). Cost Overruns and Demand Shortfalls in Urban Rail and Other Infrastructure. *Transportation Planning and Technology*, *30*(1), 9–30.

https://doi.org/10.1080/03081060701207938

Flyvbjerg, B., Ansar, A., Budzier, A., Buhl, S., Cantarelli, C., Garbuio, M., Glenting, C., Holm, M. S., Lovallo, D., Lunn, D., Molin, E., Rønnest, A., Stewart, A., & van Wee, B. (2018). Five things you should know about cost overrun. *Transportation Research Part A: Policy and Practice*, *118*, 174–190. https://doi.org/https://doi.org/10.1016/j.tra.2018.07.013

Flyvbjerg, B., Holm, M. S., & Buhl, S. (2002). Underestimating Costs in Public Works Projects: Error or Lie? *Journal of the American Planning Association*, *68*(3), 279–295. https://doi.org/10.1080/01944360208976273

Flyvbjerg, B., Skamris Holm, M. K., & Buhl, S. L. (2004). What Causes Cost Overrun in Transport Infrastructure Projects? *Transport Reviews*, *24*(1), 3–18. https://doi.org/10.1080/0144164032000080494a

Ford, D. N. (2019). A system dynamics glossary. *System Dynamics Review*, *35*(4), 369–379. https://doi.org/https://doi.org/10.1002/sdr.1641

Forrester, J. W. (1961). *Industrial dynamics*. MIT Press.

Forrester, J. W., & Senge, P. M. (1980). Tests for building confidence in system dynamics models. *TIMS Studies in Management Sciences*, *14*, 209–228.

Gambelli, D., Alberti, F., Solfanelli, F., Vairo, D., & Zanoli, R. (2017). Third generation algae biofuels in Italy by 2030: A scenario analysis using Bayesian networks. *Energy Policy*, *103*, 165–178. https://doi.org/https://doi.org/10.1016/j.enpol.2017.01.013

Gang Kou, Daji Ergu, Yi Peng, Y. S. (2013). *Data Processing for the AHP/ANP*. Springer Berlin Heidelberg.

Gogus, O., & Boucher, T. O. (1998). Strong transitivity, rationality and weak monotonicity in fuzzy pairwise comparisons. *Fuzzy Sets and Systems*, *94*(1), 133–144. https://doi.org/https://doi.org/10.1016/S0165-0114(96)00184-4

Gupta, V. K., & Thakkar, J. J. (2018). A quantitative risk assessment methodology for construction project. *Sādhanā*, *43*(7), 1–16. https://doi.org/10.1007/s12046-018-0846-6

Han, S., Love, P., & Peña-Mora, F. (2013). A system dynamics model for assessing the impacts of design errors in construction projects. *Mathematical and Computer Modelling*, *57*(9), 2044–2053. https://doi.org/10.1016/j.mcm.2011.06.039

Harrison, R. L. (2010). Introduction to Monte Carlo Simulation. *AIP Conference Proceedings*, *1204*, 17–21. https://doi.org/10.1063/1.3295638

Hendradewa, A. P. (2019). Schedule Risk Analysis by Different Phases of Construction Project Using CPM-PERT and Monte-Carlo Simulation. *IOP Conference Series: Materials Science and Engineering*, 1–9. https://doi.org/10.1088/1757-899X/528/1/012035

Hillson, D., & Simon, P. (2012). *Practical project risk management: The ATOM methodology* (Second Ed.). Management Concepts,Inc.

Hinton, P. R. (2005). *Statistics Explained* (second). Routledge, Taylor & Francis Group.

Hosseini, L., Tavakkoli-Moghaddam, R., Vahdani, B., Mousavi, S. M., & Kia, R. (2013). Using the Analytical Network Process to Select the Best Strategy for Reducing Risks in a Supply Chain. *Journal of Engineering (United Kingdom)*. https://doi.org/10.1155/2013/375628

Hossen, M. M., Kang, S., & Kim, J. (2015). Construction schedule delay risk assessment by using combined AHP-RII methodology for an international NPP project. *Nuclear Engineering and Technology*, *47*(3), 362–379. https://doi.org/https://doi.org/10.1016/j.net.2014.12.019

Huang, D., Chen, T., & Wang, M. J. J. (2001). A fuzzy set approach for event tree analysis. *Fuzzy Sets and Systems*, *118*(1), 153–165. https://doi.org/10.1016/S0165-0114(98)00288-7

Institution of Civil Engineers. (2005). *Risk Analysis and Management for Projects (RAMP)* (2nd ed.). Thomas Telford Publishing.

Islam, M. S., & Nepal, M. (2016). A Fuzzy-Bayesian Model for Risk Assessment in Power Plant Projects. *Procedia Computer Science*, *100*, 963–970. https://doi.org/10.1016/j.procs.2016.09.259

Islam, M. S., Nepal, M. P., Skitmore, M., & Attarzadeh, M. (2017). Current research trends and application areas of fuzzy and hybrid methods to the risk assessment of construction projects. *Advanced Engineering Informatics*, *33*(1), 112–131. https://doi.org/10.1016/j.aei.2017.06.001

ISO. (2009). *ISO Guide73 Risk management Vocabulary*.

ISO. (2018). *ISO 31000: 2018 Risk Management-Principles and guidelines*. ISO Geneva, Switzerland.

Issa, U. H. (2013). Implementation of lean construction techniques for minimizing the risks effect on project construction time. *Alexandria Engineering Journal*, *52*(4), 697–704. https://doi.org/10.1016/j.aej.2013.07.003

Iyer, K. C., & Sagheer, M. (2010). Hierarchical structuring of PPP risks using interpretative structural modeling. *Journal of Construction Engineering and Management*, *136*(2), 151–159. https://doi.org/10.1061/(ASCE)CO.1943-7862.0000127

Kabir, G., Sadiq, R., & Tesfamariam, S. (2016). A fuzzy Bayesian belief network for safety assessment of oil and gas pipelines. *Structure and Infrastructure Engineering*, *12*(8), 874–889. https://doi.org/10.1080/15732479.2015.1053093

Kahraman, C., Büyüközkan, G., & Ateş, N. (2007). A two phase multi-attribute decision-making approach for new product introduction. *Information Sciences*, *177*(7), 1567–1582. https://doi.org/10.1016/j.ins.2006.09.008

Kassa, Y. F. (2020). Determinants of Infrastructure Project Delays and Cost Escalations: the Cases of Federal Road and Railway Construction Projects in Ethiopia. *American Academic Scientific Research Journal for Engineering, Technology, and Sciences*, *63*(1), 102–136.

Khodakarami, V., & Abdi, A. (2014). Project cost risk analysis: A Bayesian networks approach for modeling dependencies between cost items. *International Journal of Project Management*, *32*(7), 1233–1245. https://doi.org/10.1016/j.ijproman.2014.01.001

Khodeir, L. M., & Mohamed, A. H. M. (2015). Identifying the latest risk probabilities affecting construction projects in Egypt according to political and economic variables. From January 2011 to January 2013. *HBRC Journal*, *11*(1), 129–135. https://doi.org/10.1016/j.hbrcj.2014.03.007

Kjærulff, U. B., & Madsen, A. L. (2013). *Bayesian Networks and Influence Diagrams: A Guide to Construction and Analysis* (Second). Springer Science+Business Media.

Koushki, P. A., Al-Rashid, K., & Kartam, N. (2005). Delays and cost increases in the construction of private residential projects in Kuwait. *Construction Management and Economics*, *23*(3), 285–294. https://doi.org/10.1080/0144619042000326710

Krohling, R. A., & Campanharo, V. C. (2011). Fuzzy TOPSIS for group decision making: A case study for accidents with oil spill in the sea. *Expert Systems with Applications*, *38*(4), 4190–4197. https://doi.org/https://doi.org/10.1016/j.eswa.2010.09.081

Kubler, S., Robert, J., Derigent, W., Voisin, A., & Le Traon, Y. (2016). A state-of the-art survey & testbed of fuzzy AHP (FAHP) applications. *Expert Systems with Applications*, *65*(1), 398–422. https://doi.org/https://doi.org/10.1016/j.eswa.2016.08.064

Larsen, J. K., Qiping, S. G., Munch, L. S., & Ditlev, B. T. (2016). Factors Affecting Schedule Delay, Cost Overrun, and Quality Level in Public Construction Projects. *Journal of Management in Engineering*, *32*(1), 4015032. https://doi.org/10.1061/(ASCE)ME.1943-5479.0000391

Lee, J., & McCormick, N. (2011). *Risk and Safety Analysis of Nuclear Systems*. John Wiley & Sons Inc.,.

Leśniak, A., & Janowiec, F. (2019). Risk assessment of additional works in railway construction investments using the Bayes network. *Sustainability (Switzerland)*, *11*(19), 1–15. https://doi.org/10.3390/su11195388

Leung, L. C., & Cao, D. (2000). On consistency and ranking of alternatives in fuzzy AHP. *European Journal of Operational Research*, *124*(1), 102–113. https://doi.org/https://doi.org/10.1016/S0377-2217(99)00118-6

Li. (2013). A novel Likert scale based on fuzzy sets theory. *Expert Systems with Applications*, *40*(5), 1609–1618. https://doi.org/https://doi.org/10.1016/j.eswa.2012.09.015

Li, Liu, R., Zhang, J., & Sun, Q. (2014). Quality risk management model for railway construction projects. *Procedia Engineering*, *84*, 195–203. https://doi.org/10.1016/j.proeng.2014.10.426

Li, P. cheng, Chen, G. hua, Dai, L. cao, & Zhang, L. (2012). A fuzzy Bayesian network approach to improve the quantification of organizational influences in HRA frameworks. *Safety Science*, *50*(7), 1569–1583. https://doi.org/10.1016/j.ssci.2012.03.017

Li, Wang, J., & Yuan, H. (2014). Analysis of the Interactions Between Risks Affecting Construction Project Cost. In D. Yang & Y. Qian (Eds.), *Proceedings of the 18th International Symposium on Advancement of Construction Management and Real Estate* (pp. 423–431). Springer Berlin Heidelberg.

Li, & Wang, X. (2018). Risk assessment for public–private partnership projects: using a fuzzy analytic hierarchical process method and expert opinion in China. *Journal of Risk Research*, *21*(8), 952–973. https://doi.org/10.1080/13669877.2016.1264451

Li, & Zou, P. X. W. (2011). Fuzzy AHP-based risk assessment methodology for PPP projects. *Journal of Construction Engineering and Management*, *137*(12), 1205–1209. https://doi.org/10.1061/(ASCE)CO.1943-7862.0000362

Lin. (2012). An integrated model for supplier selection under a fuzzy situation. *International Journal of Production Economics*, *138*(1), 55–61. https://doi.org/10.1016/j.ijpe.2012.02.024

Lin, Yaqi, L., & Enmao, W. (2011). Research on Risk Management of Railway Engineering Construction. *Systems Engineering Procedia*, 174–180. https://doi.org/10.1016/j.sepro.2011.08.029

Lin, Z., & Jianping, Y. (2011). Risk Assessment Based On Fuzzy Network (F-ANP) In New Campus Construction Project. *Systems Engineering Procedia*, *1*, 162–168. https://doi.org/https://doi.org/10.1016/j.sepro.2011.08.027

Liu, J., Li, Q., & Wang, Y. (2013). Risk analysis in ultra deep scientific drilling project — A fuzzy synthetic evaluation approach. *International Journal of Project Management*, *31*(3), 449–458. https://doi.org/https://doi.org/10.1016/j.ijproman.2012.09.015

Liu, Xie, Q., Xia, B., & Bridge, A. J. (2017). Impact of Design Risk on the Performance of Design-Build Projects. *Journal of Construction Engineering and Management*, *143*(6), 1–10. https://doi.org/10.1061/(ASCE)CO.1943-7862.0001299

Love, P. E. D. (2002). Influence of Project Type and Procurement Method on Rework Costs in Building Construction Projects. *Journal of Construction Engineering and Management*, *128*(1), 18–29. https://doi.org/10.1061/(ASCE)0733-9364(2002)128:1(18)

Love, P. E. D., Davis, P. R., Ellis, J. M., & Cheung, S. O. (2010). A systemic view of dispute causation. *International Journal of Managing Projects in Business*, *3*(4), 661–680. https://doi.org/10.1108/17538371011076109

Love, P. E. D., & Edwards, D. J. (2004). Forensic project management: The underlying causes of rework in construction projects. *Civil Engineering and Environmental Systems*, *21*(3), 207–228. https://doi.org/10.1080/10286600412331295955

Love, P. E. D., Lopez, R., Edwards, D. J., & Goh, Y. M. (2012). Error begat error: Design error analysis and prevention in social infrastructure projects. *Accident Analysis & Prevention*, *48*(1), 100–110. https://doi.org/https://doi.org/10.1016/j.aap.2011.02.027

Lu, S.-T., Yu, S.-H., & Chang, D.-S. (2014). Using Fuzzy Multiple Criteria Decision-Making Approach for Assessing the Risk of Railway Reconstruction Project in Taiwan. *TheScientificWorldJournal*, *2014*(1), 1–8. https://doi.org/10.1155/2014/239793

Luu, V. T., Kim, S. Y., Tuan, N. Van, & Ogunlana, S. O. (2009). Quantifying schedule risk in construction projects using Bayesian belief networks. *International Journal of Project Management*, *27*(1), 39–50. https://doi.org/10.1016/j.ijproman.2008.03.003

Macura, D., Laketić, M., Pamucar, D., & Marinković, D. (2022). Risk Analysis Model with Interval Type-2 Fuzzy FMEA – Case Study of Railway Infrastructure Projects in the Republic of Serbia. *Acta Polytechnica Hungarica*, *19*(3), 103–118. https://doi.org/10.12700/APH.19.3.2022.3.9

Mahamid, I. (2013). Contractors' perception of risk factors affecting cost overrun in building projects in Palestine. *The IES Journal Part A: Civil & Structural Engineering*, *7*(1), 38–50. https://doi.org/10.1080/19373260.2013.854180

Mao, Y., & Wu, W. (2011). Fuzzy Real Option Evaluation of Real Estate Project Based on Risk Analysis. *Systems Engineering Procedia*, *1*, 228–235. https://doi.org/https://doi.org/10.1016/j.sepro.2011.08.036

Marczyk, G., DeMatteo, D., & Festinger, D. (2005). *Essentials of Research Design and Methodology*. John Wiley & Sons, Inc.

Martinelli, R., & Milosevic, D. Z. (2016). *Project Management ToolBox: Tools and Techniques for the Practicing Project manager* (Second). John Wiley & Sons, Inc.

Meade, & Sarkis, J. (1999). Analyzing organizational project alternatives for agile manufacturing processes: An analytical network approach. *International Journal of Production Research*, *37*(2), 241–261. https://doi.org/10.1080/002075499191751

Melaku, S., Tilahun, S., Yehualaw, M., Matos, J., Sousa, H., & Workneh, E. T. (2021). Analysis of Cost Overrun and Schedule Delays of Infrastructure Projects in Low Income Economies: Case Studies in Ethiopia. *Advances in Civil Engineering*, *2021*, 1–15. https://doi.org/10.1155/2021/4991204

Mikhailov, L., & Singh, M. G. (2003). Fuzzy Analytic Network Process and Its Application to the Development of Decision Support Systems. *Trans. Sys. Man Cyber Part C*, *33*(1), 33–41. https://doi.org/10.1109/TSMCC.2003.809354

Mohammadi, A., & Tavakolan, M. (2013). Construction project risk assessment using combined fuzzy and FMEA. *Proceedings of the 2013 Joint IFSA World Congress and NAFIPS Annual Meeting, IFSA/NAFIPS 2013*. https://doi.org/10.1109/IFSA-NAFIPS.2013.6608405

Molenaar, K. R. (2005). Programmatic cost risk analysis for highway megaprojects. *Journal of Construction Engineering and Management*, *131*(3), 343–353. https://doi.org/10.1061/(ASCE)0733-9364(2005)131:3(343)

Mu, S., Cheng, H., Chohr, M., & Peng, W. (2014). Assessing risk management capability of contractors in subway projects in mainland China. *International Journal of Project Management*, *32*(3), 452–460. https://doi.org/https://doi.org/10.1016/j.ijproman.2013.08.007

Murat, G., Yasemin, N., & Mustafa, Ö. (2013). Quantification of Delay Factors Using the Relative Importance Index Method for Construction Projects in Turkey. *Journal of Management in Engineering*, *29*(2), 133–139. https://doi.org/10.1061/(ASCE)ME.1943-5479.0000129

Murray-Webster, R. (2010). *Management of risk: guidance for practitioners* (Third Ed). The Stationery Office.

Nasirzadeh, F., Afshar, A., & Khanzadi, M. (2007). System Dynamics Approach to Optimum Response Selection in Construction Project Risks. *International Project Management Conference*.

Nasirzadeh, F., Afshar, A., & Khanzadi, M. (2008a). Dynamic risk analysis in construction projects. *Canadian Journal of Civil Engineering*, *35*(8), 820–831. https://doi.org/10.1139/L08-035

Nasirzadeh, F., Afshar, A., & Khanzadi, M. (2008b). System dynamics approach for construction risk analysis. *International Journal of Civil Engineering*, *6*(2), 120–131.

Nasirzadeh, F., Carmichael, D. G., Jarban, M. J., & Rostamnezhad, M. (2019). Hybrid fuzzy-system dynamics approach for quantification of the impacts of construction claims. *Engineering, Construction and Architectural Management*, *26*(7), 1261–1276. https://doi.org/10.1108/ECAM-08-2017-0150

Nasirzadeh, F., Ghasem Kashi, M., Khanzadi, M., Carmichael, D. G., & Akbarnezhad, A. (2019). A hybrid approach for quantitative assessment of construction projects risks: The case study of poor quality concrete. *Computers & Industrial Engineering*, *131*(4), 306–319. https://doi.org/https://doi.org/10.1016/j.cie.2019.03.045

Nasirzadeh, F., Khanzadi, M., & Rezaie, M. (2014). Dynamic modeling of the quantitative risk allocation in construction projects. *International Journal of Project Management*, *32*(3), 442–451. https://doi.org/10.1016/j.ijproman.2013.06.002

Nasirzadeh, F., & Nojedehi, P. (2013). Dynamic modeling of labor productivity in construction projects. *International Journal of Project Management*, *31*(6), 903–911. https://doi.org/10.1016/j.ijproman.2012.11.003

Nepal, B., & Yadav, O. P. (2015). Bayesian belief network-based framework for sourcing risk analysis during supplier selection. *International Journal of Production Research*, *53*(20), 6114–6135. https://doi.org/10.1080/00207543.2015.1027011

Nieto-Morote, A., & Ruz-Vila, F. (2011). A fuzzy approach to construction project risk assessment. *International Journal of Project Management*, *29*(2), 220–231. https://doi.org/10.1016/j.ijproman.2010.02.002

Nunnally, J. C., & Bernstein, I. H. (1994). *Psychometric Theory* (Third). McGRAW-HILL, INC.

Olaru, M., Şandru, M., & Pirnea, I. C. (2014). Monte Carlo Method Application for Environmental Risks Impact Assessment in Investment Projects. *Procedia - Social and Behavioral Sciences*, *109*, 940–943. https://doi.org/10.1016/j.sbspro.2013.12.568

Olievschi, V. N. (2013). *Rail Transport : Framework for Improving Railway Sector Performance in Sub-Saharan Africa* (No. 94).

Oliva, G. M., Weber, P., Simon, C., & Iung, B. (2009). Bayesian networks Applications on Dependability, Risk Analysis and Maintenance. *IFAC Proceedings Volumes*, 215–220. https://doi.org/https://doi.org/10.3182/20090610-3-IT-4004.00042

Öztaş, A., & Ökmen, Ö. (2004). Risk analysis in fixed-price design–build construction projects. *Building and Environment*, *39*(2), 229–237. https://doi.org/https://doi.org/10.1016/j.buildenv.2003.08.018

Patil, M., R.D.Shinde, & S.S.Hailkar. (2017). Ranking of Risk in Railway Projects. *International Journal of Engineering Sciences & Research Technology*, *6*(6), 472–476.

https://doi.org/10.5281/ZENODO.814794

Peansupap, V., & Ly, R. (2015). Evaluating the Impact Level of Design Errors in Structural and Other Building Components in Building Construction Projects in Cambodia. *Procedia Engineering*, *123*, 370–378. https://doi.org/https://doi.org/10.1016/j.proeng.2015.10.049

Pedrycz, W., Ekel, P., & Parreiras, R. (2011). *Fuzzy Multicriteria Decision-Making: Models, Methods and Applications*. John Wiley & Sons Ltd.

Pichery, C. (2014). *Sensitivity Analysis* (P. B. T.-E. of T. (Third E. Wexler (ed.); pp. 236–237). Academic Press. https://doi.org/https://doi.org/10.1016/B978-0-12-386454-3.00431-0

Platon, V., & Constantinescu, A. (2014). Monte Carlo Method in Risk Analysis for Investment Projects. *Procedia Economics and Finance*, 393–400. https://doi.org/10.1016/s2212-5671(14)00463-8

PMI. (2009). *Practice Standard for Project Risk Management*. Project Management Institute, Inc.

PMI. (2017). *A guide to the project management body of knowledge (PMBOK® guide)* (Sixth Ed.). Project Management Institute, Inc.

Pourrostam, T., & Ismail, A. (2012). Causes and Effects of Delay in Iranian Construction Projects. *International Journal of Engineering and Technology*, *4*(5), 598–601. https://doi.org/10.7763/ijet.2012.v4.441

Purnus, A., & Bodea, C.-N. (2013). Considerations on Project Quantitative Risk Analysis. *Procedia - Social and Behavioral Sciences*. https://doi.org/10.1016/j.sbspro.2013.03.031

Qazi, A., Quigley, J., Dickson, A., & Kirytopoulos, K. (2016). Project Complexity and Risk Management (ProCRiM): Towards modelling project complexity driven risk paths in construction projects. *International Journal of Project Management*, *34*(7), 1183–1198. https://doi.org/https://doi.org/10.1016/j.ijproman.2016.05.008

Rahmani, A., Hosseinzadeh Lotfi, F., Rostamy-Malkhalifeh, M., & Allahviranloo, T. (2016). A New Method for Defuzzification and Ranking of Fuzzy Numbers Based on the Statistical Beta Distribution. *Advances in Fuzzy Systems*, *2016*(1), 1–8. https://doi.org/10.1155/2016/6945184

Rajakumar, A. (2016). Analysis of Cost Overrun in Road Construction Activities – A Critical Review. *International Research Journal of Engineering and Technology*, *06*(04), 1433–1439.

Renuka, S. M., Umarani, C., & Kamal, S. (2014). A Review on Critical Risk Factors in the Life Cycle of Construction Projects. *Journal of Civil Engineering Research*, *4*(2), 31–36. https://doi.org/10.5923/c.jce.201401.07

Rezavalipour, A., Sarvari, H., Yahaya, N., Noor, N., & A Rashid, A. S. (2013). Analytic Network Process (ANP) to Risk Assessment of Gas Refinery EPC Projects in Iran. *Journal of Applied Sciences Research*, *9*, 1359–1365.

Rodrigues, A. G. (2001). Managing and Modelling Project Risk Dynamics A System Dynamics-based Framework. *Fourth European Project Management Conference: PMI Europe*.

Roghanian, E., Moradinasab, N., Afruzi, E. N., & Soofifard, R. (2015). Project risk management using fuzzy failure mode and effect analysis and fuzzy logic. *International Journal of Services and Operations Management*, *20*(2), 207–227. https://doi.org/10.1504/IJSOM.2015.067477

Saaty. (1977). A scaling method for priorities in hierarchical structures. *Journal of Mathematical Psychology*, *15*(3), 234–281. https://doi.org/https://doi.org/10.1016/0022-2496(77)90033-5

Saaty. (1994). How to Make a Decision: The Analytic Hierarchy Process. *Interfaces*, *24*(6), 19–43. https://doi.org/10.1287/inte.24.6.19

Saaty. (1996). *Decision Making with Dependence and Feedback: The Analytic Network Process*. RWS Publications.

Saaty. (2004). Fundamentals of the analytic network process — Dependence and feedback in decision-making with a single network. *Journal of Systems Science and Systems Engineering*, *13*(2), 129–157. https://doi.org/10.1007/s11518-006-0158-y

Sadeghi, N., Fayek, A. R., & Pedrycz, W. (2010). Fuzzy Monte Carlo simulation and risk assessment in construction. *Computer-Aided Civil and Infrastructure Engineering*, *25*(4), 238–252. https://doi.org/10.1111/j.1467-8667.2009.00632.x

Saeed, K. (2003). Articulating Developmental Problems for Policy Intervention: A System Dynamics Modeling Approach. *Simulation & Gaming*, *34*(3), 409–436. https://doi.org/10.1177/1046878103255792

Salkind, N. J. (Ed.). (2010). *Encyclopedia of research design*. SAGE Publications, Inc.

Samantra, C., Datta, S., & Mahapatra, S. S. (2017). Fuzzy based risk assessment module for metropolitan construction project: An empirical study. *Engineering Applications of Artificial Intelligence*, *65*(1), 449–464. https://doi.org/10.1016/j.engappai.2017.04.019

Sangsomboon, P., & Yan, S. (2014). Analysis of Risk- Response based on Railroad Construction Project. *International Journal of Management Sciences and Business Research*, *3*(12), 81–91.

Saraph, J. V, Benson, P. G., & Schroeder, R. G. (1989). An Instrument for Measuring the Critical Factors of Quality Management. *Decision Sciences*, *20*(4), 810–829. https://doi.org/https://doi.org/10.1111/j.1540-5915.1989.tb01421.x

Sarkar, D., & Singh, M. (2020). Risk analysis by integrated fuzzy expected value method and fuzzy failure mode and effect analysis for an elevated metro rail project of Ahmedabad, India. *International Journal of Construction Management*, 1–12. https://doi.org/10.1080/15623599.2020.1742634

Sayyadi, R., & Awasthi, A. (2018). An integrated approach based on system dynamics and ANP for evaluating sustainable transportation policies. *International Journal of Systems Science: Operations and Logistics*, 1–10. https://doi.org/10.1080/23302674.2018.1554168

Seresht, N. G., & Fayek, A. R. (2018). Dynamic Modeling of Multifactor Construction Productivity for Equipment-Intensive Activities. *Journal of Construction Engineering and Management*, *144*(9), 1–15. https://doi.org/10.1061/(ASCE)CO.1943-7862.0001549

Sharma, R. K., Kumar, D., & Kumar, P. (2005). Systematic failure mode effect analysis (FMEA) using fuzzy linguistic modelling. *International Journal of Quality and Reliability Management*, *22*(9), 986–1004. https://doi.org/10.1108/02656710510625248

Shrivastava, Gupta, S., Mittal, A., & Saxena, B. (2019). Critical risk factors causing the time and cost overruns of Indian railway projects in India. *International Journal of Engineering and Advanced Technology*, *9*(1), 5395–5401. https://doi.org/10.35940/ijeat.A3075.109119

Singh, R. (2010). Delays and Cost Overruns in Infrastructure Projects: Extent, Causes and Remedies. *Economic and Political Weekly*, *45*(21), 43–54. http://www.jstor.org/stable/27807050

Siraj, N. B., & Fayek, A. R. (2019). Risk Identification and Common Risks in Construction: Literature Review and Content Analysis. *Journal of Construction Engineering and Management*, *145*(9), 1–13. https://doi.org/10.1061/(ASCE)CO.1943-7862.0001685

Siraj, N. B., & Fayek, A. R. (2020). Hybrid fuzzy system dynamics model for analyzing the impacts of interrelated risk and opportunity events on project contingency. *Canadian Journal of Civil Engineering*, *48*(8), 979–992. https://doi.org/10.1139/cjce-2020-0032

Smith, N. J., Merna, T., & Jobling, P. (2014). *Managing Risk in Construction Projects* (Third). John Wiley & Sons Ltd.

Steininger, B. I., Groth, M., & Weber, B. L. (2021). Cost overruns and delays in infrastructure projects: the case of Stuttgart 21. *Journal of Property Investment & Finance*, *39*(3), 256–282. https://doi.org/10.1108/JPIF-11-2019-0144

Sterman, J. D. (1992). System Dynamics Modeling for Project Management. In *Unpublished manuscript*.

Sterman, J. D. (2000). *Business dynamic:systems thinking and modeling for a complex world*. The McGraw-Hill Companies, Inc.

Subramanyan, H., Sawant, P. H., & Bhatt, V. (2012). Construction project risk assessment: Development of model based on investigation of opinion of construction project experts from India. *Journal of Construction Engineering and Management*, *138*(3), 409–421. https://doi.org/10.1061/(ASCE)CO.1943-7862.0000435

Suh, S. D. (2000). Risk Management in a Large-Scale New Railway Transport System Project. *IATSS Research*, *24*(2), 53–63. https://doi.org/10.1016/s0386-1112(14)60029-7

Szymański, P. (2017). Risk management in construction projects. *Procedia Engineering*, *208*, 174–182. https://doi.org/10.1016/j.proeng.2017.11.036

Tah, J. H. M., & Carr, V. (2000a). A proposal for construction project risk assessment using fuzzy logic. *Construction Management and Economics*, *18*(4), 491–500. https://doi.org/10.1080/014461900050024905

Tah, J. H. M., & Carr, V. (2000b). Information modelling for a construction project risk management system. *Engineering, Construction and Architectural Management*, *7*(2), 107–119. https://doi.org/10.1108/eb021136

Tang, W., Zhang, F., Ye, Z., & Li, J. (2011). Research on risk evaluation in urban rail transit project. *Procedia Engineering*, *15*, 5094–5099. https://doi.org/10.1016/j.proeng.2011.08.945

Taroun, A. (2014). Towards a better modelling and assessment of construction risk: Insights from a literature review. *International Journal of Project Management*, *32*(1), 101–115. https://doi.org/10.1016/j.ijproman.2013.03.004

Tavassolirizi, M., Sarvari, H., Chan, D. W. M., & Olawumi, T. O. (2020). Factors affecting delays in rail transportation projects using Analytic Network Process: the case of Iran. *International Journal of Construction Management*, 1–12. https://doi.org/10.1080/15623599.2020.1819946

Taylan, O., Bafail, A. O., Abdulaal, R. M. S., & Kabli, M. R. (2014). Construction projects selection and risk assessment by fuzzy AHP and fuzzy TOPSIS methodologies. *Applied Soft Computing*, *17*(1), 105–116. https://doi.org/10.1016/j.asoc.2014.01.003

Thiétart, R.-A. (2001). *Doing Management Research A Comprehensive Guide*. SAGE Publications Ltd.

Thomas, A. V., Kalidindi, S. N., & Ganesh, L. S. (2006). Modelling and assessment of critical risks in BOT road projects. *Construction Management and Economics*, *24*(4), 407–424. https://doi.org/10.1080/01446190500435275

Tipili, L. G., & Ilyasu, M. S. (2014). Evaluating the impact of risk factors on construction projects cost in Nigeria. *The International Journal of Engineering and Science*, *3*(6), 10–15.

Valipour, A., Yahaya, N., Md Noor, N., Kildienė, S., Sarvari, H., & Mardani, A. (2015). A fuzzy analytic network process method for risk prioritization in freeway PPP projects: an Iranian case study. *Journal of Civil Engineering and Management*, *21*(7), 933–947. https://doi.org/10.3846/13923730.2015.1051104

Ventana Systems, I. (2007). *Vensim, Ventana Simulation Environment. User's Guide*. Ventana Systems, Inc.

Wan, J., & Liu, Y. (2014). A System Dynamics Model for Risk Analysis during Project Construction Process. *Open Journal of Social Sciences*, *2*(6), 451–454. https://doi.org/10.4236/jss.2014.26052

Wang, & Chen, C. (2017). Fuzzy comprehensive Bayesian network-based safety risk assessment for metro construction projects. *Tunnelling and Underground Space Technology*, *70*(1), 330–342. https://doi.org/10.1016/j.tust.2017.09.012

Wang, Chin, K. S., Poon, G. K. K., & Yang, J. B. (2009). Risk evaluation in failure mode and effects analysis using fuzzy weighted geometric mean. *Expert Systems with Applications*, *36*(2), 1195–1207. https://doi.org/10.1016/j.eswa.2007.11.028

Wang, J., & Yuan, H.-P. (2011). Major cost-overrun risks in construction projects in China. *Int. J. of Project Organisation and Management*, *3*(3/4), 227–242. https://doi.org/10.1504/IJPOM.2011.042030

Wang, T., Wang, S., Zhang, L., Huang, Z., & Li, Y. (2016). A major infrastructure risk-assessment framework: Application to a cross-sea route project in China. *International Journal of Project*

Management, *34*(7), 1403–1415. https://doi.org/https://doi.org/10.1016/j.ijproman.2015.12.006

Wang, Y. M., & Elhag, T. M. S. (2006). Fuzzy TOPSIS method based on alpha level sets with an application to bridge risk assessment. *Expert Systems with Applications*, *31*(2), 309–319. https://doi.org/10.1016/j.eswa.2005.09.040

Wang, & Yuan, H. (2017). System Dynamics Approach for Investigating the Risk Effects on Schedule Delay in Infrastructure Projects. *Journal of Management in Engineering*, *33*(1), 1–13. https://doi.org/10.1061/(ASCE)ME.1943-5479.0000472

Wu, Kou, G., Peng, Y., & Ergu, D. (2012). Improved AHP-group decision making for investment strategy selection. *Technological and Economic Development of Economy*, *18*(2), 299–316. https://doi.org/10.3846/20294913.2012.680520

Xu, Chan, & Y., Y. J. F. (2010). Developing a Fuzzy Risk Allocation Model for PPP Projects in China. *Journal of Construction Engineering and Management*, *136*(8), 894–903. https://doi.org/10.1061/(ASCE)CO.1943-7862.0000189

Xu, X., Wang, J., Li, C. Z., Huang, W., & Xia, N. (2018). Schedule risk analysis of infrastructure projects: A hybrid dynamic approach. *Automation in Construction*, *95*(1), 20–34. https://doi.org/https://doi.org/10.1016/j.autcon.2018.07.026

Xue, Y., Xiang, P., Jia, F., & Liu, Z. (2020). Risk Assessment of High-Speed Rail Projects: A Risk Coupling Model Based on System Dynamics. *International Journal of Environmental Research and Public Health*, *17*(15), 1–26. https://doi.org/10.3390/ijerph17155307

Yamane, T. (1967). *Statistics; An Introductory Analysis* (Second). Harper and Row.

Yazdani, M., Abdi, M. R., Kumar, N., Keshavarz-Ghorabaee, M., & Chan, F. T. S. (2019). Improved Decision Model for Evaluating Risks in Construction Projects. *Journal of Construction Engineering and Management*, *145*(5), 1–13. https://doi.org/10.1061/(ASCE)CO.1943-7862.0001640

Yeager, L., Fiddaman, T., & Peterson, D. (2014). Entity-based system dynamics. *Proceedings of the International System Dynamics Conference, Delft*.

Yucelgazi, F., & Yitmen, İ. (2018). An ANP Model for Risk Assessment in Large-Scale Transport Infrastructure Projects. *Arabian Journal for Science and Engineering*, *44*(5), 4257–4275. https://doi.org/10.1007/s13369-018-3314-z

Yücelgazi, F., & Yitmen, İ. (2020). An ANP model for risk response assessment in large scale bridge projects. *Civil Engineering and Environmental Systems*, *37*(1), 1–27. https://doi.org/10.1080/10286608.2019.1702030

Zadeh, L. A. (1965). Fuzzy Sets. *Information and Control*, *8*(3), 338–353. https://doi.org/doi:10.1016/s0019-9958(65)90241-x

Zayed, T., Amer, M., & Pan, J. (2008). Assessing risk and uncertainty inherent in Chinese highway projects using AHP. *International Journal of Project Management*, *26*(4), 408–419. https://doi.org/10.1016/j.ijproman.2007.05.012

Zeng, X., Huang, N., Han, Y., Yin, Y., & Huang, J. (2022). System Dynamics Analysis of Construction Safety Risk considering Existing Railway Lines. *Computational Intelligence and Neuroscience*, *2022*, 1–12. https://doi.org/10.1155/2022/1256975

Zhang, Cai, M., Li, X., & Mu, Z. (2011). Prioritizing highway tunnel risk factors with AHP method. *2011 International Conference on Information Science and Technology, ICIST 2011*, 1205–1207. https://doi.org/10.1109/ICIST.2011.5765186

Zhang, L., Wu, X., Qin, Y., Skibniewski, M. J., & Liu, W. (2016). Towards a Fuzzy Bayesian Network Based Approach for Safety Risk Analysis of Tunnel-Induced Pipeline Damage. *Risk Analysis*, *36*(2), 278–301. https://doi.org/10.1111/risa.12448

APPENDIX A: QUESTIONNAIRES FOR THE SURVEY

SECTION C: PAIRWISE COMPARISON MATRICES

Listed below are risk factors with the potential to affect delays and cost overruns of the Addis-Djibouti railway construction project. For each statement, please rate the relative impacts over each other by putting the pairwise scale (1/9 to 9) in the corresponding columns.

Design risk	DS01	DS02	DS03	DS04	DS05	DS06	DS07
DS01							
DS02							
DS03							
DS04							
DS05							
DS06							
DS07							

Construction risk	CN01	CN02	CN03	CN04	CN05	CN06	CN07	CN08
CN01								
CN02								
CN03								
CN04								
CN05								
CN06								
CN07								
CN08								

Management risk	MN01	MN02	MN03	MN04	MN05	MN06	MN07	MN08	MN09	MN10	MN11
MN01											
MN02											
MN03											
MN04											
MN05											
MN06											
MN07											
MN08											
MN09											
MN10											
MN11											

Resource risk	RS01	RS02	RS03	RS04	RS05
RS01					
RS02					
RS03					
RS04					
RS05					

Contractual risk	CL01	CL02	CL03	CL04	CL05
CL01					
CL02					
CL03					
CL04					
CL05					

External risk	EX01	EX02	EX03	EX04	EX05	EX06
EX01						
EX02						
EX03						
EX04						
EX05						
EX06						

APPENDIX B: CONDITIONAL PROBABILITY TABLES

DS01:			
Y	N	MN06	EX01
0.95	0.05	Y	Y
0.615	0.385	Y	N
0.385	0.615	N	Y
0.05	0.95	N	N

DS04:		
Y	N	DS01
0.95	0.05	Y
0.05	0.95	N

DS07:		
Y	N	CN06
0.9	0.1	Y
0.1	0.9	N

MN03:		
Y	N	CN06
0.8	0.2	Y
0.15	0.85	N

MN02:		
Y	N	MN03
0.9	0.1	Y
0.1	0.9	N

DS05:			
Y	N	EX03	MN03
0.95	0.05	Y	Y
0.6	0.4	Y	N
0.4	0.6	N	Y
0.1	0.9	N	N

MN11:		
Y	N	DS05
0.95	0.05	Y
0.15	0.85	N

MN05:		
Y	N	MN03
0.7	0.3	Y
0.1	0.9	N

RS03:		
Y	N	MN05

APPENDIX C: SUPERMATRICES OF ANP

a) Unweighted supermatrix

b) Weighted supermatrix

c) Limit supermatrix